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Oxidation of Pure Tungsten in the Temperature Interval 400° to 900°C

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ABSTRACT

This work was done with the aim to determine the oxidation characteristics of pure tungsten at temperatures from 400°-900°C, in two different oxidizing atmospheres, one containing oxygen and the other containing water vapour. This involves investigating both tungsten oxidation kinetics and mechanisms. It was carried out by examining tungsten using two different kinds of methods. The first method was to examine small round tungsten foil samples, approx. 5.5 mm in diameter, using simultaneous thermal analysis (STA), with an atmosphere of pure inert argon containing a small impurity of maximum 5 ppm oxygen (i.e. a maximum partial pressure of $\sim 5 \cdot 10^{-6}$ atm). The other atmosphere was containing the same pure argon, but this time it was passed through two closed beakers filled with water. The partial pressure of the water vapour in this case was $6.6 \cdot 10^{-3}$ atm. The experiments with the STA were conducted for 48 h in 500° and 550°C. The results showed that even a small oxygen impurity in argon will oxidize the tungsten at such low temperatures as 500 °C. The other conclusion was that even though the partial pressure of water vapour was several times higher, the tungsten samples which were exposed to a relatively lower oxygen partial pressure were more oxidized.

The other method used in this work was thermogravimetric analysis (TGA). Larger samples were used here, approximately 18 mm in diameter. The samples were oxidized in a furnace and the mass change was continuously monitored at the same time, using a microbalance connected to a computer. These experiments were conducted in different oxidizing atmospheres. The first series of experiments were done in an atmosphere containing helium with 0.5 % oxygen, i.e. $p_{O2} \sim 5 \cdot 10^{-3}$ atm, at temperatures from 400°-900°C, for two hours. The second atmosphere was pure helium which was passed through the same two closed beakers filled with water vapour, as in the STA experiments. The partial pressure of water vapour was ~0.0078 atm. Experiments were conducted in this atmosphere for two hours at temperatures from 400° to 900°C. The third atmosphere was pure helium with an impurity of max. 5 ppm oxygen, i.e. $p_{O2} \leq 5 \cdot 10^{-6}$ atm. Experimental runs in this atmosphere were carried out at 500° and 600°C for two hours.

Results from the TGA showed that tungsten oxidation follows a mixed parabolic and linear oxidation rate. Two different types of oxide layers were formed; the innermost oxide layer was black, thin and adherent. The outermost oxide layer was very different from the innermost one. It was yellowish green, porous and thicker than the innermost layer. Based on literature data, it was concluded that this oxide must be the tungsten trioxide.

Furthermore, the results confirmed the observation during STA experiments that oxidation proceeds to a greater extent even with small amounts of oxygen as compared to larger amounts of water vapour in the inert gas. Oxidation was observed even at temperatures as low as 400°C. As temperatures go up to

about 750°C, volatilization of tungsten trioxide assumes significance. It has been suggested in the literature that the presence of water vapour at these temperatures speeds up the volatilization rate through the formation of tungstic acid.

In this work, activation energies for the phase boundary and diffusion limited reactions have been determined. The kinetic data have been analyzed using a Power Law model which can be expressed as

$\frac{\Delta m}{A} = kt^n$ where Δm is the mass change, A is the surface area, k is the oxidation rate constant, t is the time and n is the rate exponent. The power law is valid for oxidation of pure tungsten at temperatures ranging from 400°-700°C. An attempt has also been made to improve the model in order to take into account the volatilization of tungsten trioxide at higher temperatures.

The activation energy for the phase boundary controlled reaction was found to be approximately 64 kJ/mol for the He+0.5% O_2 gas mixture, and 74 kJ/mol for the He+Ar+H_2O gas mixture. For the diffusion controlled reaction below 750°C the values of the determined activation energies are 95 and 183 kJ/mol, for the respective gas mixture.

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ABBREVIATIONS

$CaWO_4$	Scheelite
DSC	Differential scanning calorimetry
ESS	European Spallation Source
$FeWO_4$	Ferberite
$[Fe, Mn]WO_4$	Wolframite
$MnWO_4$	Huebnerite
STA	Simultaneous thermal analysis
TBO	Tungsten blue oxide
TGA	Termogravimetric analysis
WO_3	Tungsten trioxide
α-WO_3	α-phase tungsten oxide, WO_3
β-WO_3	β-phase tungsten oxide, $WO_{2.9}$ ($W_{20}O_{58}$)
γ-WO_3	γ-phase tungsten oxide, $WO_{2.72}$ ($W_{18}O_{49}$)
δ-WO_3	δ-phase tungsten oxide, WO_2
WO_2	Tungsten dioxide
$WO_3 \cdot H_2O$	Tungstic acid

1. INTRODUCTION

The aim of this master´s thesis is to investigate the oxidation behaviour of tungsten. This is of particular interest for the European Spallation Source (ESS AB), which is one of the largest science and technology infrastructure projects being built today. The ESS uses spallation which in short is a process where neutrons are produced using a particle accelerator and a heavy metal target. The accelerator will shoot protons at the target material at a velocity just below the speed of light. When the protons collide with the tungsten nuclei a collection of high-energy neutrons are produced and scattered. These neutrons are then assembled into beams and directed towards a range of scientific instruments where the interaction between the beam and a material sample will be analysed [3].

The heavy target at ESS is designed as a rotating tungsten wheel which will distribute the irradiation over a large volume of target material. The spallation process will produce an extreme level of highly penetrating gamma, a large amount of radioactive isotopes and fast neutron radiations [4], thus making safety issues regarding a worst case scenario the top priority.

The powerful proton beam will generate heat which will be absorbed by a helium cooling system surrounding the tungsten target. Although helium is an inert gas it may contain a small amount of oxygen impurity which could possibly lead to oxidation and consequently erosion.

The oxidation of tungsten is highly dependent on temperature and the amount of oxygen present, therefore the ESS has suggested a temperature interval for this project of 400°-900°C. This interval is assumed to cover the working temperature, and the temperature which the target might reach in a worst case scenario.

1.1 Objectives

The main objective of the project is to determine the oxidation characteristics of pure tungsten and contribute with understanding of the oxidation mechanism. This will be carried out by examining the effect of time, temperature and surrounding atmosphere on the rate of oxidation of pure tungsten from 400˚ to 900˚C. The oxidation behavior will be observed with thermogravimetry and differential scanning calorimetry. The gas used in these setups will be pure helium, a helium-oxygen mix, and pure argon. This study will also examine the effect of water vapor on oxidation; therefore these gases will be used both dried and saturated with water (i.e. passed through water). Finally, an attempt to create a suiting model to the overall process will be carried out.

1.2 Limitations

Due to the limited amount of time available, some assumptions and limitations must be set. The experiments will be performed under conditions as similar as possible to the conditions which the target material at the European Spallation Source (ESS) will be exposed to.

However, there are some big differences which need to be taken into consideration. For example, the samples used in the experiments are considerably smaller than the target at ESS. The experiments will only be carried out in the temperature interval of 400˚ to 900˚C, but the target at ESS might be exposed to a different temperature outside of the investigated interval.

The tungsten at ESS will be exposed to a variety of pressures. However, the tests performed in the laboratory at LTH will only be carried out at some specific pressures. Therefore the results acquired from the tests may not always be applicable to the conditions at ESS, due to discontinuity.

As the first experiments will be carried out with thin tungsten foils in the STA (see section 4.1.1) argon gas will be used instead of a helium/oxygen mixture due to the high buoyancy effect of helium on the foil. As stated earlier, pure helium is used as the inert gas at ESS but because both argon and helium are inert gases the results should not differ.

The rest of the experiments will be performed in the TGA (see section 4.1.2) with a gas mixture of helium and 0.5% oxygen – both humid and dry. The tungsten samples which will be used in those experiments are much thicker than the ones in the STA, consequently the buoyancy effect will not be as pronounced and may be neglected. However, as oxygen only enters the target station at ESS in case of a leakage, there is no way to predict how much oxygen the helium atmosphere is going to contain, the gas mixture used in this thesis may therefore not be equal to the real case scenario.

1.3 Background

In the following subchapters the necessary background information is covered. Firstly, information about the European Spallation Source is given, i.e. what it is and how it will work. Furthermore, an introduction of tungsten is made and then the history, applications and the production of tungsten is discussed.

1.3.1 European Spallation Source

The European Spallation Source (ESS) is one of the largest science and technology infrastructure projects being built today. This multi-disciplinary research center is designed to become the world´s most powerful facility for research with neutrons and is estimated to be around thirty times brighter than today's existing facilities [5]. The construction will consist of a linear proton accelerator, a heavy-metal target station, a large selection of state-of-the-art neutron instruments, laboratories; and a supercomputing data management and software development center. Sweden and Denmark are the hosting nations and an additional fifteen European countries will participate in the building of the ESS facility, which will be situated in Lund. The ESS Data Management and Software Centre (DMSC) will be located in Copenhagen. More than fifty universities, laboratories and research institutes from all over the world take part in this collaboration, both of the Design Update and in the Construction Phase.

The construction work will begin in 2014 and the launch and startup is planned to take place in 2019 [6]. It is estimated that around 2000-3000 guest researchers will carry out experiments at ESS each year.

Plant operation

Spallation [3] is a process where neutrons are produced using a particle accelerator and a heavy metal target, in the case of ESS, tungsten will be used. The accelerator will shoot protons at the target material, at a velocity just below the speed of light. When the protons collide with the tungsten nuclei a collection of high-energy neutrons are produced and scattered. These neutrons are then assembled into beams and directed towards a range of scientific instruments where the interaction between the beam and a material sample will be analyzed.

The heat generated by the powerful five MW proton beam [7] (the world's most powerful proton accelerator today, the accelerator at the Spallation Neutron Source facility in USA reaches an energy of one MW) will be absorbed by a helium cooling system [8], which will include the necessary containment systems and barriers.

The tungsten target systems will be surrounded by a twelve-meter wide, ten-meter high cylinder shielding system, consisting of 7000 tons of steel [4]. This shielding system is designed to keep unwanted radiation from escaping into the surrounding environment, both in normal operation and in the case of accidents. The spallation process will produce an extreme level of highly penetrating gamma, a large amount of radioactive isotopes and fast neutron radiations which must be shielded from the surroundings. The target itself is designed as a rotating tungsten wheel which will distribute the irradiation over a large volume of target material. This technology is new for spallation sources because none of the existing target designs are sufficient for the higher power level of ESS.

The ESS facility´s proton pulses will last 2.86 milliseconds and there will be fourteen pulses every second [7]. This will generate six times more neutrons per MW of power compared to a short pulse source. Today all existing neutron sources provide short pulses or continuous flux of neutrons; this means that ESS will be the first long-pulse spallation facility in the world. The most powerful proton accelerator today is the Spallation Neutron Source facility in USA (SNS) and yet it only reaches a fifth of the five MW energy that the ESS proton accelerator will provide. In conclusion the ESS will give a peak neutron flux that is thirty times larger than possible today – and the more neutrons, the more detailed and realistic the results of research are.

1.3.2 Tungsten

Tungsten is a transition metal with atom number 74 [9]. The average relative atomic mass is 183.85 ± 0.03 u. According to Lassner and Schubert [1, p. 1] thirty-five isotopes are known with 84-116 neutrons. However, according to Hammond [10] thirty-seven isotopes and isomers are known. Only five of the isotopes are occurring naturally and the remaining can be made artificially but they are all unstable [9]. The isotopes have a half-life ranging from milliseconds to more than 200 days. The five naturally occurring stable isotopes are the following, W-180, W-182, W-183, W-184 and W-186 [11]. Most occurring isotopes are W-182, W-184 and W-186.

Tungsten exists in four different types [9]. These are amorphous tungsten, α-, β- and γ-Tungsten. Of the three latter types, only α-Tungsten is stable and has a body centered cubic structure. β-Tungsten is a metastable phase and converts back to α-Tungsten when it is heated above 600°-700°C. γ-Tungsten will do the same when it is heated above 700°C. Moreover, this thesis will further refer to α-Tungsten when generally mentioning tungsten.

The density of tungsten will vary accordingly to the manufacturing process which has been used. The theoretical density is approximately 19.3 g/cm^3 and the melting point of 3422°C [10] is the highest of all metals.

Four different minerals containing tungsten exist in nature [10]. These are *wolframite* (Fe, Mn)WO_4, *scheelite* $CaWO_4$, *huebnerite* $MnWO_4$, and *ferberite* $FeWO_4$. The biggest finds of these ores are located in California, Colorado, Bolivia, Russia and Portugal, although reports have been saying that China has around 75 % of the world's tungsten resources.

History and applications of tungsten

Tungsten comes from the Swedish word *tung sten*, which means heavy stone. Tungsten is also known by the name *wolfram* which comes from the mineral *wolframite.* Tungsten minerals have been known since the Middle Ages, long before the discovery of tungsten itself [7, p.77]. Wolframite was first named *spumi lupi* (wolf foam) referring to the wolf-like nature of the mineral in tin smelting operations where it violently devoured tin causing a foam and thus decreasing the yield.

It was first in 1779 that Peter Woulfe established that wolframite might contain a new unknown substance. Three years later the Swedish chemist Carl Wilhelm Scheele examined Scheelite, another tungsten mineral at the time known as tungsten, and concluded that it contained limestone and a new acid – tungstic acid, which he thought could be reduced to produce a new metal [9, p.949]. Still, it would take another two years before metallic tungsten was first produced from wolframite. This was done in Spain in 1787, by the de Elhuyar brothers. They derived an acid from wolframite and by reducing it they obtained a new metal, naming it tungsten. Today both *tungsten* and *wolfram* are used when referring to the metal, although the latter is only used in Germany and Sweden [7, p.79].

About a decade later in 1890, Henry Moissan discovered some very hard components during his attempt to create diamonds. He did not succeed with producing any diamonds but instead he found the tungsten carbide. This discovery is said to have an unbelievable impact on the further development of tungsten technology on a long-term basis. Within the next thirty years tungsten carbide grew to be the biggest tungsten consumer, and was mostly used in high speed steel cutting tools.

In 1903 A. Just and F. Hanamann produced the first tungsten filaments for incandescent lamps. These filaments were made by forming a paste from fine tungsten powder mixed with sugar solution and gum (the tungsten powder was derived from tungstic acid by hydrogen reduction – which was a complicated and expensive method). The paste was then squirted through diamond dies and the coils were thereafter sintered in hydrogen by an electric current. The following years these tungsten filaments gradually replaced Edison´s carbon filament in the commercial production of incandescent bulbs. This was due to their much better light yield and lower energy consumption. A few years later, in 1909, W. D. Coolidge came up with a procedure for a powder metallurgical production of ductile tungsten wire. This procedure then resulted in a large-scale powder metallurgy and the main features of this method are still valid for today´s technology.

Figure 1.1 below shows the increase in tungsten production since 1910. The steady growth is due to increasing industrialization in the world. One can also notice a greater increase in war times and a decrease with economic recessions.

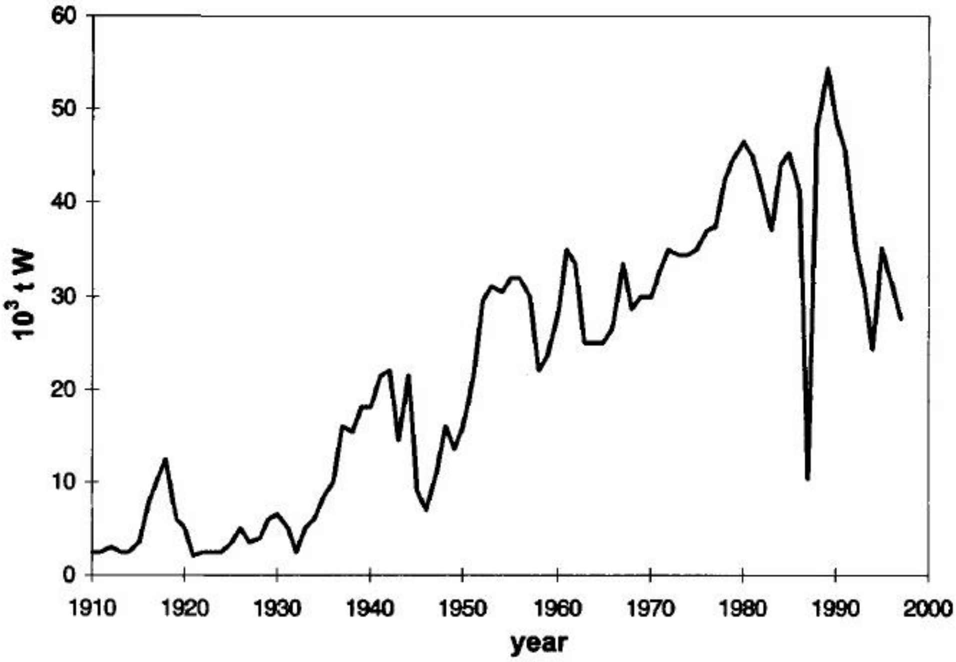

Figure 1.1*Tungsten world production 1910-1996. By courtesy of ITIA and A. P. Newey, in: Proc. 3rd Int. Tungsten Symp. Madrid, pp. 19-33 (1985)* [7, p.81]

During World War I tungsten played an important role. In 1913, before the war had begun, the British mining industry had no use for tungsten - on the contrary they considered it a waste and a nuisance because it disturbed the tin extraction [10, p.9]. The Germans on the other hand were secretly using it as high–speed steel in cutting tools, so they were very eager to buy all the "useless" tungsten the British gladly sold. When the war began, military and economic experts were certain that Germany could not keep up its industrial pace and that their ammunition supply would be exhausted within six months. They were proved wrong when it was discovered that the Germans were increasing their munitions output, even exceeding that of the Allies. Later the British found out that it was because of the tungsten ore – and that it came from their own mines. Immediately an international race for tungsten was on, and by now the metal was established as a strategic military item in the munitions race of World War I.

When the Second World War started, the Germans introduced a tungsten carbide armor piercing shell, thus making the military requirements for tungsten astronomical. All equipment of war – tanks, trucks, guns, shells etc. depend on high-speed steel tools, and the best are made of tungsten alloys. All in all tungsten was used in 15 000 different types of war items in World War II.

Germany had bought up nearly the entire world supply of off-grade tungsten ore, and they were using it to produce high-velocity armor-piercing projectiles with tungsten carbide cores. It took two years before the United States came up with similar missiles and in a quantity sufficient to defeat the Germans. It is said that tungsten in the form of a high-velocity projectile´s inner core, and in the form of tool steels helped immensely to bring victory and an end to World War II.

Today tungsten is used in a wide range of fields - both as a pure metal, as an alloy and as a carbide. It is used for filaments for electric lamps, in television tubes, X-ray targets, windings and heating elements for electrical furnaces and for a great number of spacecraft and high-temperature applications [8, p.4-39]. Another very important application for tungsten is high-speed tool steels. These are of great importance to metal-working, mining and petroleum industries.

Production of Tungsten

Tungsten mines are often small and rarely produce more than 2000 tons of ore per day [7, p. 179-254]. Tungsten deposits typically contain only some tenth of a per cent of WO_3 and because the ore concentrates in international trading require 65-75% WO_3, the result will be a very high amount of accompanying material (gangue) which requires separation. Here two things are important: the particle size of the tungsten ore which determines the degree of the disintegration needed to release the tungsten mineral (i.e. liberation size); and the type and concentration of the accompanying minerals which have to be separated, this determines the mode and number of separation steps.

There are two main steps in ore beneficiation – the comminution (pulverization) and concentration (separation of gangue minerals). Comminution is firstly done by crushing. This can be performed with jaw, cone, or impact crushers working mostly in closed circuits with vibratory screens. Secondly grinding is carried out in rod or ball mills working in closed circuits with classifiers. For concentration, several methods can be applied depending on the composition of the ore. These methods are for instance ore sorting, gravity methods, flotation, magnetic and electrostatic separation.

Because of its extremely high melting point, nearly 80% of tungsten worldwide is produced by powder metallurgy. Past advances in powder technology have greatly contributed to the development of tungsten and its alloys. Currently, production of tungsten metal powder is accomplished almost solely by the hydrogen reduction of high-purity tungsten oxides. The starting material is either WO_3 or tungsten blue oxide (TBO is a mixture of different constituents, such as ammonium, hydrogen and hydronium tungsten phases, and tungsten oxides). The reduction is carried out in furnaces where the tungsten powder passes through several temperature zones between 600°-1100°C in an atmosphere of hydrogen. The hydrogen is not only a reducing agent but also carries away the water formed.

Powder characteristics like average grain size, grain size distribution, agglomeration, apparent density, and grain morphology can be regulated by changing the reduction parameters. For example, humidity is a very important parameter which affects the average grain size. This is because the water vapour partial pressure strongly influences the nucleation rate of the metal phase and also lead to the high mobility of tungsten due to the presence of the volatile species – therefore the lower the humidity, the higher the nucleation rate and the smaller the grain size (under isothermal conditions).

A general rule when combining the parameters is that a small grain size is achieved with low temperature, dry hydrogen, high hydrogen flow rate, low dew point, small powder layer height, and high porosity. For large grain sizes the reverse applies.

The compacting of tungsten powder is not easily performed due to the metals relatively high hardness and difficult deformation. It is generally done either by pressing in rigid dies (uniaxial pressing) or isotactic pressing in flexible moulds (compaction under hydrostatic pressure) – in most cases without any lubricant to avoid any contamination by this additive. To obtain a completely dense material with the chosen shape and mechanical properties, a complex forming process is necessary. The most common techniques for forming tungsten are rolling (rods and sheet products), round forging (large diameter parts), swaging (rods), forging (large parts) and drawing (wires and tubes).

Tungsten is normally worked below the recrystallization temperature since the recrystallization is combined with grain boundary embrittlement – however, if the temperature is too low during the working, the metal will develop cracks and splits. The forming is usually performed in air, without any protecting gas, the thin oxide layer that thus forms acts as a protective layer against contamination form the working tools.

1.4 Literature Review

The study of tungsten has been of great interest for nearly a century – both from the scientific and the technological point of view. Tungsten has played an important role in technology mainly because of its exceptionally high melting point in combination with a unique high-temperature strength and high density. However, the biggest drawback with tungsten is the low resistance to oxidation. It has been shown that oxidation occurs at room temperature: tungsten oxidizes readily at 300°C [13] and the rate becomes substantial at temperatures higher than 600°C [14]. Unfortunately this limits the use of pure unprotected tungsten as a high-temperature structural material. As a consequence of this the oxidation of tungsten in particular has been studied extensively throughout the past sixty years – with the main focus being studies of the structural diagram of the W-O system, the kinetics of oxidation, the pressure dependence and other various factors effecting the rate of tungsten oxidation. This chapter will present a selection of the most relevant literature used for gathering information for the theoretical part of this project.

One of the most extensive and thorough books on tungsten published recently is *Tungsten – Properties, Chemistry, Technology of the Element, Alloys and Chemical Compounds* written by Erik Lassner and Wolf-Dieter Schubert [9]. This book has been of great use since it covers all possible aspects of tungsten (e.g. extraction and production of the metal; history and application; ecology; economy etc.) and since it was published in 1999 it covers a lot of modern day research and can be considered to contain up to date information about tungsten.

Another source of up to date values and information about tungsten – although very brief and concise – can be found in the most recent editions of handbooks about chemistry e.g. *Handbook of Inorganic Chemicals* [11] and *CRC Handbook of Chemistry and Physics* [10].

A more dated yet extremely informative and comprehensive source is *High Temperature Oxidation Protection of Tungsten* [15], a report first published in 1968 in Moscow, then translated and reissued a year later by NASA. The report is well over one hundred pages and with more than 330 sources it appears to have covered all available (at least American and European) research regarding tungsten oxidation.

One of the scientists that has contributed the most to the understanding of the mechanisms and kinetics of tungsten oxidation is E. A. Gulbransen. In 1947, together with W. S. Wysong, he published an article called *Thin Oxide Films on Tungsten* [13] where they conducted a microbalance study with the purpose to characterize the oxidation behavior of pure tungsten in oxygen. The temperature interval was chosen to 25°-550°C. One of the resulting conclusions was that pressure has a small impact on the oxidation rate as compared to the temperature effect. They also studied the volatilization of tungsten, in the interval of 600°-1025°C and found that for thick films no apparent weight loss is noted until a temperature of 800°C is reached – for thinner films the weight loss occurred at 900°C and over. The experiments show that the volatility of the oxide is not only a function of the temperature but also of the thickness of the film.

In 1960 E. A. Gulbransen and his colleague K. F. Andrew yet again studied the kinetics of the oxidation of pure tungsten, except this time at higher temperatures [16]. This is one of the more comprehensive and detailed papers dealing with the effect of time and temperature on the rate of oxidation of tungsten from 500° to 1300°C, the effect of pressure on the time course of oxidation at four temperatures, physical structure and crystal structure of the oxide scale, and the mechanism of reaction.

The volatilization of tungsten has not been studied as extensively, especially not volatility in the presence of water vapour. There is however a paper on this subject written by Belton and McCarron [17] where they conclude that the gaseous species WO_3H_2O might be responsible for the increased volatility of the tungsten oxides. Furthermore they concluded that the gaseous species is formed by the following reaction:

$$W(s) + 4H_2O(g) \rightarrow WO_3 \cdot H_2O(g) + 3H_2(g) \qquad (1.1)$$

However, a more recent study dealing with tungsten oxidation at low temperatures (20°-500°C) in both dry and humid air [18] did not result in any evidence of the forming of this gaseous species.

Despite the large amount of studies conducted on the oxidation of tungsten throughout the years, there is still no single opinion on the kinetics and the mechanisms involved. Inconsistent and contradictory results from various researchers show just how complex and difficult the behaviour of tungsten is. There is not even an agreement which of the tungsten oxides that exist and which of them that are stable, all this making it more difficult to predict the results from this thesis. In addition, none of the literature reviewed has used the exact same conditions, as going to be used in this project. Especially the gas mixture is going to be different. Most of the previous experiments were conducted in either pure oxygen, dry or humid air whereas this paper will deal with dry and humid argon gas, and with helium containing a small addition of oxygen.

2. THEORY

In the following subchapters, the general oxidation mechanisms and kinetics for metals are given. Also a brief introduction of the Wagner theory is discussed and lastly the specific oxidation mechanisms and kinetics of tungsten oxides are provided.

2.1 General Oxidation Mechanisms

Tungsten oxides are classified as non-stoichiometric ionic compounds [17, p.39-100]. This will in turn lead to that they are either an n-type or p-type semiconductor. The two different types of semiconductors are discussed in the following subchapters.

2.1.1 Negative (n-type) semiconductor

The name refers to the fact that the electrical charge is transferred by negative carriers [17, p.39-100]. There are two possible scenarios where this can happen, either by having an excess of metal or a deficit of non-metal.

Metal excess

For convenience ZnO is considered. If there is a metal excess then there will be interstitial cations and an equivalent number of electrons existing in the compound as seen in Figure 2.1 below. Both Zn^{2+} and Zn^{+} can occupy the interstitial sites.

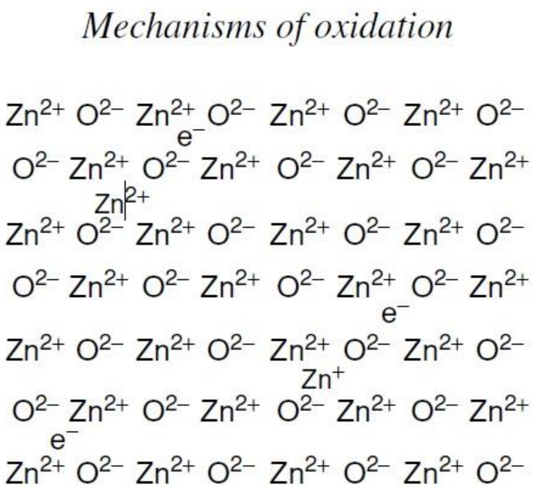

Figure 2.1*Interstitial cations and excess electrons in ZnO* [17, p.42].

This defect is formed by letting a perfect ZnO crystal lose oxygen. This can be represented as two equations.

$$ZnO = Zn^{2+} + 2e^{-} + \frac{1}{2}O_2 \quad (2.1)$$

$$ZnO = Zn^{+} + e^{-} + \frac{1}{2}O_2 \quad (2.2)$$

Non-metal deficit

This type of behaviour can be represented as evaporation and discharging of an oxygen ion. It will lead to an anion vacancy and excess electrons. It can be represented as the equation below:

$$O_O = V_O^{\cdot\cdot} + 2e^- + \frac{1}{2}O_2 \tag{2.3}$$

O_O is the oxygen in the metal oxide and $V_O^{\cdot\cdot}$ represent the oxygen ion vacancy. The process can be represented as in Figure 2.2 below.

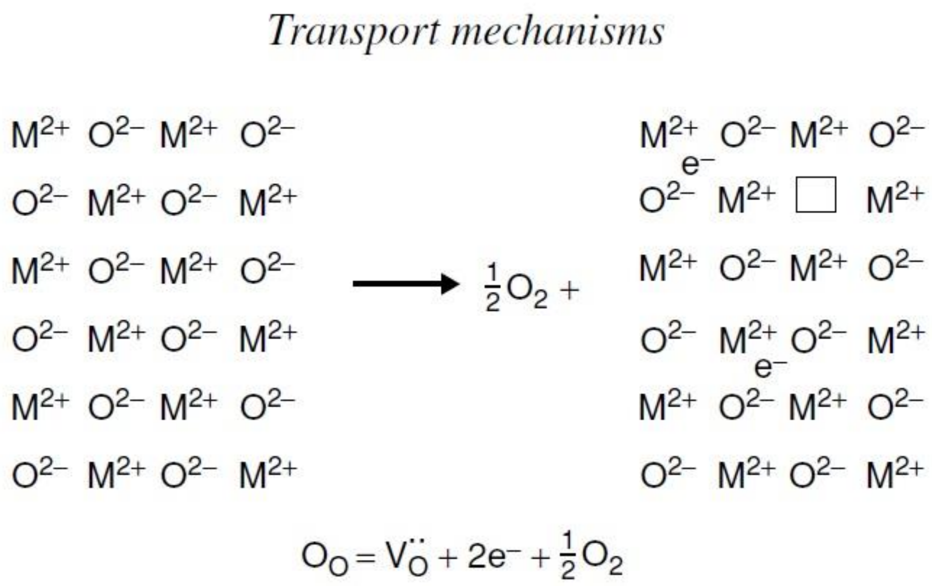

Figure 2.2 *Formation of oxygen deficit MO with oxygen vacancies and excess electrons* [17, p.43]

2.1.2 Positive (p-type) semiconductor

The name refers to the electrical charge being transferred by positive carriers. There are two possible scenarios where this can happen, either by having a deficit of metal or an excess of non-metal.

Metal deficit

The positive semiconductors of this type are made by the formation of cation vacancies together with electron holes. In order to be able to form electron holes more easily, the metal ions are preferable to be able to exist in various valence states. For convenience NiO is considered. It is relatively easy for an electron to go from a Ni^{2+} to a Ni^{3+} which will lead to a change in charge of the two ions. Therefore the site Ni^{3+} is called an electron hole. The process can be represented as in Figure 2.3 below.

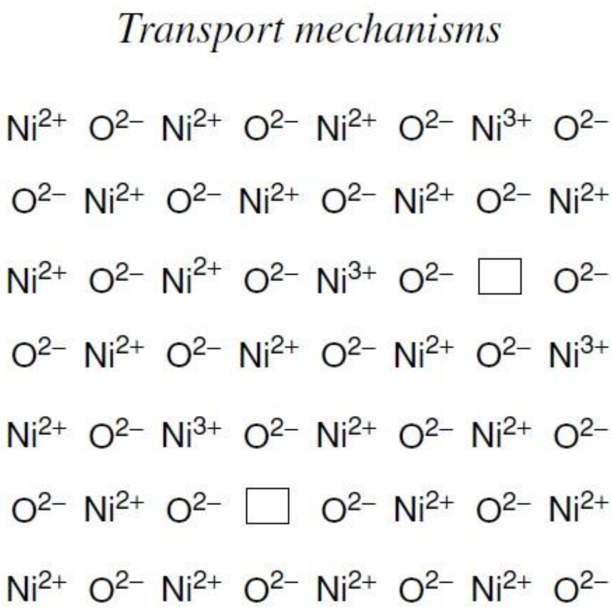

Figure 2.3 A t*ypical p-type metal deficit semiconductor – NiO with cation vacancies and electron holes.*[17, p.47]

2.1.3 Wagner theory of oxidation

The Wagner theory of oxidation [19] is based on various assumptions listed below [17, p.50-64]:

1. The oxide layer is compact and perfectly adherent to the metal.
2. The migration of ions or electrons across the oxide scale is the rate controlling process.
3. Thermodynamic equilibrium is established at both the oxide-gas and metal-oxide interfaces.
4. The oxide scale shows only small deviations from stoichiometry and the ionic fluxes are independent of position in the oxide scale.
5. Thermodynamic equilibrium is established locally throughout the oxide scale.
6. The oxide scale is thick compared with the distances over which space charge effects (electrical double layer) take place.
7. Oxygen solubility in the metal is neglected.

For comments regarding the oxidation nature of tungsten, see section 2.3 below.

Assumption number three states that thermodynamic equilibrium is expected to be established at both the oxide-gas and the metal-oxide interfaces. This will lead to the establishment of activity gradients of both metal and non-metal throughout the oxide scale (see Figure 2.4 below).

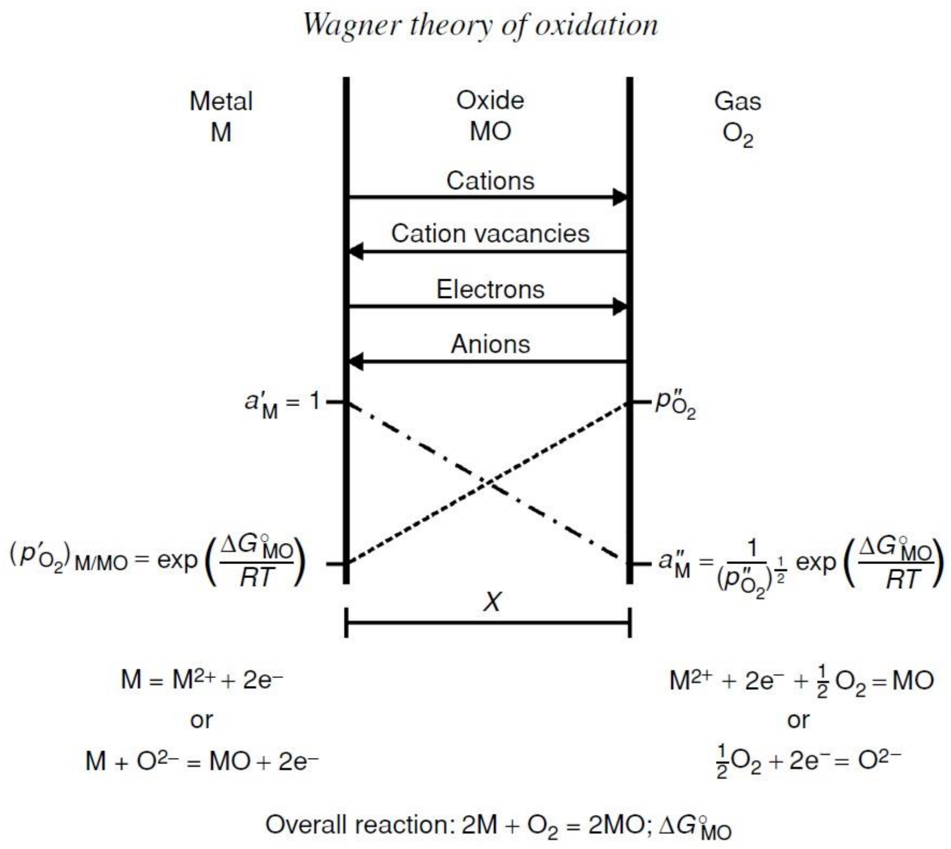

Figure 2.4 *Schematic of oxide scale formation according to the Wagner theory* [17, p.51]

This will in turn lead to migration of metal ions and oxide ions in opposite direction, throughout the oxide scale. As the ions are charged, the migration will build up an electric field across the oxide scale. The electric field will cause the electrons to transport from the metal to the atmosphere. However, as there is migration of ions at the same time as migration of electrons, no net charge transfer takes place throughout the oxide scale.

As ions are charged particles, they will respond to both chemical and electrical potential gradients, which together provide the net driving force for ion migration.

2.2 General Oxidation Kinetics

There are essentially three types of oxidation kinetics. These are linear, parabolic and logarithmic type of oxidation.

2.2.1 Linear oxidation

Under certain conditions the oxidation of a metal proceeds at a constant rate and follows the linear rate law below [17, p. 64]:

$$x = \left(\frac{\Delta m}{A}\right) = k_l \cdot t \qquad (2.4)$$

Where x is the thickness of the oxide scale, Δm is the mass change, A is the area of which oxidation is taken place over and k_l is the linear rate constant.

Oxidation at a linear rate is often observed under conditions when a phase-boundary process is the rate determining step for the reaction. Therefore the oxidation is more probable to follow the linear rate law in the initial oxidation, when we only have thin oxide layers. At this point, diffusion through the oxide scale is probably not the rate determining step.

2.2.2 Parabolic oxidation

In the initial stage of oxidation the oxide scale will be rather thin and diffusion through it will be fast. But as the oxidation proceeds and the oxide scale thickens, the metal activity gradient reduces throughout the oxide scale. This will lead to a reduction in ionic flux and reaction rate. When this happens, the rate determining process will be changed to the transport of ions across the oxide scale and the rate will decrease with time according to the parabolic rate law below [17, p. 72]:

$$x^2 = \left(\frac{\Delta m}{A}\right)^2 = k_p \cdot t \qquad (2.5)$$

Where k_p is the parabolic rate constant.

The parabolic rate constant will vary with temperature and oxygen partial pressure according to the Arrhenius equation [17, p. 87]:

$$k_p = constant \cdot \left(p_{O_2}\right)^{\frac{1}{n}} exp\left(\frac{-Q}{RT}\right) \qquad (2.6)$$

p_{O_2} is the oxygen partial pressure, n is a temperature dependant constant, Q is the activation energy for the present oxidation process, R is the gas constant and T is the absolute temperature.

2.2.3 Logarithmic oxidation

When metals are oxidized under special conditions (usually at low temperatures of up to 400°C or in the initial stage of oxidation for very thin layers of up to 0.1μm) they have an initial rapid reaction rate which quickly reduces to a very low oxidation rate. This type of oxidation follows a logarithmic law like the one below [17, p.69]:

$$x = \left(\frac{\Delta m}{A}\right) = k_{log} \log(t + t_0) + A \tag{2.7}$$

k_{log} is the logarithmic rate constant and t_0 and A are constants at constant temperature.

3. TUNGSTEN OXIDES

The oxidation mechanisms of tungsten have been widely studied over the past 50-60 years, but there are still many uncertainties and contradictions. There have been numerous discrepancies reported in the literature concerning kinetics, composition, and structure. This is in great extent due to the complexity of the oxidation mechanisms as well as the wide variety of oxides formed during oxidation. The oxides that have been detected during these investigations of the phases of the W-O system are:

> W_3O, $WO_{0.75}$ (W_4O_3), WO, $WO_{1.5}$ (W_2O_3), $WO_{1.8}$ (W_5O_9), WO_2, $WO_{2.5}$ (W_2O_5), $WO_{2.66}$ (W_3O_8), $WO_{2.72}$ ($W_{18}O_{49}$), $WO_{2.75}$ (W_4O_{11}), $WO_{2.8}$ (W_5O_{14}), $WO_{2.9}$ ($W_{20}O_{58}$), $WO_{2.92}$, $WO_{2.96}$, WO_3.

However, only some of the oxides mentioned above are considered stable and have been confirmed with sufficient reliability. Thermodynamic and crystallographic studies [13, p.32] state that the W-O system contains the following stable oxides: WO_3, $WO_{2.9}$, $WO_{2.72}$, WO_2. These oxides are sometimes referred to as α-WO_3, β-WO_3, γ-WO_3, δ-WO_3, see Table 3.1 below [2].

Stoichiometric formula	O/W ratio	Color
WO_3 (α)	3.00	Yellow
$W_{20}O_{58}$ (β)	2.90	Blue–violet
$W_{18}O_{49}$ (γ)	2.72	Reddish–violet
WO_2 (δ)	2.00	Brown

Figure 3.1 *Oxides in the W-O System* [2]

For some of these oxides there has been reported a wide range of nonstoichiometry: e.g. for β-WO_3 the composition changes between $WO_{2.88}$ [20] and $WO_{2.935}$ [21], and between $WO_{2.87}$ and $WO_{2.9}$ [22]. For γ-WO_3 the following compositions have been observed: $WO_{2.654}$ – $WO_{2.765}$ [23], $WO_{2.64}$ – $WO_{2.71}$ [22] and $WO_{2.7}$ – $WO_{2.73}$ [20]. The figure below shows the phase diagram of the binary W-O system.

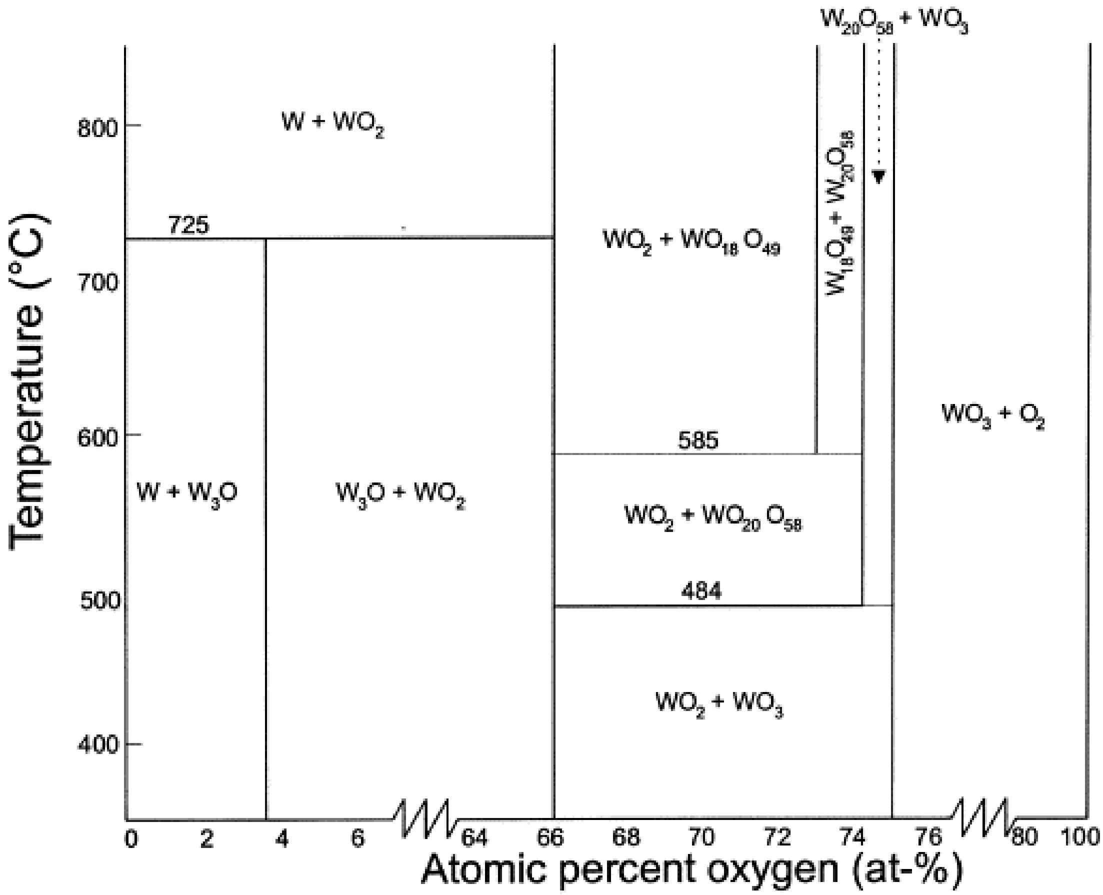

***Figure 3.2** Phase diagram of the binary W-O system* [28]

Tungsten oxides can also be expressed as WO_{3-X}, where 0<x<1. In other words: the removal of oxygen from WO_3 results in lower oxides. The stability of these oxides is highly dependent on the oxygen partial pressure. This leads to the formation of oxides with different stoichiometries - the lower the oxygen partial pressure the lower the stoichiometry. Unlike WO_2 and WO_3, the non-stoichiometric oxides have not been investigated as thoroughly. The activity for the non-stoichiometric oxides is assumed to take a value between that of the WO_2 and WO_3 and the oxidation is limited by the diffusion rate of oxygen ions.

The oxidation of tungsten can be divided into three steps each bound by a different mechanisms. The first step takes place in the beginning of the oxidation when the pure and unprotected tungsten surface comes in contact with oxygen. This initial oxidation is phase boundary controlled; it does not depend on diffusion until the oxide layer completely covers the tungsten surface. This oxide layer is often very thin, adherent and protective i.e. it will prevent the pure tungsten from further direct oxidation. At this first stage the majority of researches observed a dark blue or black layer close to WO_2 in composition. Webb et al. [24] found a dark-blue layer and assumed it to be $WO_{2.75}$, whilst Kellet et al. [25] attributed the darker protective layer to $WO_{2.72}$. A third study made by J.W Hickman, and E. A. Gulbransen [26] concluded that the oxide layer corresponds to WO_2. As stated in section 2.2 about general oxidation kinetics, this oxidation usually follows a logarithmic law below 400°C and up until the oxide layer is 0.1 µm, then the oxidation rate changes to follow a parabolic rate law.

The second stage involves the growth of this dark layer as well as the formation and growth of a bright yellow oxide layer (above 600°C). This stage is diffusion controlled because it occurs when the tungsten is completely covered by an oxide. This yellow oxide consists of WO_3 and is found in the outermost layer where the oxygen content is highest. It has a structure that differs from the other oxides; it is porous and permeable to oxygen. The formation rate of the WO_3 is determined by the tungsten ion transport to the phase boundary where the lower non-stoichiometric oxide meets WO_3 [9]. However, the *growth rate* of the trioxide is dependent on the oxygen ion diffusivity in WO_3 because the oxide is an n-type semiconductor meaning that it is the oxygen ions that diffuse in to the oxide.

In order to determine the predominant mechanism involved in tungsten oxidation Sikka and Rosa [27] performed marker experiments. During their experiment the markers made out of Pt-wires moved from the oxide/metal interface toward the oxide/gas interface. Thus, meaning that oxygen ions diffuse inward through the oxide. This confirms the theory that predominant mechanism is oxygen-anion vacancy diffusion. Sikka and Rosa state that this is the main defect in WO_{3-X}. The oxygen is mainly consumed in the oxide growth at the metal/oxide interface, some oxygen is said to dissolve in the oxide.

In Cifuentes, Monge and Perez´s study from 2012 [14], the oxidized tungsten surface consisted of two distinct layers of oxide. After fifty hours the outermost layer was eight micrometres thick and porous. The innermost layer was denser, with very little porosity and about forty micrometres thick. This sample was then compared to another sample exposed to the same environment for one hundred hours. When the second sample was examined, it showed the same two distinct oxide layers with the outermost one being practically identical in both structure and thickness to that found in the first sample. The innermost layer however, was about eighty-five micrometre thick which would again indicate that the oxide scale grows by inward oxygen ion diffusion.

The growth of the oxide scale follows a mixed parabolic linear rate law as long as the inner layer has not yet reached its maximum thickness [7, p.86]. After this the growth rate becomes strictly linear. However, according to a report by NASA [13, p.33] the transition from parabolic to linear rate occurs because of cracking in the oxide film which eases the approach of oxygen to the metal. This cracking of the oxide film is due to the arising stresses from the very high volume ratio (3.35) of the tungsten trioxide. A linear oxidation rate means that the scale is not protective against further oxidation. The time for the transition from parabolic law for the growth of the scale to a linear one depends on the temperature.

The third and last stage takes place at about 750°C. At temperatures above 750°C sublimation of WO_3 [26] is taking place and is beginning to influence the characteristics of tungsten oxidation. At even higher temperatures, above 1300°C [7, p.86] the sublimation rate is equal to the oxidation rate which means there is no formation of oxide on the surface because the oxide is completely volatilized. At these temperatures, the oxygen pressure has a strong effect on the tungsten oxidation [16] and the volatilization of tungsten trioxide also has an effect of the oxidation rate which must be taken into consideration.

Contact with humid atmospheres containing water or water vapor, will increase the volatility of tungsten oxides and hence speed up the oxidation of tungsten [7, p.86]. Grossweiner and Seifert [28] came to the conclusion that the gaseous species $WO_3 \cdot H_2O$ might be responsible for the increased volatility of the tungsten oxides. Furthermore they concluded that the gaseous species was formed by the following reaction:

$$WO_3(s) + H_2O(g) = WO_3 \cdot H_2O(g) \tag{3.1}$$

This means that water molecules reacts with the solid tungsten trioxide on the surface and form the gaseous species. Water molecules will therefore leach the solid tungsten trioxide.

However the gaseous species may also be formed by the following reaction according to Belton and McCarron's study [17]:

$$W(s) + 4H_2O(g) \rightarrow WO_3 \cdot H_2O(g) + 3H_2(g) \tag{3.2}$$

According to another paper on this topic, written by Baur et.al. [29], tungsten reacts with oxygen and first forms an oxide which is assumed to be WO_2 by the reaction formula:

$$W(s) + O_2(g) \rightarrow WO_2(s) \tag{3.3}$$

This reaction is then followed by the reaction to form the oxide WO_3:

$$WO_2(s) + \frac{1}{2}O_2(g) \rightarrow WO_3(s) \tag{3.4}$$

The solid oxide WO_3 then sublimes according to the reaction formula:

$$WO_3(s) \rightarrow \frac{1}{n}(WO_3)_n(g) \tag{3.5}$$

As there is sublimation of tungsten trioxide ongoing (above 750°C) as well as the formation of the gaseous species, then the leaching of the $WO_3(s)$ is higher at this temperature than if water was not present in the oxidation atmosphere.

The innermost tungsten oxide is generally accepted to follow the Wagner theory of oxidation (see section 2.1.3). For example assumption one from the Wagner theory is that the oxide layer must be compact and perfectly adherent to the metal. Studies [7, p. 86] have shown that this is actually close to the truth. However as more oxide layers are formed on top of the innermost layer, and as the scale thickens, one can no longer rely on the Wagner theory. This is due to the fact that this theory only takes one oxide layer into consideration – and for tungsten in particular the oxide scale consists of layers of different composition. This formation of different tungsten oxides on top of each other is far more complex and requires a different approach. For instance the outermost oxide layer, represented as tungsten trioxide, is reported as porous and non-adherent [25] which is the opposite to the innermost layer. A combination of theories and semi empirical approaches are often used in this case.

4. EXPERIMENTAL

The experimental part of this thesis is divided into two different setups. The first four experiments were conducted at two temperatures, 500° and 550°C, with a *Simultaneous Thermal Analysis* using dry and humid argon gas. The rest of the experiments were carried out in a much larger furnace (*Thermo gravimetrical analysis)* using a combination of helium and oxygen gas, also both dry and humid.

4.1 Experimental Part One – STA Isothermal Oxidation Studies

The experiments were done with a thin round tungsten foil which had a diameter of approximately 5.5 mm. The experiment was performed in a STA (see section 4.3.1) at a constant temperature of 550° or 500°C, for forty-eight hours. For the first two experiments dry argon gas was used to create the desired inert atmosphere. These runs were repeated but this time with humid argon. For setup and procedure see section 4.5.1.

4.2 Experimental Part Two – TGA Isothermal Oxidation Studies

The second part of the experiment was performed in a large furnace (see section 4.3.4) in combination with a highly accurate electrical balance (see section 4.3.3). The experiments were performed according to the plan seen in Table 4.1 below. The tungsten samples were approximately twenty mm in diameter and three mm thick, and they were kept in the furnace at the desired temperature and atmosphere for two hours.

Table 4.1 *Experiments in the TGA*

Experiment No.	Temperature [°C]	Gas atmosphere
1	400	He-0.5%O_2
2	500	He-0.5%O_2
3	600	He-0.5%O_2
4	700	He-0.5%O_2
5	750	He-0.5%O_2
6	800	He-0.5%O_2
7	900	He-0.5%O_2
8	500	Dry Helium
9	600	Dry Helium
10	400	He-Ar-H_2O
11	500	He-Ar-H_2O
12	600	He-Ar-H_2O
13	700	He-Ar-H_2O
14	750	He-Ar-H_2O
15	800	He-Ar-H_2O
16	900	He-Ar-H_2O

4.3 Materials

4.3.1 Simultaneous thermal analysis (STA)

The instrument used is an NETZSCH STA 449 **F3** *Jupiter*. It measures mass changes and thermal effects between -150° and 2400°C. An STA refers to the simultaneous application of Thermogravimetry (TGA) and Differential Scanning Calorimetry (DSC) to the same sample during an experiment, using only one instrument. The are many advantages to this method, e.g. the test conditions (that is same atmosphere, gas flow rate, vapor pressure on sample, heating rate, thermal contact to the sample crucible and sensor, radiation effect, etc.) are identical for the TGA and DSC signals. It improves the throughput as more information is gathered per run when combining two experiments in one. In Table 4.2 below, some of the possibilities with a DSC analysis respectively a TG analysis, are listed.

Table 4.2 *Possibilities of the DSC and the TGA* [30]

DCS analysis possibilities	**TG analysis possibilities**
Melting/crystallization behaviour	Mass changes
Solid-solid transitions	Temperature stability
Polymorphism	Oxidation/reduction behaviour
Degree of crystallinity	Decomposition
Glass transitions	Corrosion studies
Cross-linking reactions	Compositional analysis
Oxidative stability	Thermo kinetics
Purity determination	
Specific heat	
Thermo kinetics	

A DSC uses two pans (as seen in Figure 4.1 below) – an empty reference pan and a pan where the sample is placed. Below each pan there is a heater. The principle of the DSC is based on the idea of maintaining the exact same temperature for both pans during the whole experiment. This means that the flow rate will be different between the pans **-** naturally the pan containing the sample will have a different heating rate compared to the empty pan. If any transformation, accompanied with heat exchanges, occurs this will be reflected as a peak in the graphs that the PC unit is processing.

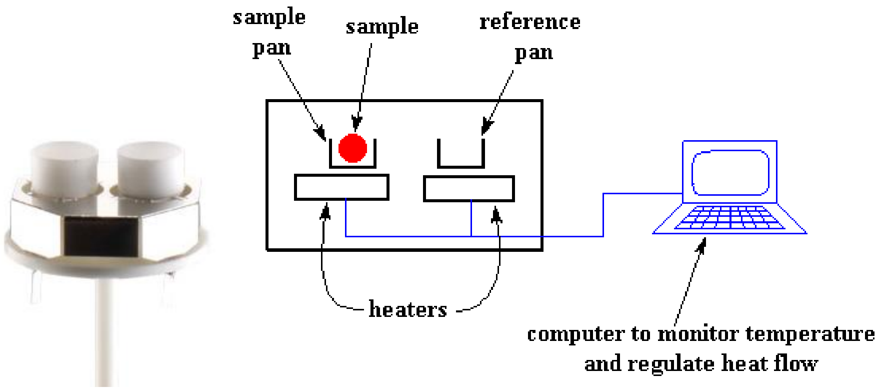

Figure 4.1 *Left: Shows the pans on the heater* [31], *Right: A schematical picture of the DSC setup* [32]

The NETZSCH STA 449 **F3** *Jupiter* has three gas inlets. One is protective and directed against the balance system, and the other two are for purge gases acting on the sample. In order to achieve the desired atmosphere in the sample chamber (before starting the experiment) the gas is flushed into the chamber and then sucked out until vacuum occurs. This is usually repeated three times to make absolutely sure that the chamber is completely filled with the chosen gas. A schematic view of the STA can be seen in Figure 4.2 below.

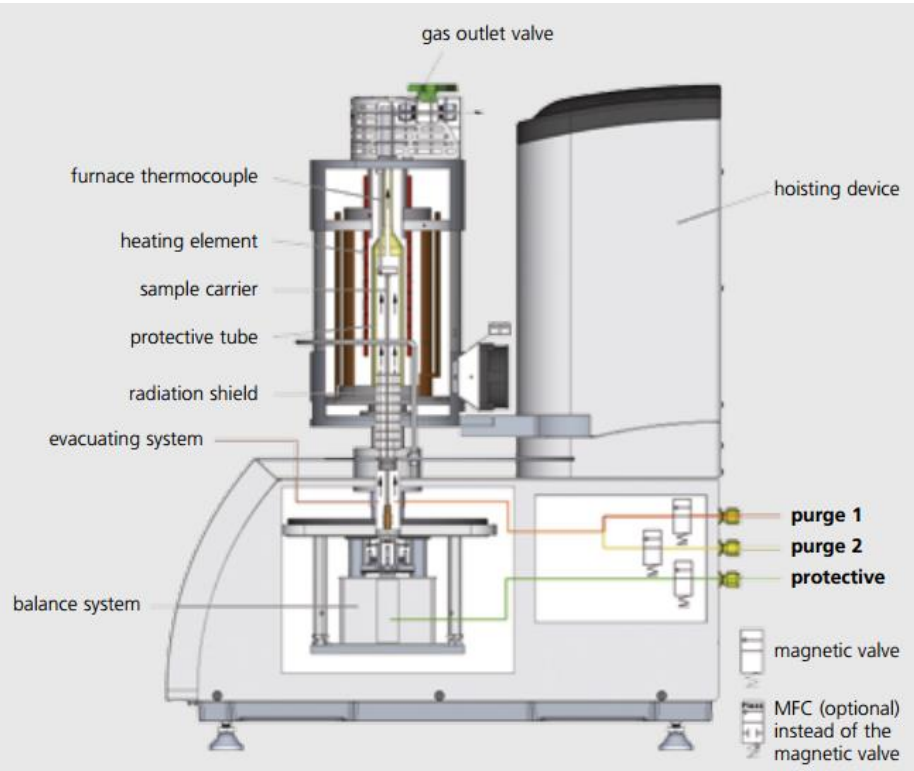

Figure 4.2 *A schematic view of the STA* [30]

Because the DSC is combined with a highly sensitive balance it shows the possible mass change during the experimental run. Thus, with the knowledge of oxide formation and growth it is possible to combine the mass change together with the exothermic or endothermic behavior of the sample in order to determine if (and possibly which) oxides have been formed during the experiment. The real STA can be seen in Figure 4.3 below.

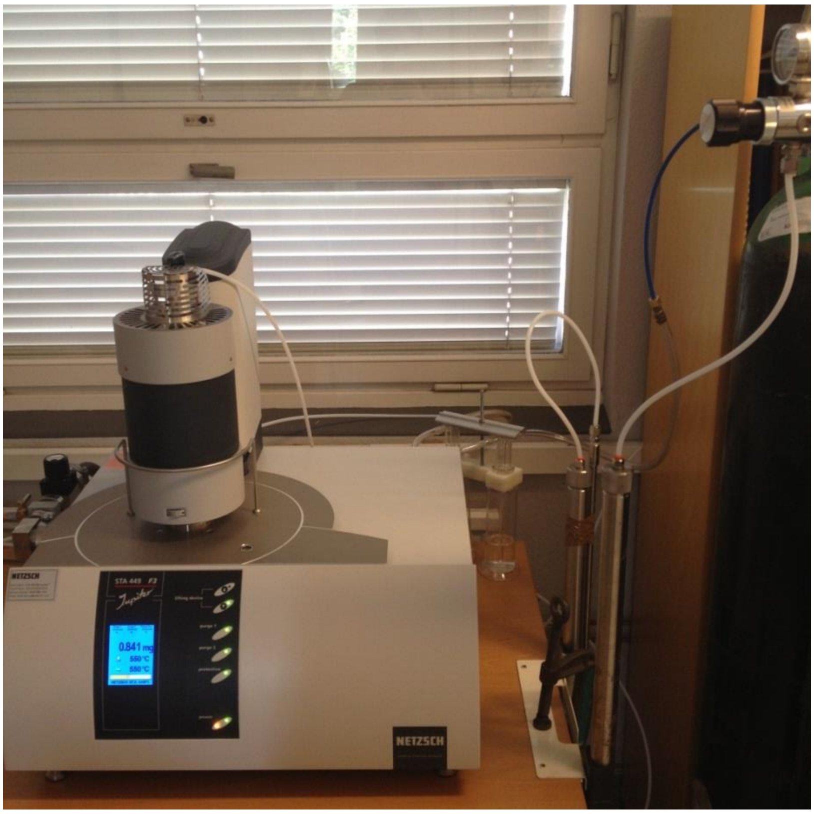

Figure 4.3 *NETZSCH STA 449 F3 Jupiter*

4.3.2 Thermogravimetric analysis (TGA)

A thermogravimetric analysis (TGA) [33] refers to a method where you measure changes in mass of a system (element, mixture or a compound), as a function of temperature. This technique can provide information about some physical and chemical phenomena such as those given in Table 4.3 below.

Table 4.3 *Phenomena that can be studied using thermo gravimetric analysis* [33]

Physical phenomena	**Chemical phenomena**
Second order transition	Chemisorption
Vaporization	Desolvation (especially dehydration)
Sublimation	Decomposition
Absorption	Oxidative degradation
Adsorption	Solid-state reactions (that occur with a change in weight)
Desorption	Solid-gas reactions (e.g. oxidation or reduction)

The general and basic instruments needed for a thermogravimetric analysis are a precision balance and a furnace. For time saving, nowadays computers keep automatic continuous recording of the mass and temperature.

The thermo gravimetric analysis setup used in this thesis consists of an electrical balance provided by Shimadzu, AUW120D (for information about the balance see section 4.3.3 below), a vertical furnace provided by Carbolite®, model type STF 15/75/450 (for information about the furnace see section 4.3.4 below) with a temperature controller. The setup also has a gas flow meter by SHO-RATE™.

4.3.3 Electrical balance Shimadzu AUW120D

The electrical balance has an upper maximum capacity of 120 grams and a lower capacity of forty-two grams [34]. For the capacity of 120 grams the balance has a minimum display of 0.1 mg and for the capacity of fort-two grams it has a minimum display of 0.01 mg. It has a built-in calibration weight, which makes it easy to calibrate. The main body weighs approximately seven kg and its dimensions are approx., 220 mm in width, 330 mm in depth and 310 mm in height. When using, the ambient temperature range is 10°-30°C. The Shimadzu balance can be seen in Figure 4.4 below.

Figure 4.4 *Electrical balance, Shimadzu AUW120D*

4.3.4 Furnace Carbolite® STF 15/75/450

The tube furnace Carbolite® STF 15/75/450 has a maximum working temperature of 1500°C [35] and has a tube length of 900 mm (heated length of 450 mm). Its inner diameter is seventy-five mm. The time required for the furnace to heat up is seventy minutes and the heating up is done by a thermocouple type R. Furthermore, the weight of the whole furnace is approximately thirty-four kg. A picture of the furnace can be seen in Figure 4.5 below.

Figure 4.5 *Furnace Carbolite® STF 15/75/450*

4.3.5 Optical microscope

The LEICA DMRME optical microscope was used to investigate the oxidized samples. This microscope is specially designed for metallographic studies, the industry and material research [36]. It has a motorized specimen stage and a computerized user interface which makes it user friendly. The operating software used is Qwin. The magnification rate varies from 16 x up to 1500 x. A picture of the optical microscope can be seen in Figure 4.6 below.

Figure 4.6 Optical microscope LEICA DMRME

4.3.6 Environmental scanning electron microscope (ESEM)

The ESEM used is a Philips XL-30 ESEM [37]. It uses a LaB6 single crystal as an electron source and has an ultimate resolution of 3.5 nm. It has a large chamber and can be used for conventional high vacuum pumping or in the environmental mode. The samples can be examined in an atmosphere of up to 1333 Pascal of water vapor, oxygen, nitrogen carbon dioxide or any other non-corrosive gas. Even wet or non-conductive samples can be examined [38]. The basic detection modes are: secondary electron, backscattered electron for variable pressure, gaseous secondary electron, and light element analysis such as oxygen and carbon.

4.3.7 Struers Rotopol –2 polishing machine

In order to polish some of the tungsten samples, a Rotopol-2 [39] polishing machine from Struers, was used. The Rotopol-2 has two motors which both can be set independently at two different rotational speeds of 150 rpm and 300 rpm. The motor output is 225 W at 150 rpm and 450 W at 300 rpm. The polishing machine has a width of 700 mm, a depth of 700 mm, a height of 215 mm, and has a weight of forty-seven kg. Various grinding papers with SiC can be mounted on the rotational discs. Polishing can also be carried out with cloths applied with diamond abrasives. In Figure 4.7 below one can see the physical Rotopol-2 polishing machine used in this thesis.

Figure 4.7 *Struers Rotopol –2 polishing machine*

4.3.8 Digital ultrasonic cleaner CD-4800

The ultrasonic cleaner cd-4800 provided by Codyson has a power output of seventy W [40]. Its dimensions are 230x180x160 mm and weigh approximately 1.75 kg. The working frequency of the ultrasound is forty-two kHz.

The ultrasonic cleaner creates an ultrasonic high frequency sound that in turn creates small microscopic vacuum-bubbles in the medium. These vacuum-bubbles are then rapidly drawn together, creating pressure shocks in the medium which dislodges the dirt particles in the small scratches of the cleaned object. A picture of the ultrasonic cleaner can be seen in Figure 4.8 below.

Figure 4.8 *Digital ultrasonic cleaner CD-4800*

4.4 Sample Preparation

For the experiments conducted in the STA thin tungsten foil samples of 99.97% purity were used. The samples were turned from a tungsten sheet and cleansed in ethanol to ensure clean surfaces. The size of the foils was approximately 5.5 millimeters in diameter and the weight was between nine and eleven milligrams. The small tungsten foil samples can be seen in Figure 4.9 below.

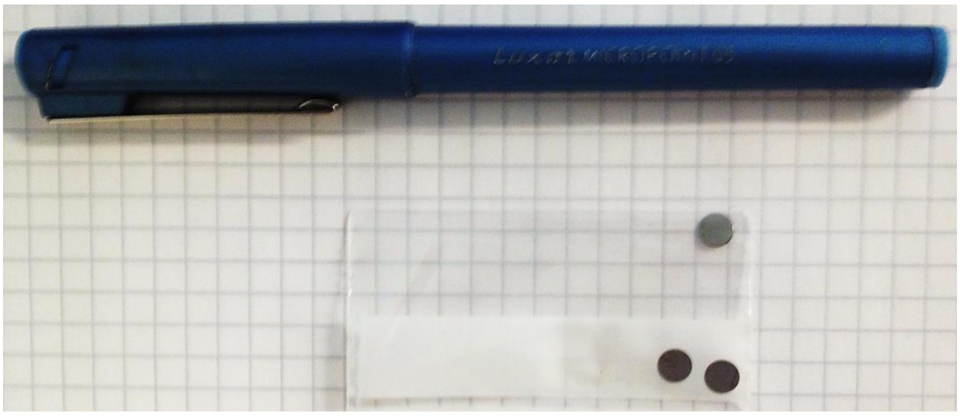

Figure 4.9 *Small round tungsten foil samples*

The larger samples used in the TGA experiments were received already electro-polished and therefore the only preparation performed was cleaning the tungsten disks with acetone in an ultra-sonic cleaner (see section 4.3.8 above) for 280 seconds. The size of the disks was approximately twenty mm in diameter and three mm in thickness, the weight was about eighteen grams per sample. Figure 4.10 below shows a picture taken of a disk prior to oxidation. The disks are bright and shiny in reality, without the dark shade as in the picture. There are some shallow scratches, and some marks going in one direction probably due to the machining processes.

Figure 4.10 *Picture of an unoxidized electro-polished tungsten sample disk.*

4.4.1 Examination of the tungsten disc samples

Prior to any experiments a tungsten disc sample was etched and examined in the optical microscope. This was done in order to characterize the microstructure of the tungsten. The samples were thoroughly grinded and polished before etched with Murakami´s reagent and observed in the optical microscope. Murakami´s reagent was prepared according to ASTM 98 C and consists of one part $K_3Fe(CN)_6$, one part KOH and ten parts of H_2O. The pictures of the etched surfaces are shown below in a 200 x resp. 100 x magnification.

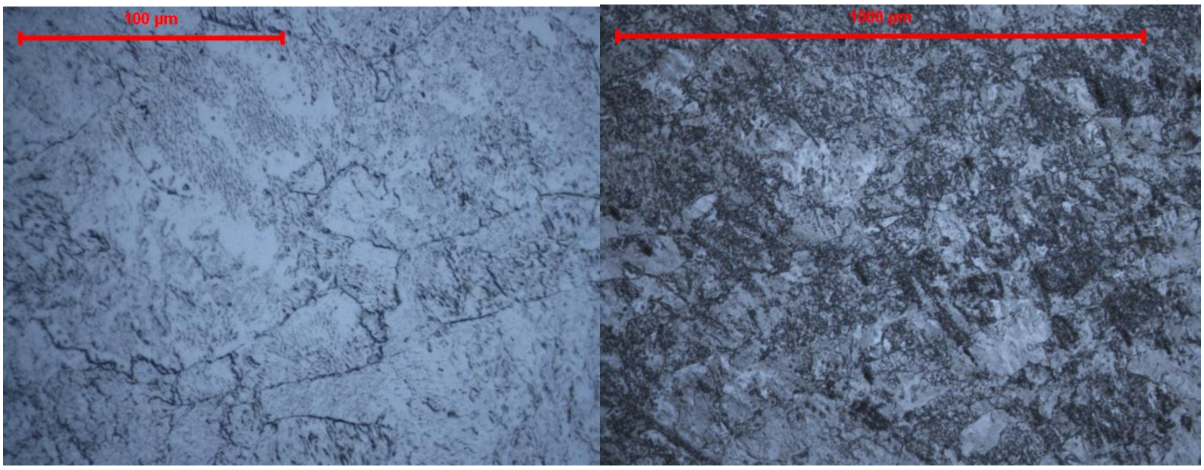

Figure 4.11 *Optical microscopy pictures of etched tungsten discs. Left: 200 x magnification. Right: 100 x magnification*

It was quite difficult to obtain sharp images with well-defined grains, however it seems like the grains vary in size between twenty and eighty µm.

Rockwell C hardness tests were also performed on the discs. The result can be seen in the table below.

Table 4.4 *Tabulated values of a Rockwell C hardness test. The disc was tested on both sides*

Electro-polished ChinaTungsten	
Side A [HRC]	**Side B [HRC]**
43.9	42.0
44.2	43.6
44.1	44.1
Mean 43.7 HRC	

4.5 Setup and Procedure

4.5.1 STA Setup and procedure

The gas used in the STA chamber is Argon 4.6 (ARGON PLUS) from AGA. It has an argon content of minimum 99.996 % [41] and a maximum impurity of $5 \cdot 10^{-6}$ atm. of oxygen partial pressure. The total gas flow in both purges one and two and in the protective inlet always adds up to seventy ml/min.

Before the experiment is started the samples are weighed in the STA. The chamber is completely emptied of any gas with a pump generating a vacuum and then flushed with the argon gas. The procedure is repeated three times to make absolutely sure that the experimental environment is the desired one. The STA is programed with the NETZSCH Proteus software to start at 26°C and increases the temperature by 15°C/min until it reaches the selected temperature, where it is held for forty-eight hours.

To subtract unwanted background noise (e.g. due to gas flow fluctuations) from the actual results a correction file is made. This is done by running the experiment at the exact same conditions as the real one, but without any sample. The correction file is then combined with the file from the main run to show a more correct result.

Setup with dry argon gas (oxygen partial pressure ≤ $5 \cdot 10^{-6}$ atm.)

Two experiments, at 500° and 550°C, were carried out with dried argon gas. The argon gas had a maximum impurity of $5 \cdot 10^{-6}$ atmospheres of oxygen partial pressure [41]. Before the gas entered the STA it was passed through two containers with calcium chloride and one molecular sieve in order to eliminate water molecules. For this experiment only the protective inlet (twenty ml argon gas/min) and purge two (fifty ml argon gas/min) were used.

Setup with moist argon gas (water vapour partial pressure ~ $6.6 \cdot 10^{-3}$ atm.)

The setup here was a bit different from the previous. The gas was divided into all three inlets with twenty ml/min dried argon used as the protective gas and thirty ml/min dried argon going into purge two. The last twenty ml/min were first passed through two water filled gas tight beakers, before going into purge one. Two experiments were done with this setup, also at 500° and 550°C.

In order to derive the partial pressure of water vapor, it's necessary to have the vapour pressure of water. The vapor pressure is here taken at 20°C:

$$p_{vap.} = \frac{2339.3\ [Pa]}{101325\ [Pa]} = 0.0231\ atm.$$ [8, p. 6-5]

To obtain the partial pressure of water vapor the vapor pressure of water is multiplied with the ratio of volume humid argon and total volume of argon gas according to Equation (4.1) below (the volumes in the equation represents volume flow per minute):

$$p_{H_2O} = p_{vap.} * \frac{20*10^{-6}\,[m^3]}{70*10^{-6}\,[m^3]} \approx 0.0066\,atm. \tag{4.1}$$

4.5.2 TGA Setup and procedure

Setup with dry helium+0.5 % O_2 gas (oxygen partial pressure ~ $5 \cdot 10^{-2}$ atm.)

The setup for the second part of this study is shown in a schematic picture in Figure 4.12 below. The different parts of this setup are described in detail in their respective sections in chapter four. The gas used in these experiments had an oxygen content of 0.5 mol %. According to customer service at AGA Gas AB, the impurities of water and oxygen was maximum of $5 \cdot 10^{-6}$ atm. The partial pressure of oxygen in this gas mixture is then ~ $5 \cdot 10^{-2}$ atm.

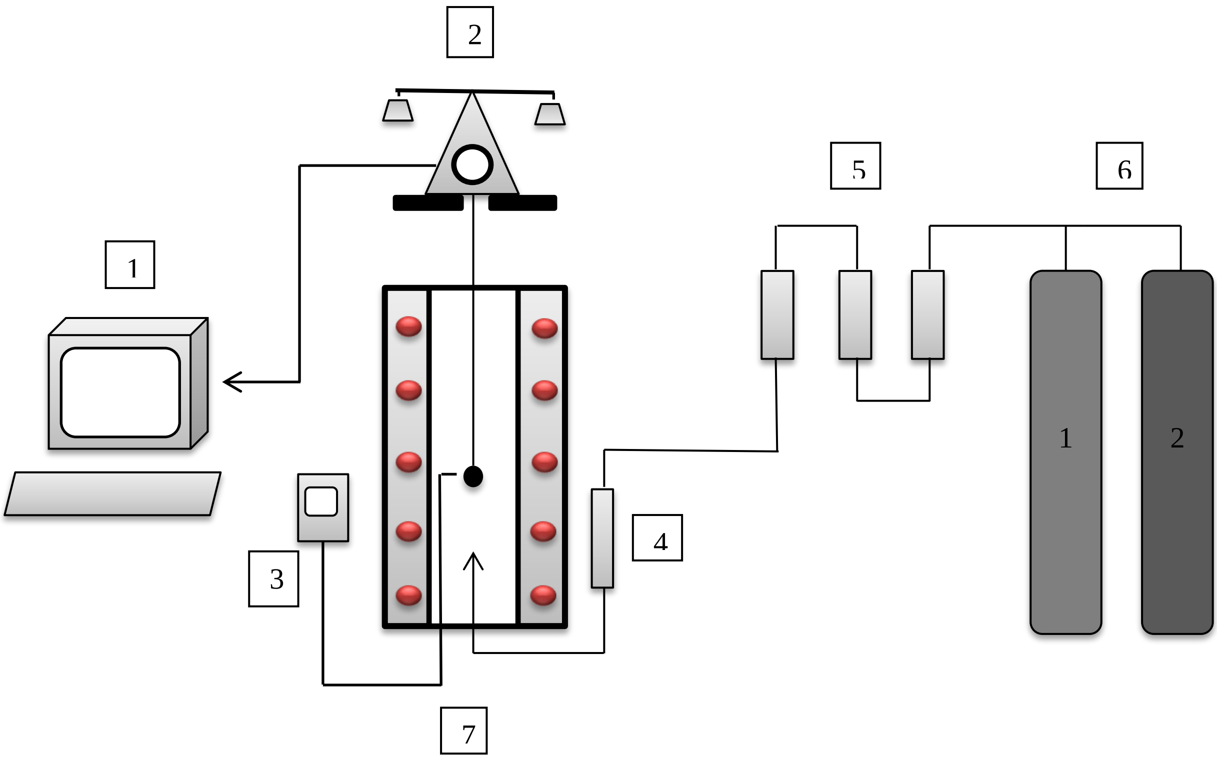

Figure 4.12 *Schematic picture of the TGA setup: (1) Computer taking notes from balance every ten seconds, (2) Balance with suspended sample, (3) Voltmeter connected to a thermocouple, (4) Flow meter, (5) Dryers, (6) Gas containers, (7) Furnace.*

The gas (6) is passed through three containers (5) filled with coarse grained (~two-six mm sized) calcium chloride. The gas flow into the furnace (7) is controlled with a flow meter (4). From a balance (2) suspended approximately one meter above the furnace a thin stain less steel thread is hung carrying the sample. The thread holding the sample (see Figure 4.13) is a 0.5 mm *Chromaloy O®* - *Resistance Alloy (Fe75/Cr20/Al5)* wire.

Figure 4.13 *Front and back view of the wiring of the sample. The disk seen here is an unpolished tungsten sample.*

The sample is hung in the middle of the furnace (level two), ca. fifty cm from the top and as near the thermocouple (3) as possible. During the experimental run the balance continuously measures the mass and sends the information to the computer (1) every tenth second.

The TGA part of this study consists of three variations of the previously mentioned setup (see Figure 4.11). The first experiments were performed in an atmosphere of helium and 0.5% oxygen. Initially the samples are hung right at the top of the furnace (level one, see Figure 4.14), at the level of the water cooling system used to protect the rubber gasket in the opening. The temperature here is far below the temperature in the middle of the furnace, therefore the oxidation taking place at this position is negligible.

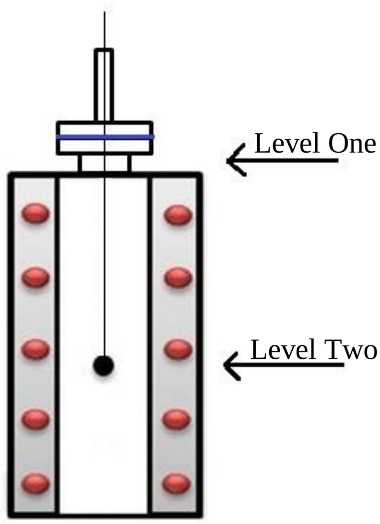

Figure 4.14 *Furnace*

The sample is kept at level one during the warm-up of the furnace, which takes approximately twenty to thirty minutes depending on the temperature set. When the furnace reaches its operating temperature the sample is lowered to level two and the weight measurements begin. During the warm-up (in all three variations of the setup), dried helium gas is passed through the furnace. This is done to ensure that no air remains in or enters the furnace. When the sample has been lowered to level two, the dried helium is replaced with the desired gas atmosphere (dry helium, dry helium-oxygen mixture, or humid helium).

Before the samples are hung they must be prepared. The extent of preparation depends on the quality and roughness of the sample, this is described in detail in section 4.4.

There are a number of steps that have to be followed strictly before and during the experimental run to ensure the consistency of the experiment. These steps are as follows: measurement of the diameter and thickness of the cleaned sample; creation of a suspension device (see Figure 4.13); weighing of the thread and the suspension device and weighing of the sample before oxidation. Notes are taken of the gas flows; the temperature according to the voltmeter of the thermocouple; the starting time and the starting weight. During the run these values are closely monitored to avoid any errors or unexpected deviations.

When the experimental time runs out the gas is switched back to helium and the sample is raised to level one again to cool off. The sample is held at level one for approximately twenty-thirty minutes, before the furnace lid is opened and the sample is taken out. A photograph is taken for each sample and these photographs can be seen in the results chapter.

Setup with moist helium/argon (water vapour partial pressure ~ 0.0078 atm.)

In this setup we use two different kinds of gases which combine into a gas mixture before entering the furnace. The first one is dried helium. The helium is passed through three containers filled with coarse grained (~two-six mm sized) calcium chloride (same as for the previous setup), in order to dry it. The gas flow is controlled by a flow meter before it enters a valve. The valve connects the two different gas inlets (one with dried helium and one with humid argon) into one outlet before it enters the furnace. The gas flow of the dried helium was tried to be kept at 150 ml/min during the oxidation. The flow meter was however measured in millimetres. A brief description of the conversion from millimetres to litres/min is here given:

Gases in normal condition and many liquids (for example water) are usually considered as Newtonian fluids. If we consider the momentum balance for steady flow of a Newtonian fluid through a long cylindrical tube, we will reach to the following equation:

$$Q = \left(\frac{P_0 - P_L}{L} + \rho g\right)\left(\frac{\pi R^4}{8\mu}\right) \tag{4.2}$$

Q is the volume flow rate, L is the length of the cylinder, P_0-P_L is the fluid pressure difference between two ends of the cylinder, ρ is the density of the fluid, g is the acceleration due to gravity, R is the radius of the cylindrical tube and μ is the viscosity of the fluid.

This leads to the equation:

$$millimetres = 2.016 * V_{O_2}\left(\frac{litres}{hour}\right) + 17 \tag{4.3}$$

From Poiseuille's equation we get:

$$V_{O_2} * \mu_{O_2} = V_{He} * \mu_{He} \leftrightarrow V_{O_2} = \frac{V_{He} * \mu_{He}}{\mu_{O_2}} = 8.6538 \tag{4.4}$$

$V_{He} = 0.15 * 60$ [m^3/s], $\mu_{He} = 20.0$ [μPa s] (at 300K)[8, p.6-174] and $\mu_{O_2} = 20.8$ [μPa s] (at 300K) [8, p.6-174]

If we substitute the answer from equation (4.4) into equation (4.3) we get:

$$millimetres(helium) = 34.4 \tag{4.5}$$

The other gas is argon which is passed through two water filled gas tight beakers (the same beakers as in the experiments with humid argon in the STA). The gas flow is controlled by an adjustable flow meter before it enters the valve.

Moreover the setup is identical to the previous setup described above.

During the warm up of the furnace when the sample is kept at level one, the dried helium flow is kept somewhat higher than when it is kept at level two. This is done to ensure that no air remains in or enters the furnace. When the furnace has reached the correct temperature the sample is lowered down to level two. At this point the flow of helium is changed to approximately thirty-four mm (150ml/min) (according to Equation (4.5)) and we introduce the humid argon which is kept at fifty ml/min during the oxidation time.

To derive the partial pressure of water vapour the steps are the same as done in section 4.5.1 with the humid argon. The vapour pressure of water is here taken at 25°C instead:

$$p_{vap.} = \frac{3169.9\ [Pa]}{101325\ [Pa]} = 0.0313\ atm.\ \text{[8, p. 6-5]} \rightarrow$$

$$\rightarrow p_{H_2O} = p_{vap.} * \frac{Vol.humid\ Ar}{Tot.vol.(humid\ Ar + He)} = p_{vap.} * \frac{50*10^{-6}\ [m^3]}{200*10^{-6}\ [m^3]} \approx 0.0078\ atm. \tag{4.6}$$

5. RESULTS AND DISCUSSION

The results from the all the experiments are presented and discussed here. This chapter is divided into several sections with results from the different setups. The results from the forty-eight hour runs in the STA are presented first, followed by the results from the shorter two hour TGA experiments.

For the experiments in the TGA, the chosen temperatures were 400°, 500°, 600°, 700°, 750°, 800°, and 900°C. As the furnace temperature is different from the sample temperature, the actual sample temperatures recorded differ somewhat from the desired values. The sample was placed in the even temperature zone of the furnace where the temperature variation was ±5°. A separate thermocouple was placed near the sample to measure the actual temperatures.

The tungsten foil samples used in the STA were kept at two isothermal temperatures, 500° and 550°C, for forty-eight hours. However the experiments in the STA were quite difficult to perform for a number of reasons. Firstly, it can be problematic to obtain absolutely correct values because the weight of the foil sample is very small. Secondly, the balance is very sensitive to humidity. The first experiment with moist argon had to be redone because the vapor condensed on the balance and this resulted in inaccurate results. As a consequence of this, the STA was cleaned, dried and calibrated before further use. For the following runs the amount of water vapor was decreased and the gas in the protective inlet aimed at the balance was kept completely dry. This experiment was then repeated but with the new lower water vapor pressure.

Moreover, when all the four STA experiments were run they did not clearly show the expected tendency of a larger mass gain at a higher temperature. There was also a contradiction in the wet versus dry aspect of the experiment. It was therefore decided that the run at 500°C with dry gas, where the sample was barely showing any weight gain after the oxidation, should be repeated again. The experiment was done twice to ensure that the balance was working properly. This time there was a clear increase in weight in both the tested samples. But with this new result a new concern arose. The weight gain was greater than that for the sample oxidized in the dry gas at a higher temperature. Therefore the oxidation experiment at 550°C with the dry gas was repeated, but limited to twelve hours due to time limitations. The comparison with the previous result and all other experimental data can be found in the respective sections below.

The STA also records changes in heat during the experiments. If for example, a phase change occurs (or any other endo- or exothermic reaction) it would be indicated as a sharp peak in the DSC curve. For most of the experiments in the STA, the DSC curves are flat, but for some of them the curves show small, but not well-defined peaks. These peaks are probably not connected with any phase changes in the sample between 500°-550°C. The unevenness of the DSC curve is rather believed to be just an error, and sometimes the peaks in the curves look bigger because of the scaling.

The graphs from the STA and TGA, the microscope pictures of the oxidized samples and the raw data can be found in the appendix.

5.1 Tungsten Foil Kept for forty-eight hours in STA with Dry Argon

The first two runs described in the following sections were conducted in an atmosphere of dry argon gas. The magnified pictures of the tungsten foil are shown in Figures 5.4, 5.5, 5.10, 5.12. These are captured using a light microscope, without any prior preparation – e.g. etching, surface cleaning, etc. Presented first are the results from the 550°C run.

5.1.1 Results from the 550°C experiment (partial pressure of oxygen ≤ $5 \cdot 10^{-6}$ atm.)

As mentioned in the introductory text to this chapter, this experiment was done once for forty-eight hours and then repeated with a new sample for twelve hours. The result for the twelve hour run was then compared to the result of the forty-eight hour run at t = twelve hours. An attempt was made to extrapolate (linearly) the values from the twelve hour run to forty-eight hours. Table 5.1 contains the resulting weight gains as well as the extrapolated value.

Table 5.1 *Summary of results from the STA runs at 550°C in dry argon.*

	Weight gain [mg/cm^2]
1st 48 hour run	0.726
1st 48h run at t = 12h	0.240
2nd 12 hour run	0.345
2nd 12 hour run extrapolated	1.425

The second run shows a greater mass gain at twelve hours compared to the first run, and the extrapolated value of the second run is also much greater. The figure below shows the mass change per unit area versus time for both of the experiments at t = twelve hours. The difference is significant; the oxidation is higher and more linear the second time. The result from the second run should be more reliable since it was done after the recalibration.

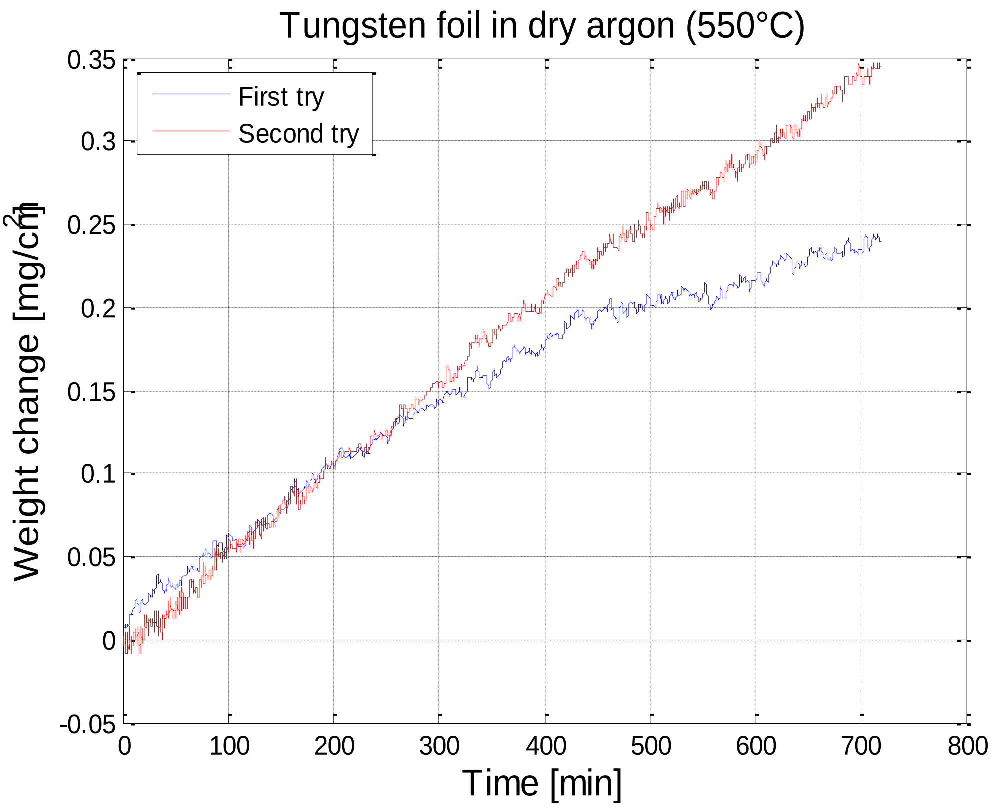

Figure 5.1 *Plot showing the weight change for the both runs at 550°C and twelve hours in dry argon*

Next figure is a plot showing the oxidation of the whole forty-eight hour run, the twelve hour run and the extrapolated curve.

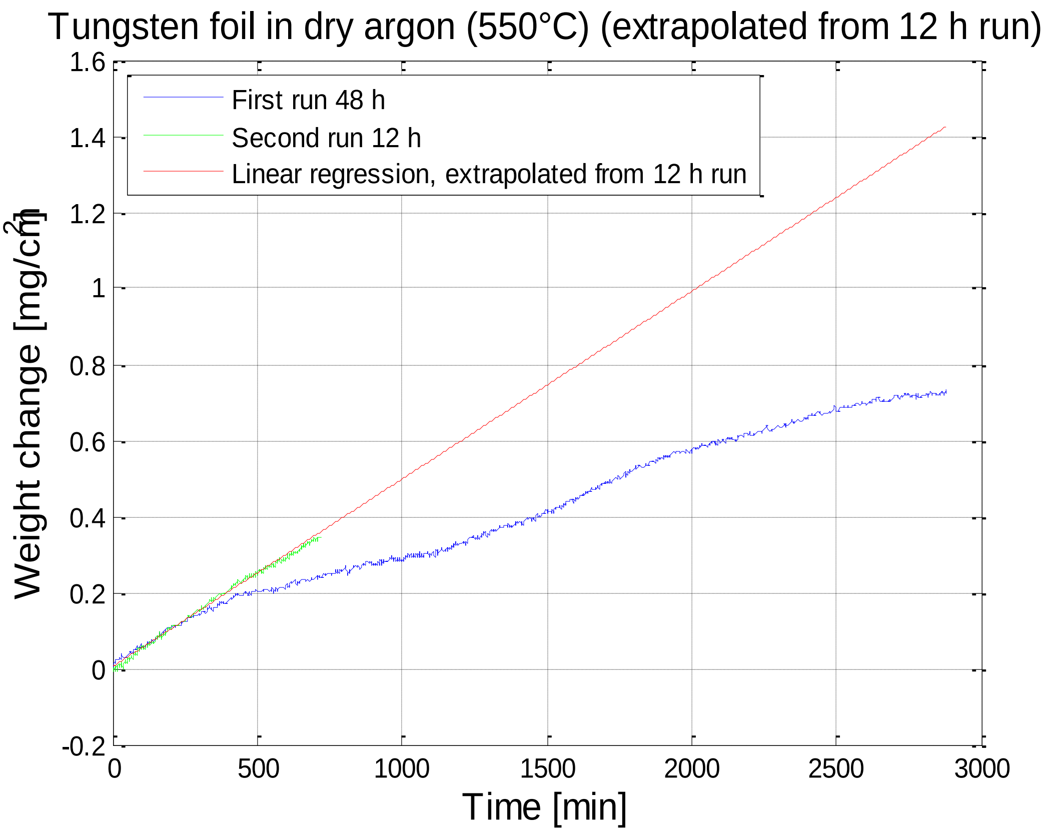

***Figure 5.2** Plot showing the weight change for the first and second try, and the extrapolated curve at 550°C in dry argon*

Though the linear regression fits the twelve hour curve well, the end value is still a very rough estimation. Looking at the curve for the first run one can see that the oxidation behavior is not simply linear or parabolic all the way. It is not certain that the second run would have reached as high of a mass change as the regression suggests if it were to continue for forty-eight hours. However, it is most probable that the second run still would have reached a higher value than the first run.

Microscope pictures were taken of the oxidized samples in 100 and 200 x magnifications. The first picture is taken of the long run sample. It shows a rough porous surface with light and dark patches evenly distributed over the surface. The second picture is a close up of the same surface.

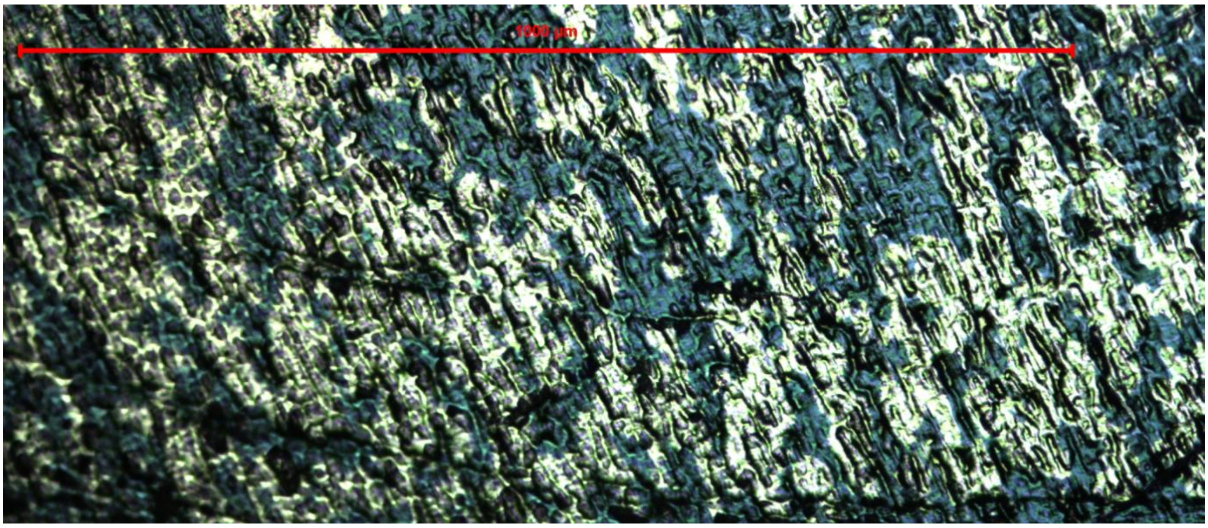

Figure 5.3 *Optical microscopy picture of tungsten foil kept in dry argon for forty-eight hours at 550°C. 100 x magnification*

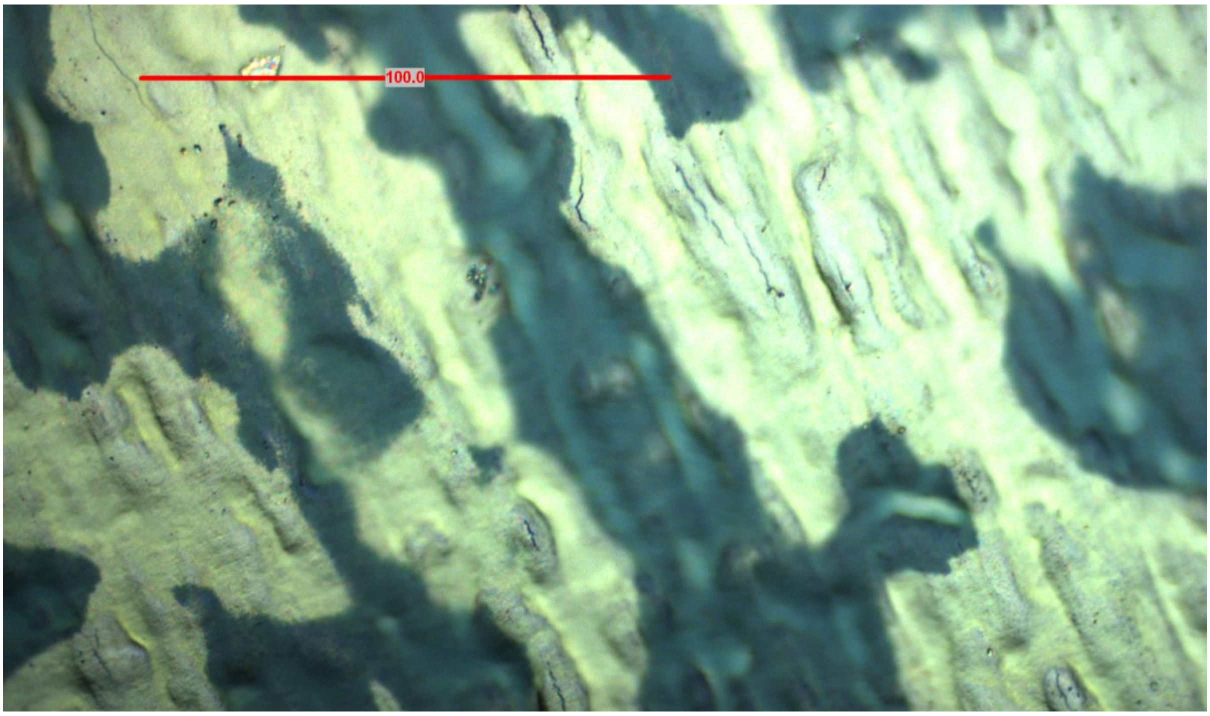

Figure 5.4 *Optical microscopy picture of tungsten foil kept in dry argon for forty-eight hours at 550°C. 200 x magnification*

This close-up clearly shows the two different colours on the surface of the sample, yet the texture does not seem to differ. There is a possibility that these colours represent two different oxides, however it is more likely that difference between them is not one of composition but rather of structural perfection and orientation [25]. This was stated in 1963 by E. A. Kellet and S. E. Rogers, who examined the structure of oxide layers on tungsten oxidized at 650°, 700° and 800°C, using x-ray analysis. According to Kellet and Rogers their experiments show that variations from the stoichiometric composition WO_3 do not appear to be significant. Furthermore it is suggested that the shift from the adherent black oxide to the non-adherent yellow oxide is associated with an advance in crystal growth.

The second sample shows a completely different texture. The surface is homogenous in color and rather smooth. The weight gain was less here and therefore the oxide layer is thinner.

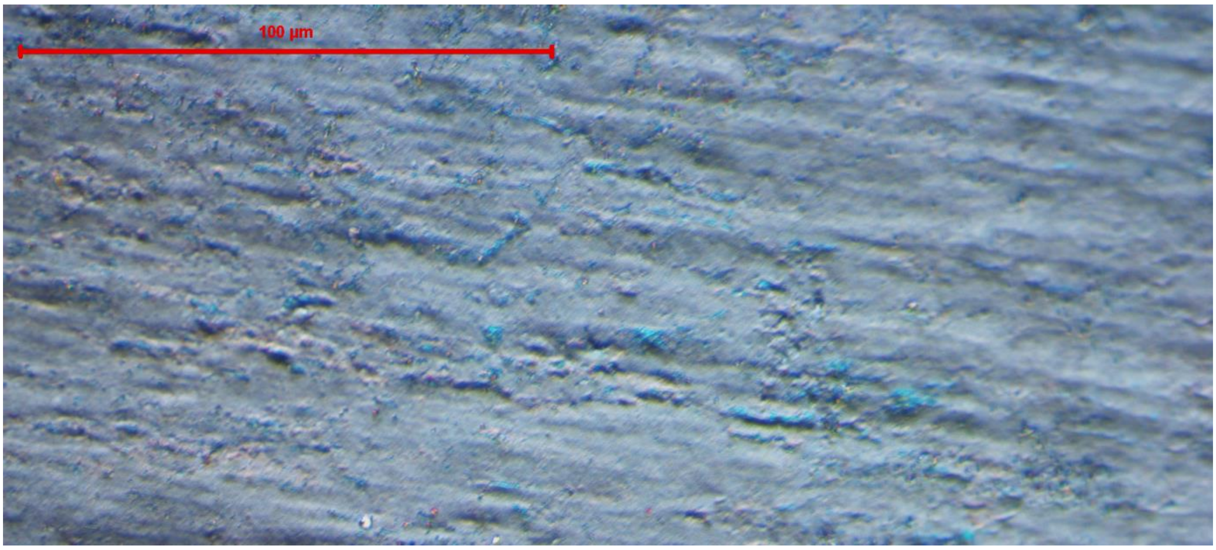

Figure 5.5 *Optical microscopy picture of tungsten foil kept in dry argon for twelve hours at 550°C. 200 x magnification*

5.1.2 Results from the 500°C experiments (oxygen partial pressure ≤ $5 \cdot 10^{-6}$ atm.)

At 500°C three attempts were made with dry argon gas. The first experiment was conducted before the calibration and the other two after. The table below shows the results of these experiments.

Table 5.2 *Summary of results from the STA runs at 500°C in dry argon*

	Weight gain [mg/cm^2]
1st run (before calibration)	0.0779
2nd run (after calibration)	1.073
3rd run (after calibration)	1.000

Plots of the mass gains are showed in the following figures. They are presented in the same order as they experiments were conducted.

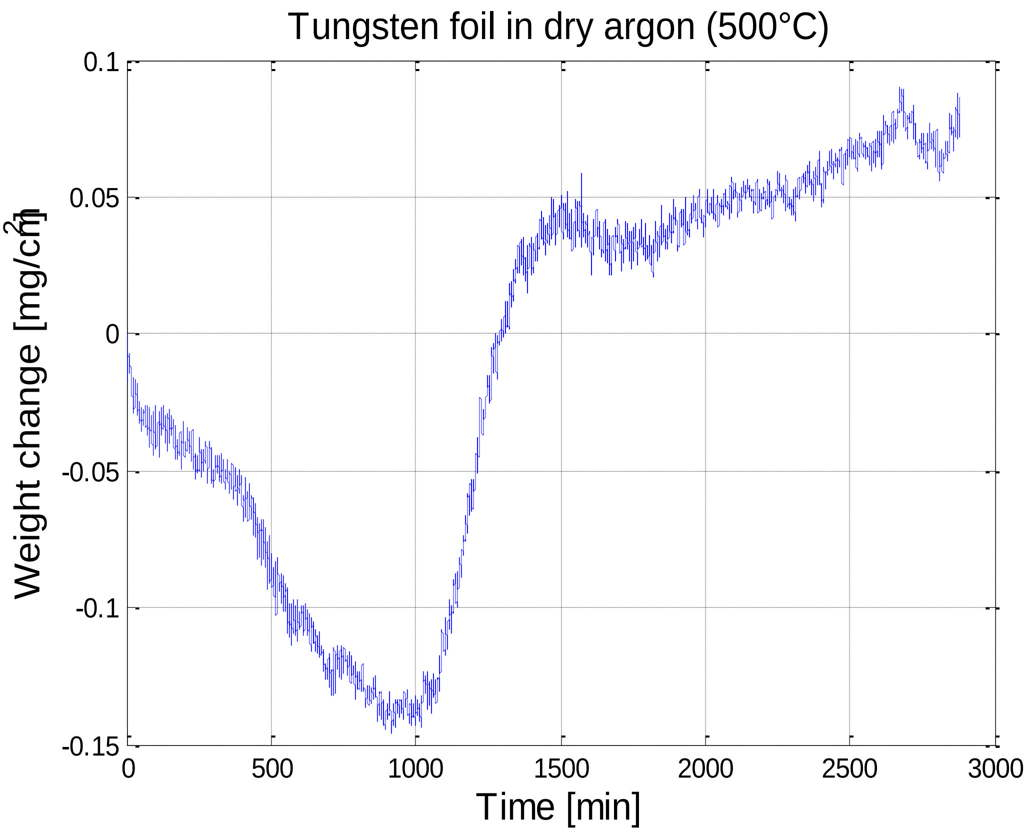

Figure 5.6 *Plot showing the weight change for the first try at 500°C in dry argon*

This first plot shows very little oxidation of the sample. The shape of the curve is not the expected, but since the values are small it is probably only measuring errors. The second try definitely shows a mass increase, and a much greater one than for the previous run. After about half the oxidation time the curves shows a linear oxidation rate.

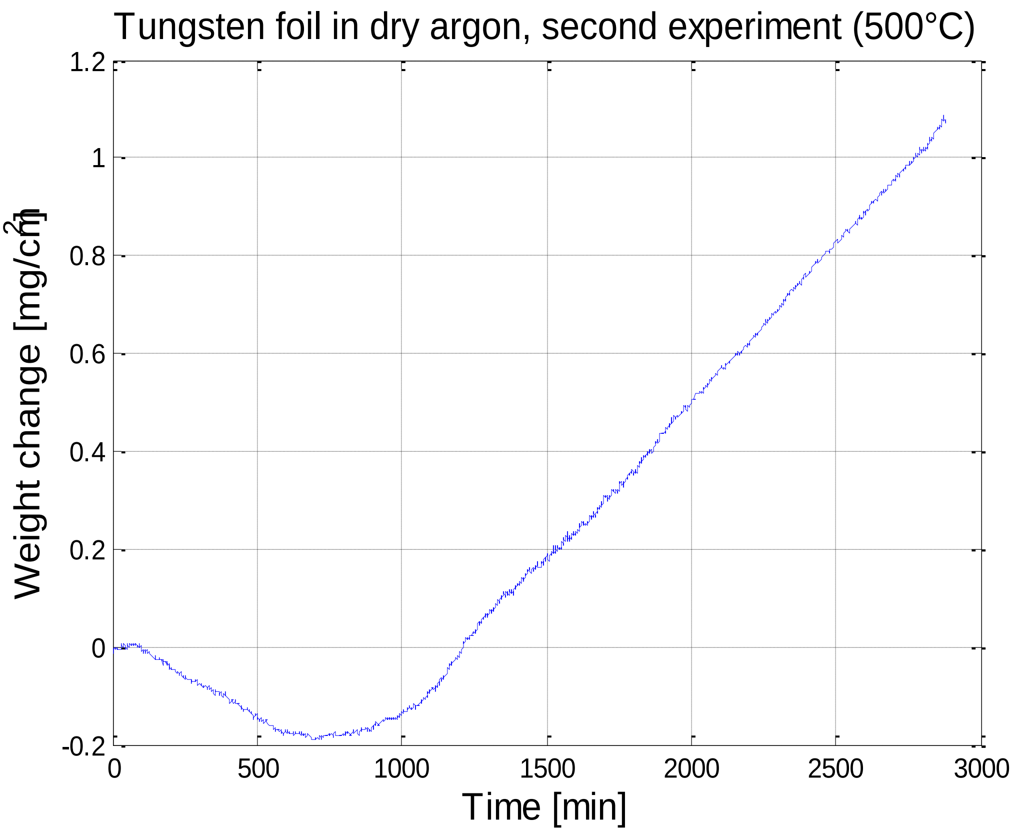

Figure 5.7 *Plot showing the weight change for the first try at 500°C in dry argon*

The third try was done to ensure that the results above can be trusted. The corresponding plot is shown below. There is the same linear behaviour after about half the time, and the amount of oxidation is roughly the same. This confirms that the first value is faulty.

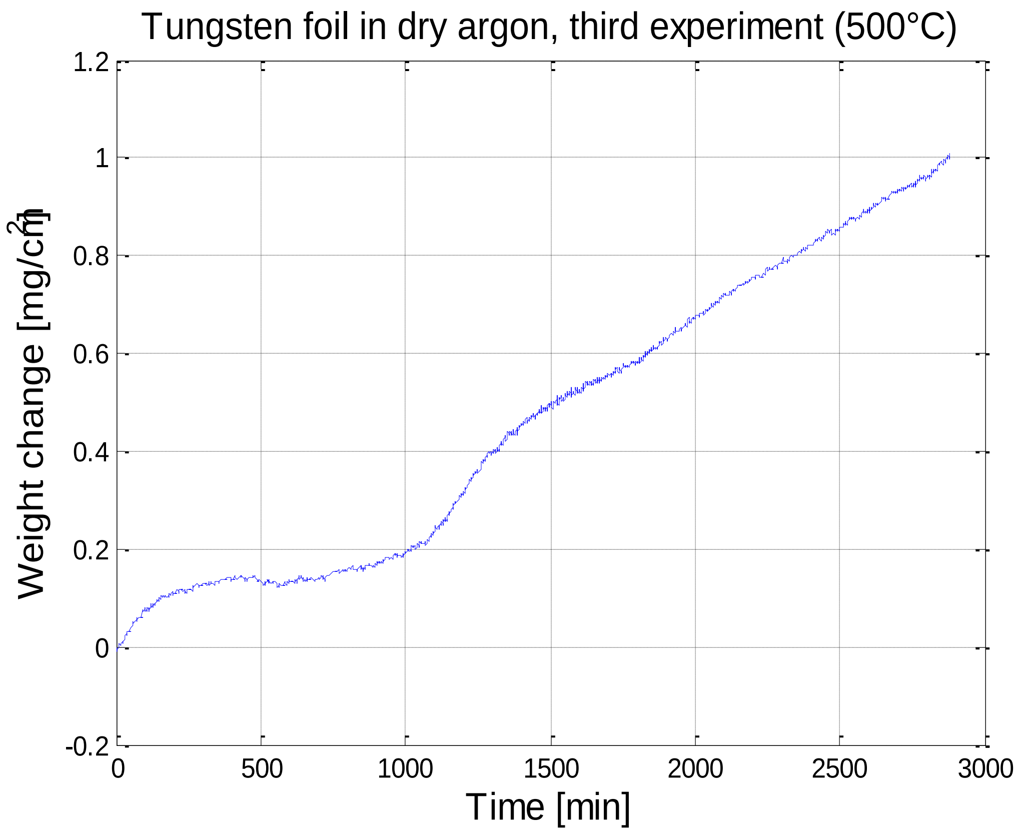

Figure 5.8 *Plot showing the weight change for the third try at 500°C in dry argon*

5.2 Tungsten Foil Kept for forty-eight hours in STA with Humid Argon

These sets of experiments were carried out in an environment of humid argon gas. The argon was passed through water containers and thereby becoming saturated with water vapor. According to a calculation made in section 4.5.1 the partial pressure of water vapor in this particular set up is ~0.0066 atmospheres. Results from the 550°C experiments are presented first.

5.2.1 Results from the 550°C experiments (water vapour partial pressure ~ $6.6\cdot10^{-3}$ atm)

As mentioned in the introduction to this chapter there were initially some problems with this experiment. As it was the first try with humid gas in the STA there was no experience of how the vapor would affect the result. The first try was planned with a greater amount of water; unfortunately the vapor contaminated the balance and the experiment failed. The STA went through a time consuming cleaning and recalibrating process before it could be used again. The amount of water vapor was lowered by adjusting the set up by redirecting all the humid gas to sample chamber, ensuring that the sensitive balance was kept dry during the run.

The value of the total mass gain in the humid 550°C run is *0.579* mg/cm^2

The plot in Figure 5.9 shows the oxidation behavior of this sample. The curve indicates a slow oxidation the first 1000 minutes then there seems to be an increase in the oxidation rate.

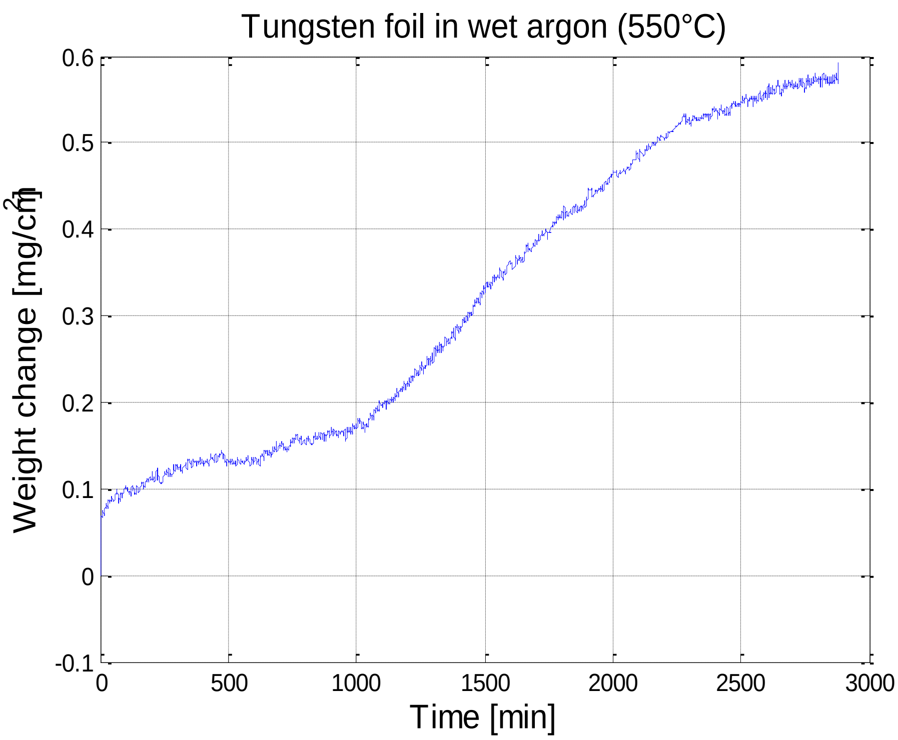

Figure 5.9 *Plot showing the weight change for a tungsten foil sample. 550°C, 48h in humid argon*

The microscopy picture taken in a 100 x magnification is presented below. The surface of this sample is rough and porous, and the color is dark and monochromatic.

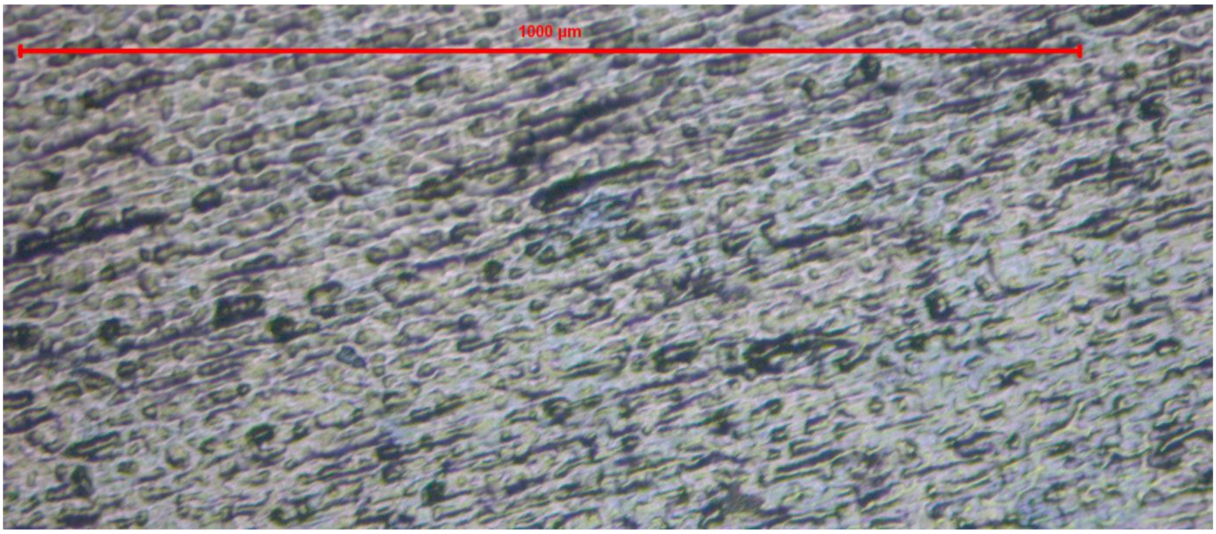

Figure 5.10 *Optical microscopy picture of tungsten foil kept in humid argon for forty-eight hours at 550°C. 100 x magnification.*

5.2.2 Results from the 500°C experiments (water vapour partial pressure ~ $6.6{\cdot}10^{-3}$ atm.)

The run at 500°C with humid argon was done after the calibration, thus the result is considered reliable and no repetition of this run was made.

The value of the total mass gain after forty-eight hours is *0.473* mg/cm^2

Below a plot of the oxidation is presented. The shape is rather parabolic at the beginning, but does not look strictly linear at the end.

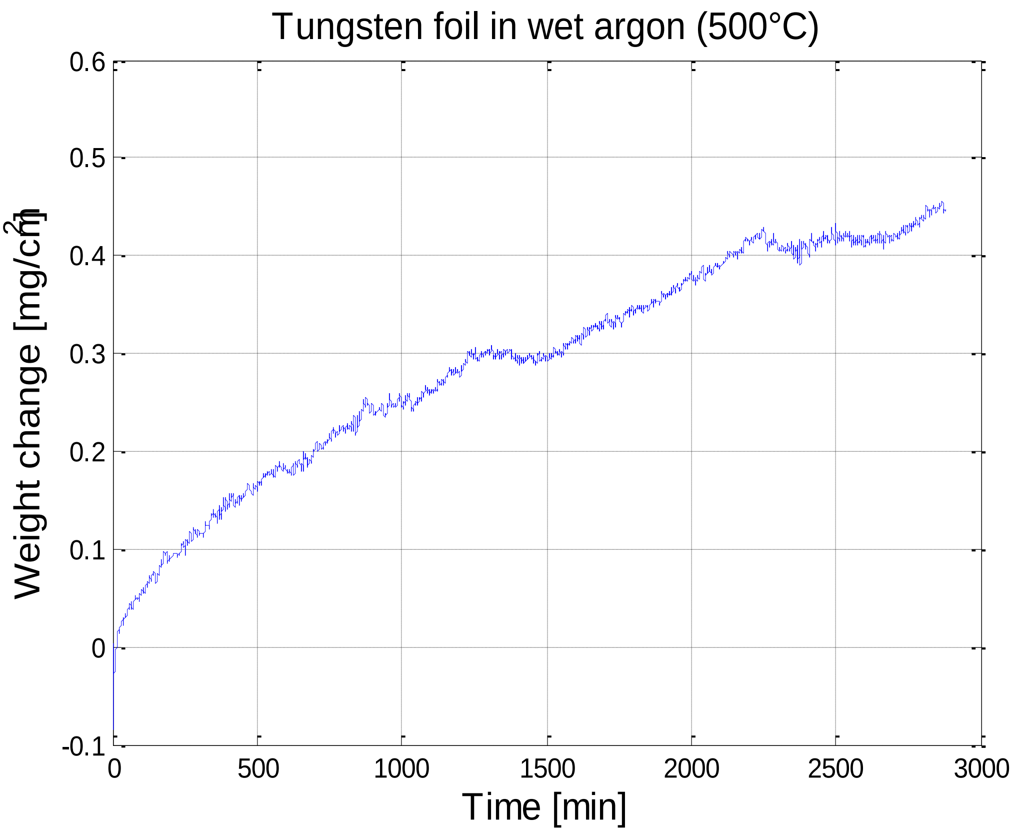

Figure 5.11*Plot showing the weight change for the 500°C experiment in humid argon*

An optical microscopy picture of the oxidized sample can be seen if Figure 5.12.

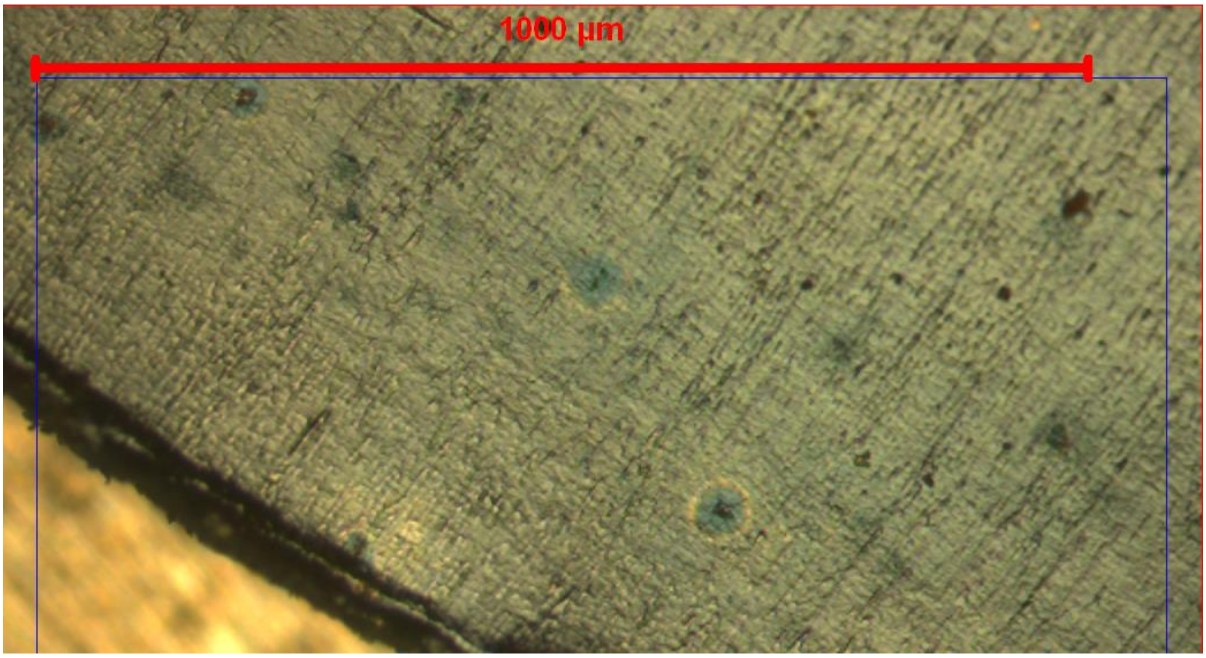

Figure 5.12 *Optical microscopy picture of tungsten foil kept in humid argon for forty-eight hours at 500°C. 100 x magnification.*

The surface is of a lighter colour and seems much smoother. The oxide layer looks very thin.

5.3 TGA, two hours with He+0.5%O_2 (oxygen partial pressure ~ 0.005 atm.)

The samples used in the TGA were pure tungsten discs approximately twenty mm. in diameter. The gas was a dried helium/oxygen mix with an oxygen vapor pressure of ~0.005 atmospheres. The mass change, which was measured continuously during the two hour run, was divided with the surface of the sample and plotted against time. Table 5.3 below, contains the values of the temperature at which the samples were oxidized; the surface area for each sample; the total mass gain; and the color of the oxidized sample.

Table 5.3 *Summary of results from the TGA runs with helium and 0.5 % oxygen*

TGA, two hours in Helium+0.5% Oxygen (partial pressure of O_2 ~ 0.005 atm.)			
Temp. [°C]	**Surface area [mm^2]**	**Total weight gain [mg/cm^2]**	**Color and texture**
422	811.6034	0.0444	Clear, blue metallic, very thin layer
522	819.4342	0.380	Matte black, even, thin layer
618	818.8361	1.407	Matte dark grey layer
716	818.2599	4.953	Green layer with thin yellow edges
763	819.5177	6.450	Green/yellow, cracked yellow edges
811	818.1754	12.21	Thick porous yellow layer
907	817.3273	17.93	Darker green layer, thick cracked edges

The surface area was calculated according to the following equation:

$$A = 2\pi r * t + 2(\pi r^2) \quad (5.1)$$

A is the surface area, *r* is the radius of the sample and *t* is the thickness of the disc.

In Figure 5.13 below the results from all seven of the experiments with dry helium and 0.5 % oxygen are shown.

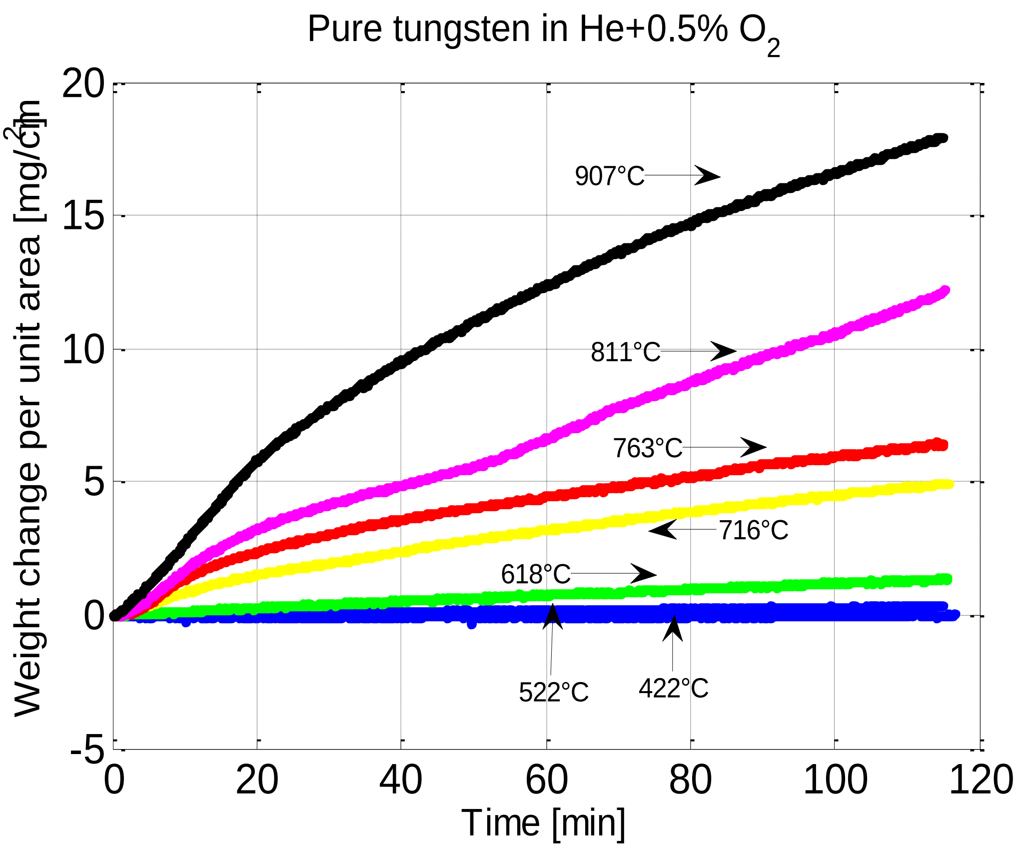

Figure 5.13 *Results from the experiments with tungsten in the TGA with helium and 0.5 % oxygen*

The curves for temperatures above 700°C clearly show an initial parabolic oxidation rate. This rate turns into a more linear one after approximately 40-70 min, depending on the oxidation temperature. The shape of the 716° and 763°C curves are quite similar to each other, however something different seems to have occurred at 811°C. This curve shows a slight S-shaped form which could indicate changes in the oxide scale, possibly cracking or spalling, leading to a parabolic breakaway oxidation. This type of oxidation involves cracking of the scale were the exposure of a new unoxidized surface temporarily speed up the oxidation rate. Curves with similar behavior have been found in other papers as well. Figures 5.14 and 5.15 show two examples of this S-shaped curve.

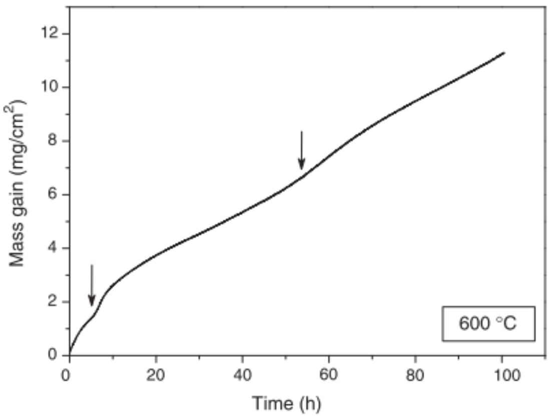

Figure 5.14 *Mass gain curve of a sample oxidized 100 h at 600 °C in dry air. Arrows indicate points at which protective nature of the scale was lost.* [14]

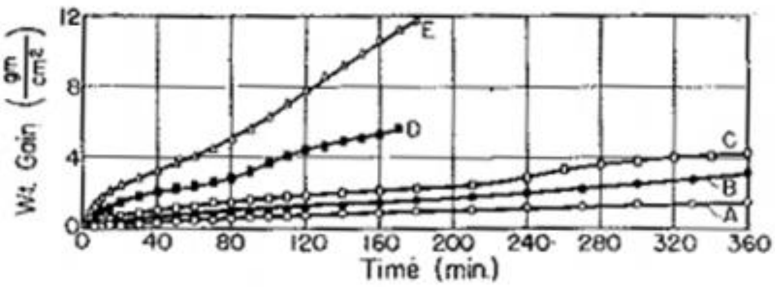

Figure 5.15 *Oxidation of tungsten, 600°-750°C in 0.1 atm. O2. A-600°, B-625°, C-650°, D-700°, E-750°C* [16]

The oxidation curves for the three lowest temperatures, 422°-618°C, are quite small compared to the other curves; they are therefore plotted in separate Figures 5.16-5.18 to elucidate the details and the shape of the curve.

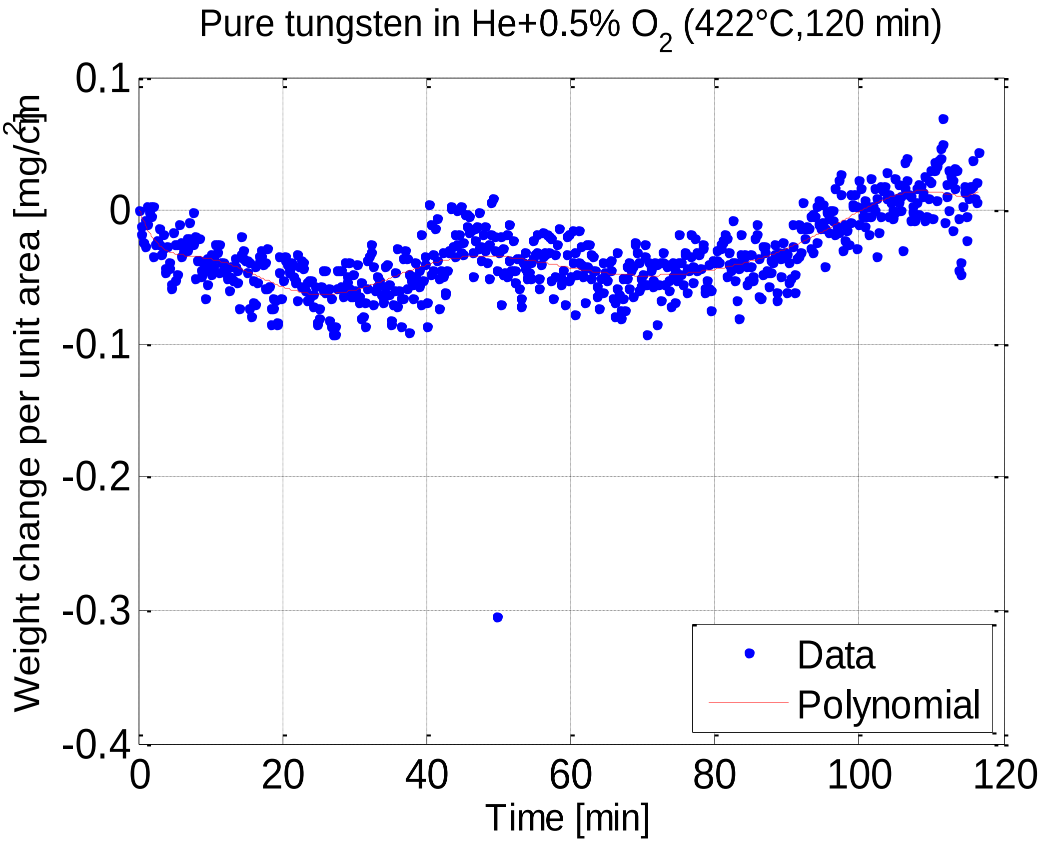

Figure 5.16 *Results from the experiment with tungsten in the TGA with helium and 0.5 % oxygen at 422°C*

The mass change for the lowest temperature in this study is very small and therefore difficult to measure correctly. The curve above shows an initial weight loss although this should not be possible theoretically. It is most probable that the balance was affected by external influences during the experiment.

The result at 522°C is more reliable and shows a clear increase in mass. The first twenty minutes are of a more parabolic shape, while the rest of the curve seems linear.

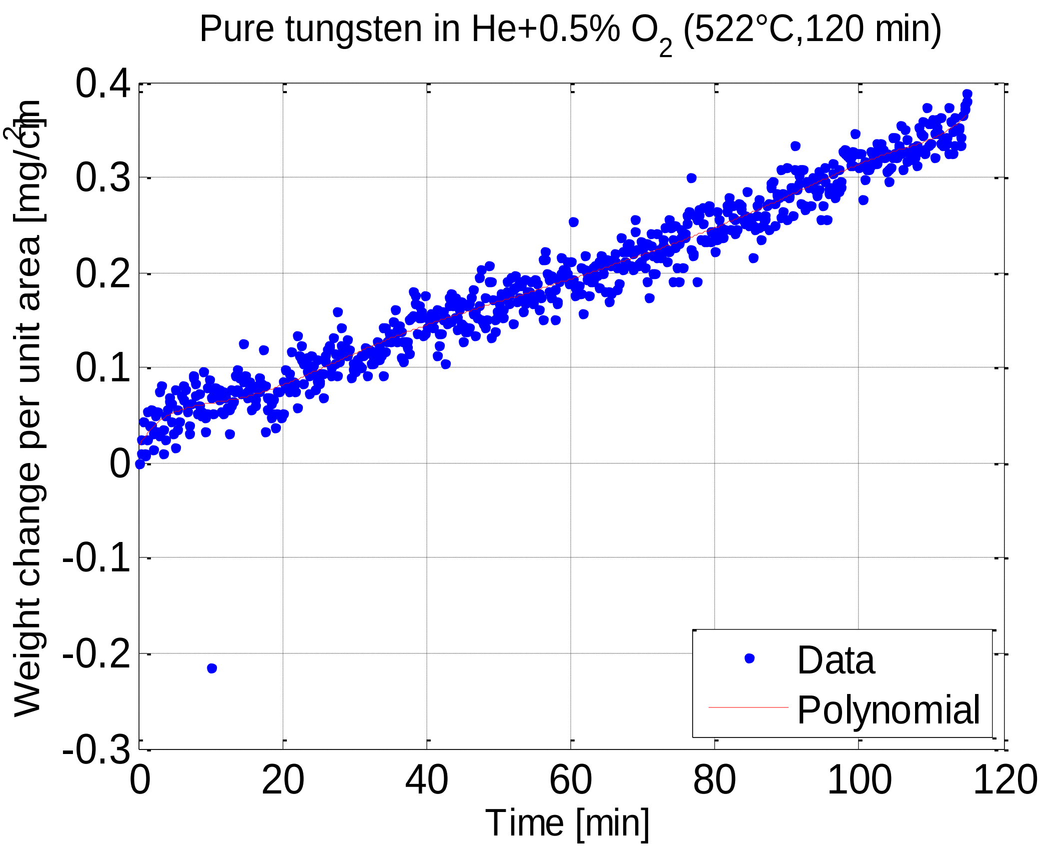

Figure 5.17 *Results from the experiment with tungsten in the TGA with helium and 0.5 % oxygen at 522°C*

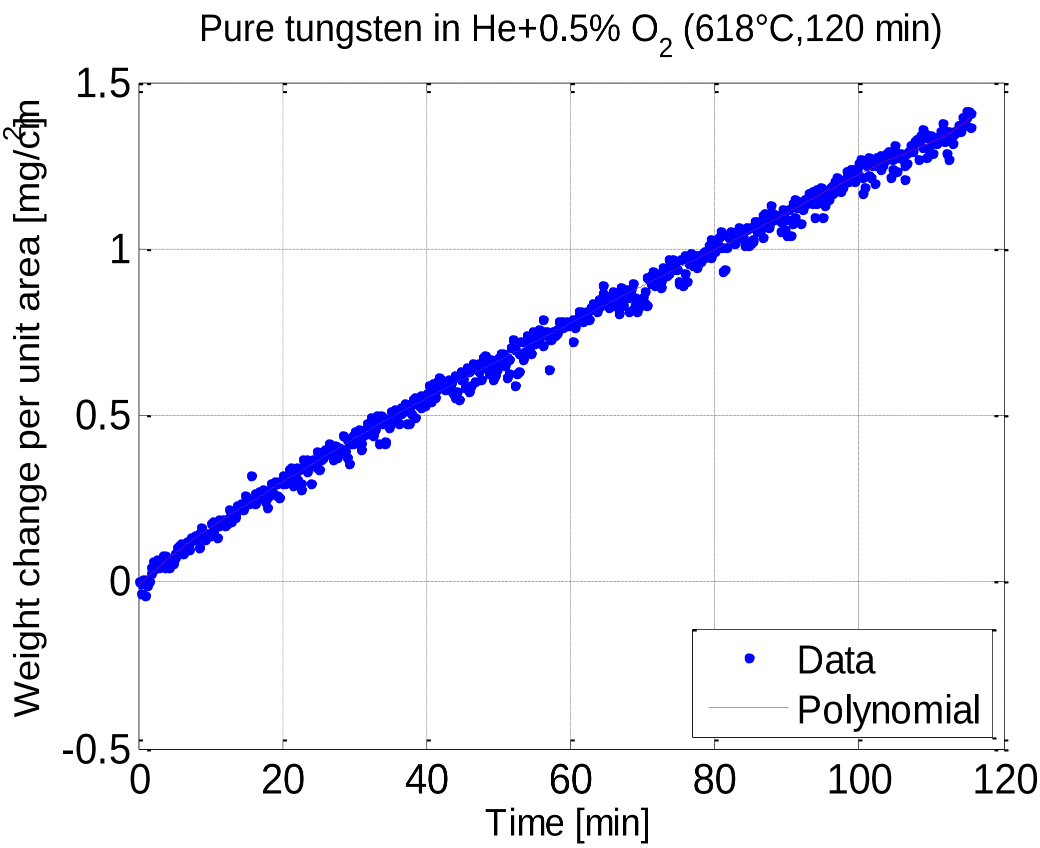

Figure 5.18 *Results from the experiment with tungsten in the TGA with helium and 0.5 % oxygen at 618°C*

At 618°C the oxidation is substantial and the oxidation rate appears to be linear. The oxide formed at temperatures between 522°- 618°C is dark, adhesive and thin. At higher temperatures the oxide is green and becomes thicker and more and more yellow with increasing temperatures. The scale thickness and brightness of the yellow color peaks at 811°. At 907°C the oxide scale is again thinner and less yellow. This is due to the increased volatility at higher temperatures which means that the WO_3 in the porous outer layer evaporates and the scale becomes thinner. The samples were photographed after the oxidation and are presented in Figure 5.19 below. Microscopy pictures of all the samples can be found in the appendix.

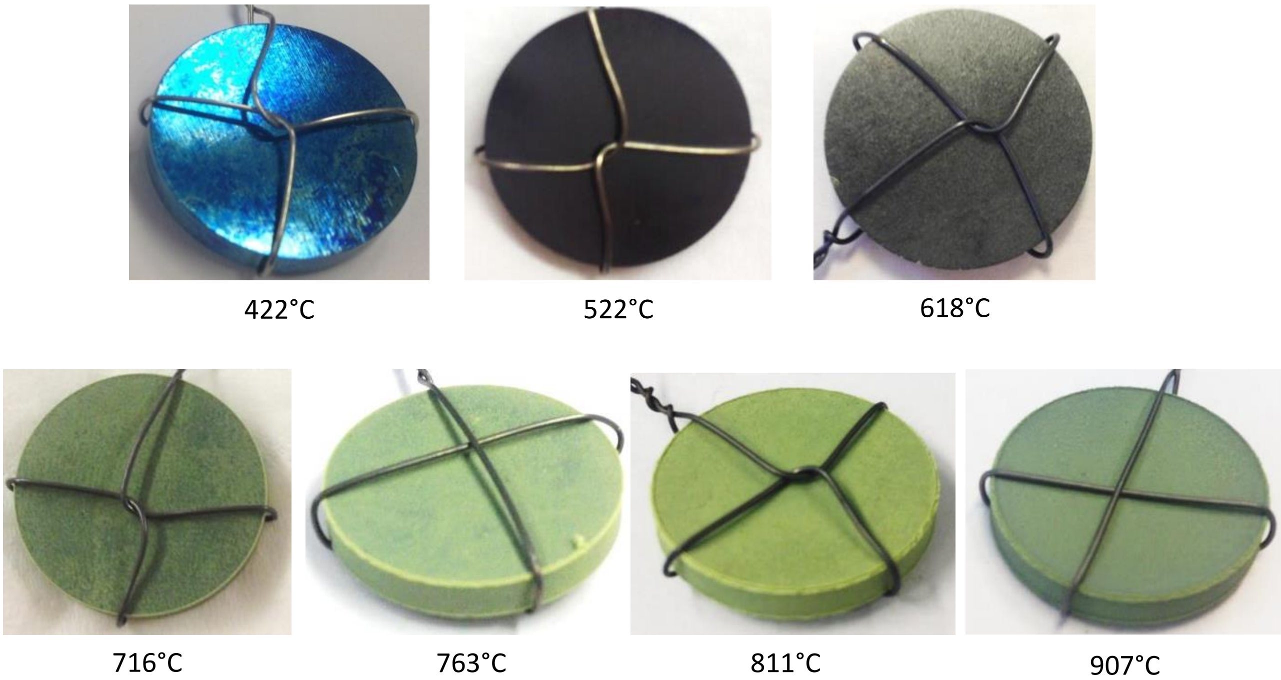

Figure 5.19*Photographed samples. 422°-907°C, TGA 2h, He+0.5% O2*

There is a clear division between the different types of oxides. The oxidation has begun at 422°C but the oxide layer does not completely cover the surface until 522°C, where one can see a dark adhesive texture. At 716°C the oxide seems to be of a different type. The oxide layer thickens steadily until it reaches a maximum at 811°C. At 907°C the volatilization rate has become higher and the oxide layer seems to have become thinner and less porous.

In Figure 5.20 below, a tenth degree polynomial is fitted to each TGA run, i.e. for each temperature. The reason for choosing a tenth degree polynomial is for its reasonable residual between the actual values and the polynomial. The polynomial is on the form:

$$r = r(temperature, time) = \frac{\Delta m}{A} = a_0 + a_1 t + a_2 t^2 + \cdots + a_{10} t^{10} \qquad (5.2)$$

All the coefficients a_0-a_{10} for each TGA run can be found in appendix.

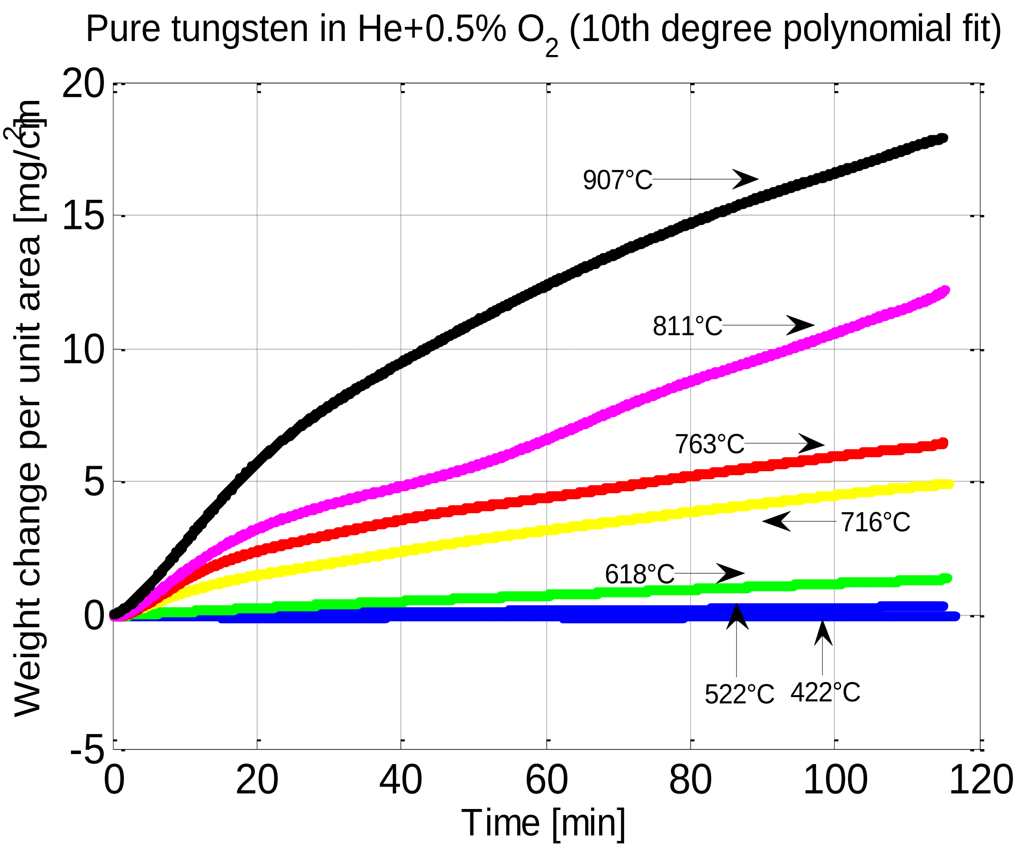

Figure 5.20 *Tenth degree polynomial fit to the results in the TGA with helium and 0.5% oxygen*

A derivation of Equation 5.2 above with respect to time gives the rate of oxidation:

$$\dot{r} = r(\dot{temperature}, time) = \frac{dr}{dt} = a_1 + 2a_2t + 3a_3t^2 \dots + 10a_{10}t^9 \quad (5.3)$$

In Figure 5.21 below a plot between the natural logarithm of the rate of oxidation ($\ln(\dot{r})$) at zero time, and the reciprocal of the temperature is made (Arrhenius plot). This is done in order to derive the activation energy for the chemical reaction between tungsten and oxygen. The value taken at 422°C has not been included because of inaccuracy of the plot. The amount of oxidation at this temperature is very small – approximately of the same order as the errors. A linear regression of the data points is made in a least squares sense.

The slope of the linear regression in the figure below is equal to minus the activation energy divided by the gas constant:

$$slope = \frac{-Q}{R} \rightarrow Q = -slope * R = -(-7.641 \dots e^3) * 8.314 \approx 64000\, J/mol \quad (5.4)$$

This means the chemical reaction between the pure tungsten and oxygen has an activation energy of approximately *64 000 J/mol*.

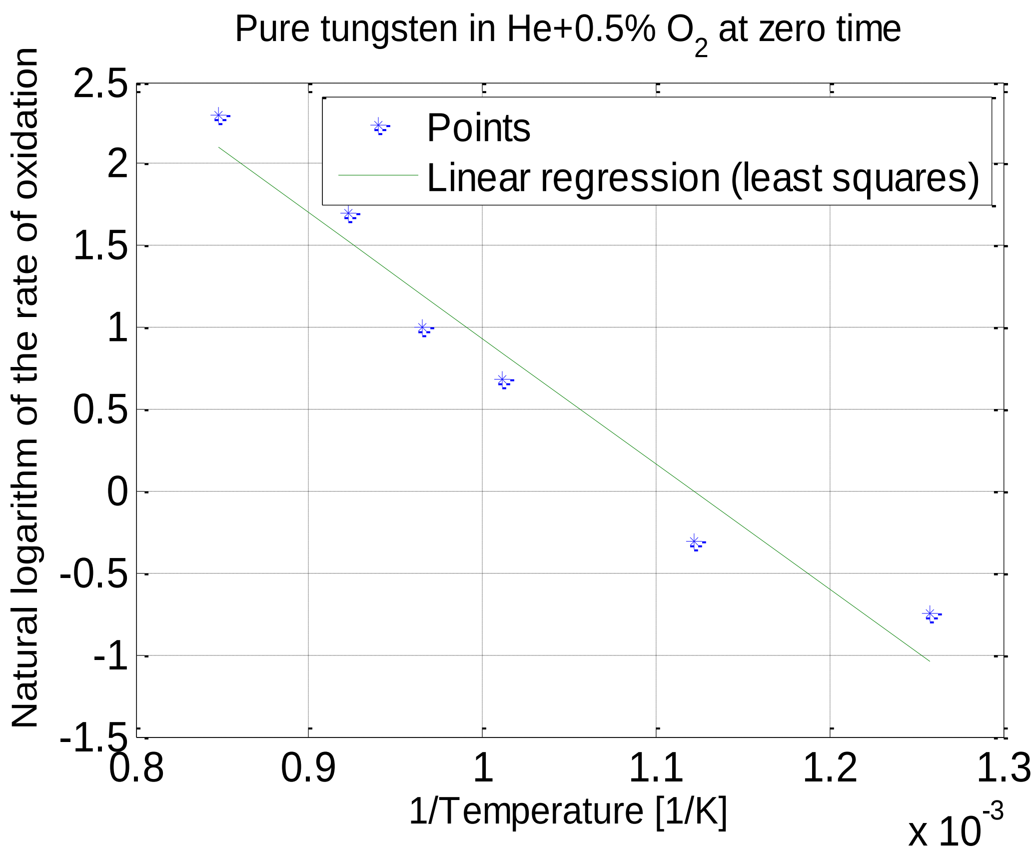

Figure 5.21 *Arrhenius plot*

The activation energy only changes when the oxidation mechanism does. The value given above is valid in the very initial stage of oxidation when the tungsten surface is clean and not yet covered with oxide – meaning that no diffusion is involved in this stage. Different activation energies must therefore be determined for the second and third stage of tungsten oxidation (these three stages are described in detail in chapter three).

The activation energy Q for the diffusion controlled oxidation (stage two) in this specific atmosphere and under the volatilization temperature of 750°C was calculated according to the same procedure as above. The results from the oxidation at 522°, 618° and 716°C was used to create the Arrhenius plot. From this plot the activation energy was extracted. The value is approximately *95000 J/mol*.

The same was done in order to calculate the activation energy for oxidation above the volatilization temperature (stage three). Here two mechanisms are taking place at the same time; formation of the different oxide layers and volatilization of the tungsten trioxide. The combined activation energy is calculated from the Arrhenius plot constructed of results from the 763°, 811° and 907°C experiments. The value for this activation energy is *72000 J/mol*.

5.4 TGA, two hours in He+Ar+H_2O (water vapour partial pressure ~ $7.8 \cdot 10^{-3}$ atm.)

These sets of experiments were performed in a similar way as the ones described in the section above. The main difference is the gas atmosphere; here a small, controlled amount of water vapor was introduced in the gas. The partial pressure of the water vapor amounts to ~$7.8 \cdot 10^{-3}$ atm. Table 5.4 below contains the experimental temperatures, surface areas, weight gains and appearance of the samples.

Table 5.4 *Summary of results from the TGA runs with helium and humid argon*

TGA, two hours in Helium+Argon+H_2O (partial pressure of water vapour ~ $7.8 \cdot 10^{-3}$ atm.)			
Temp. [°C]	**Surface area [mm^2]**	**Total weight gain [mg/cm^2]**	**Color and texture**
415*	816.6360	0.1567	Gold/purple/blue metallic, very thin layer
419	819.9053	-0.5793	Purple/blue metallic, very thin layer
522	816.7379	0.1249	Dark grey thin layer
619	822.1422	1.107	Matte light grey layer
714	815.5886	4.453	Dark green layer with yellowish spots
763	818.1654	5.797	Green, yellowish spots, cracked edges
811	817.5461	7.627	Thick porous yellowish layer
906	817.7149	10.69	Dark green porous, yellow under wire

*Second try at ~400°C

The run at ~ 400°C (419°) was not successful the first time and was therefore redone. The new result oxidized at 415°C shows a positive weight change, unlike the first try. The curves were the weight change per unit area is plotted against time, are presented in the figure below.

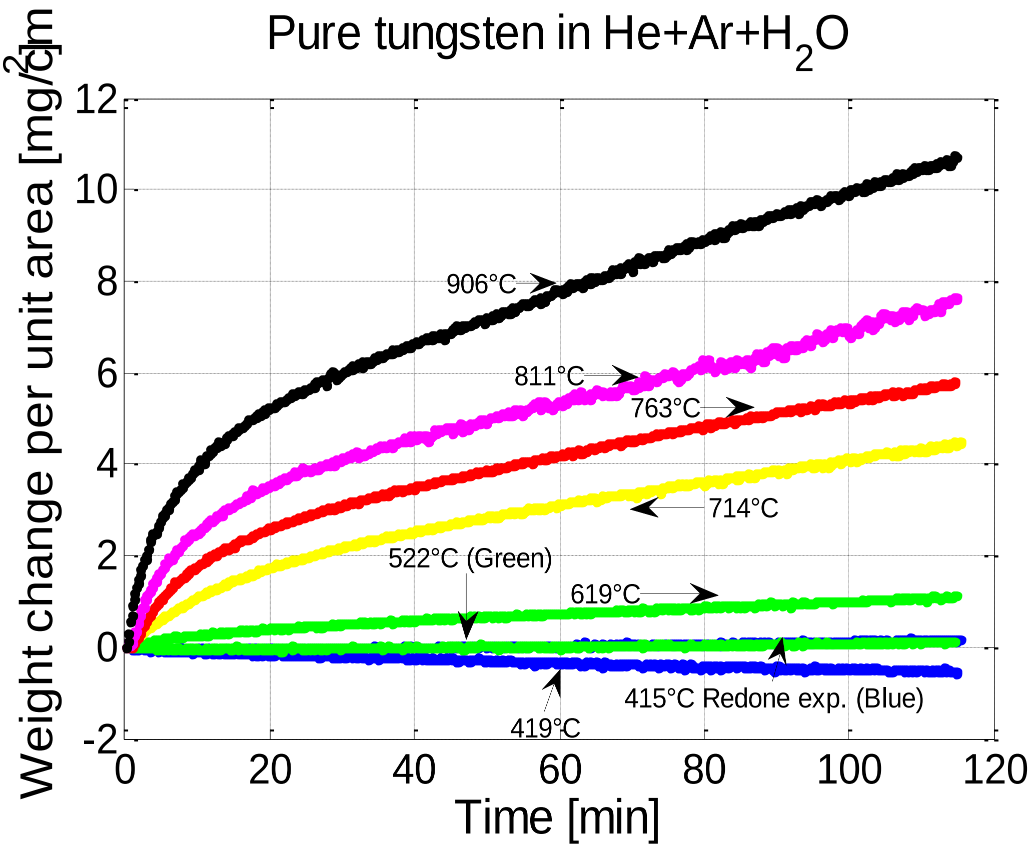

Figure 5.22 *Results from the experiment in the TGA with helium, argon and water vapour.*

The figure shows that temperatures above 700°C seem to follow a parabolic oxidation rate initially and then level out into a linear rate. Temperatures below 700°C are more linear and have oxidized relatively less. The following figures show the curves at low temperatures in more detail.

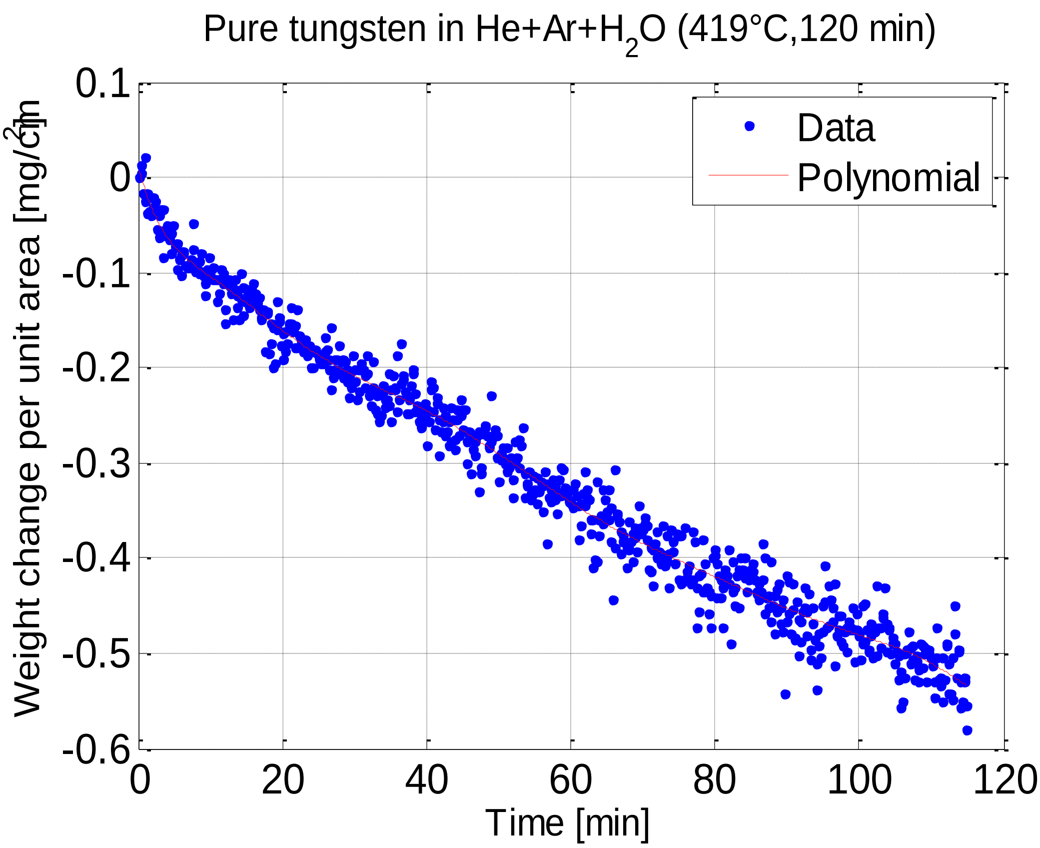

Figure 5.23 *Results from the experiment with tungsten in the TGA. Helium, argon and water vapour at 419°C*

The first experiment at 419°C was considered a failure due to the negative weight change. The experiment was redone, see figure below. This new curve clearly shows a weight gain, although very small. As with the 400°C run described in the previous section, these values are not very reliable. The measuring errors due to external factors are probably in the same order of magnitude as the mass change of the oxidized sample.

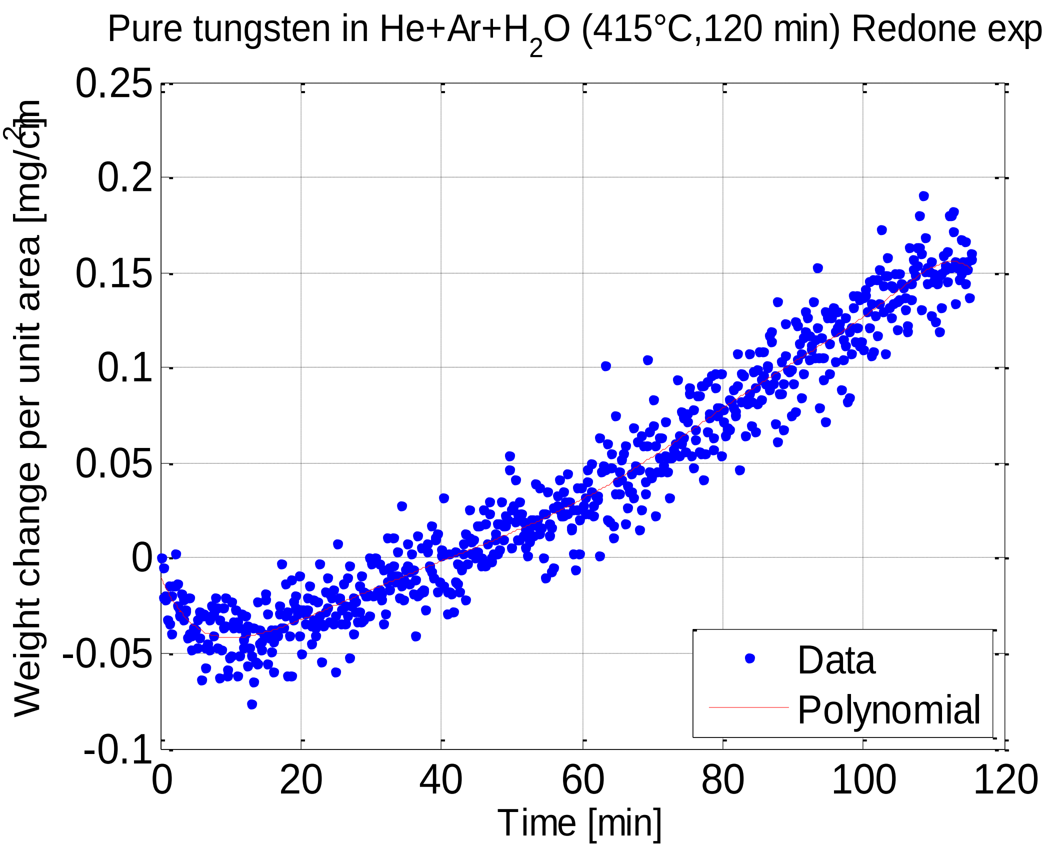

Figure 5.24 *Results from the experiment with tungsten in the TGA. Helium, argon and water vapour at 415°C*

At 522°C (figure below) the oxidation is still very small, it is even less than the oxidation at 415°C, although the shape of the curve is a bit different. Also, there seems to be more scattering here.

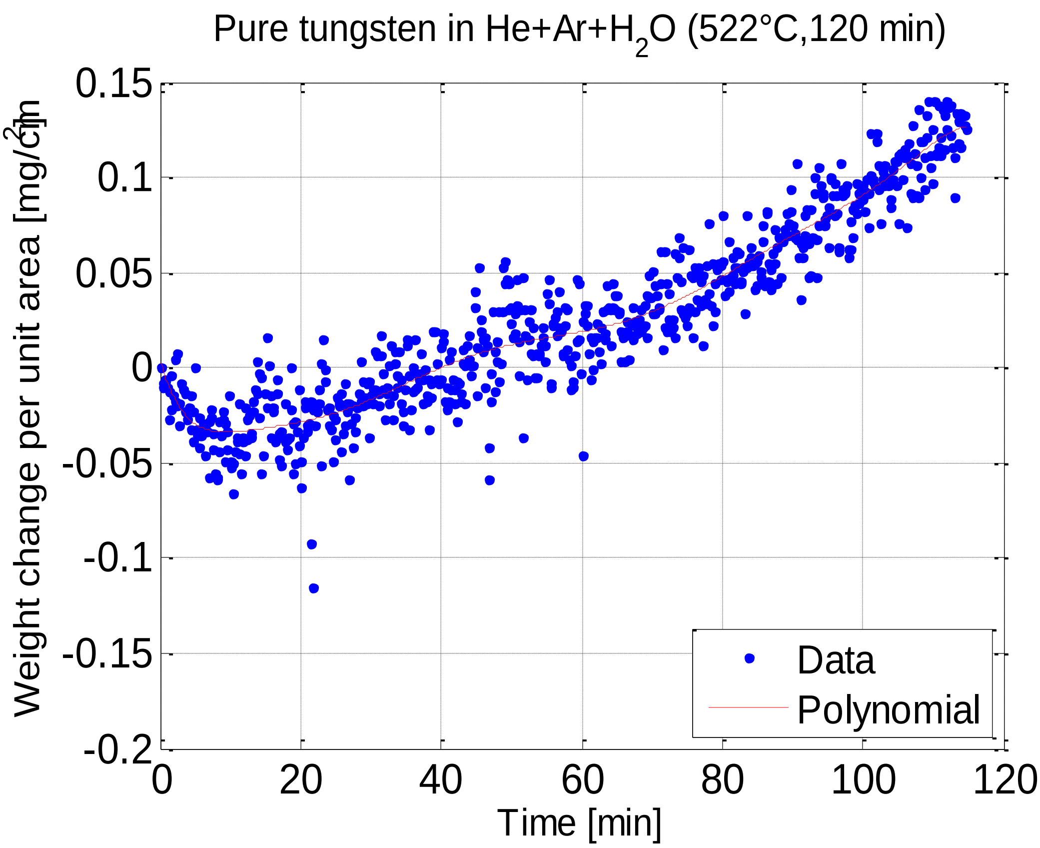

Figure 5.25*Results from the experiment with tungsten in the TGA. Helium, argon and water vapour at 522°C*

The curve for the oxidation at 619°C (Figure 5.26) is clearly parabolic the first forty minutes and then linear. It shows much more oxidation than the curves at lower temperatures.

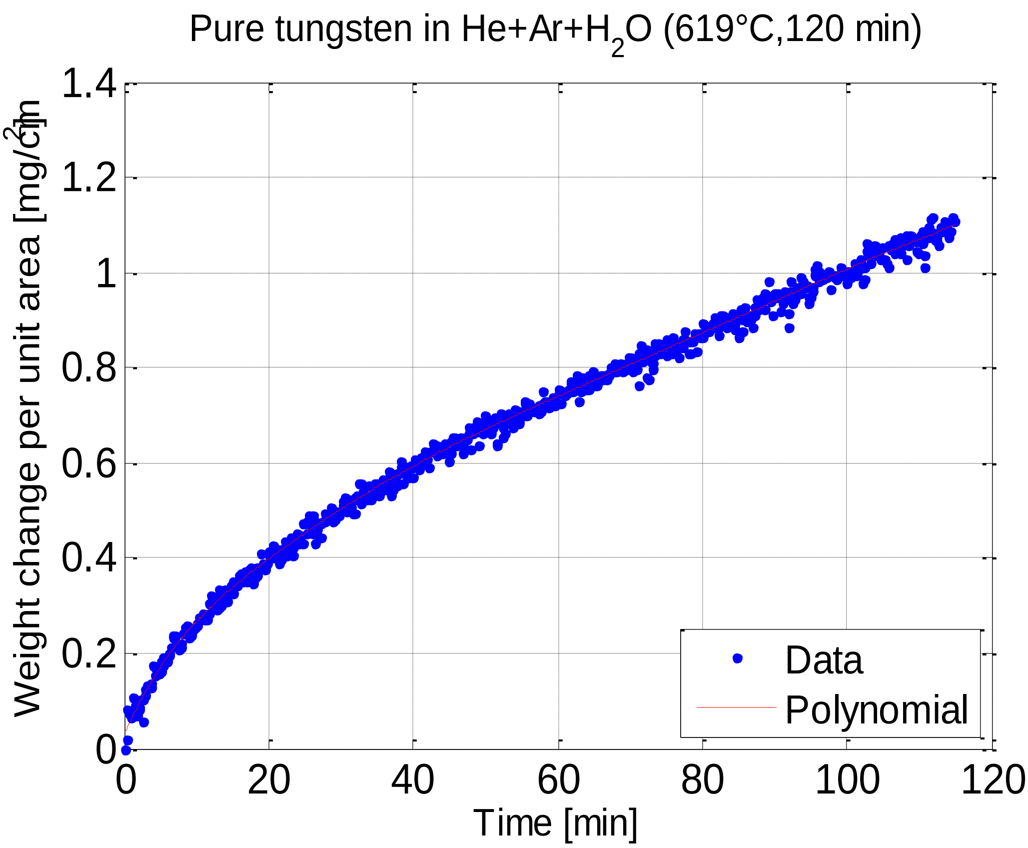

Figure 5.26 *Results from the experiment with tungsten in the TGA. Helium, argon and water vapour at 619°C*

The oxidation below 500°C is very small and the colour and texture of the sample does not resemble any of the other samples. See figure below were all of the samples are presented in photographs. Between 500° and 600°C the oxide is dark black/grey and adherent. At temperatures above 700°C the outer oxide scale seem to be of a different sort: it is porous and becomes more yellow as the scale thickens.

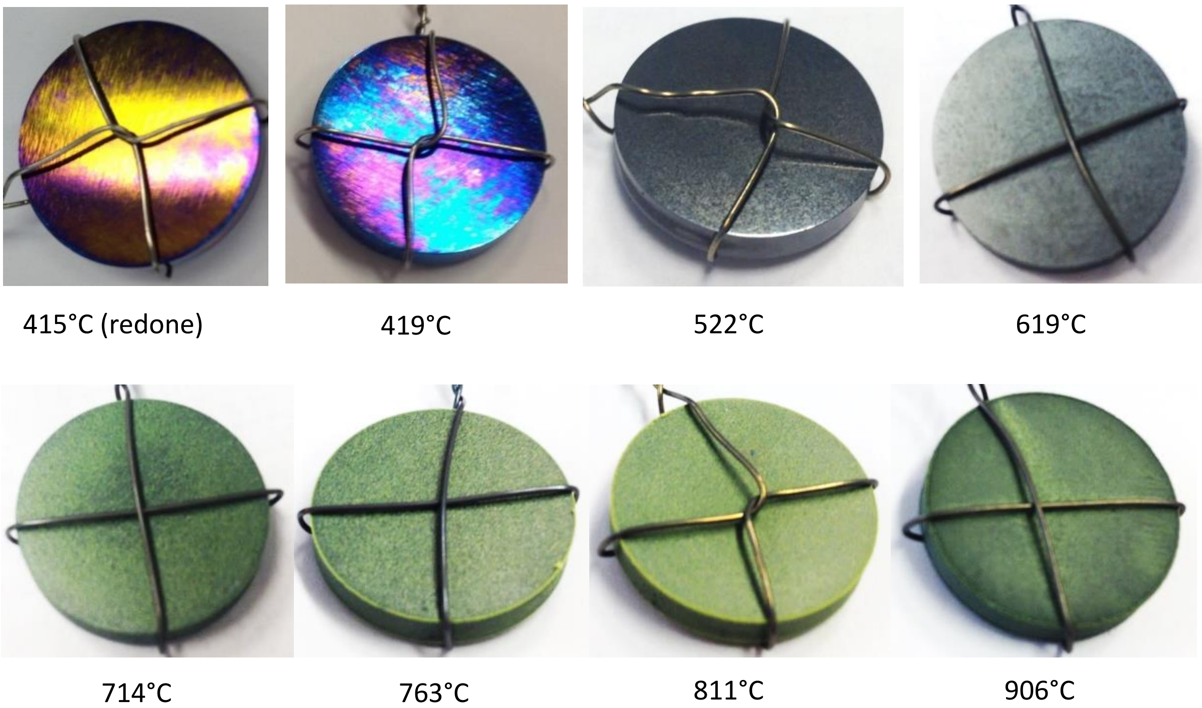

Figure 5.27 *Photographed samples. 415°-906°C, TGA 2h, He, Ar, H_2O*

In order to calculate the activation energy for the chemical reaction between the pure unprotected tungsten and the oxygen in this specific humid gas atmosphere, a tenth degree polynomial is fitted to each curve. This is shown in the figure below.

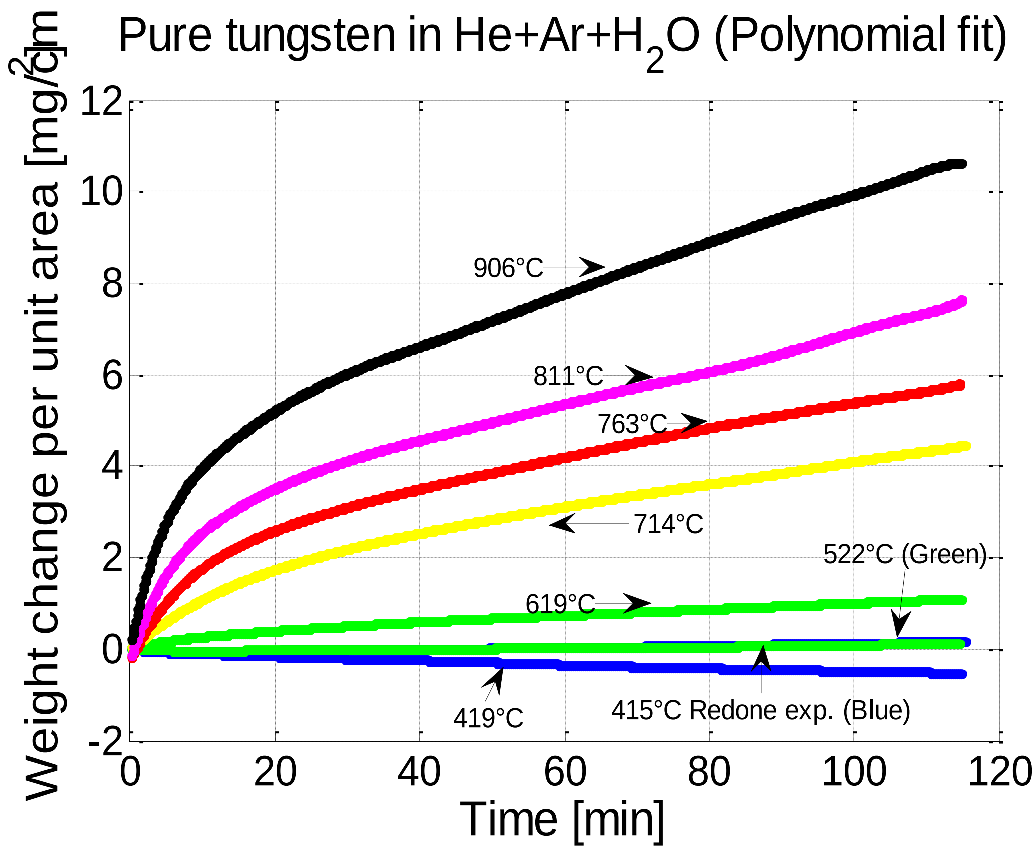

Figure 5.28 *Tenth degree polynomial fit to the results in the TGA. He, Ar and H_2O*

The equation for the polynomial has been shown above in the previous section, and the coefficients can be found in the appendix. Derivation of this said equation gives the oxidation rate. The figure below shows the plot between the natural logarithm of the rate of oxidation ($\ln(\dot{r})$) at zero time, and the reciprocal of the temperature. A linear regression of the data points is made in a least squares sense. The slope of the linear regression in the figure below is equal to minus the activation energy divided by the gas constant:

$$slope = \frac{-Q}{R} \rightarrow Q = -slope * R = -(-8.875 \ldots e^3) * 8.314 \approx 74000\, J/mol \qquad (5.5)$$

This means the chemical reaction between pure tungsten and oxygen in an atmosphere containing helium, argon and water vapour, has an activation energy of approximately *74000 J/mol*.

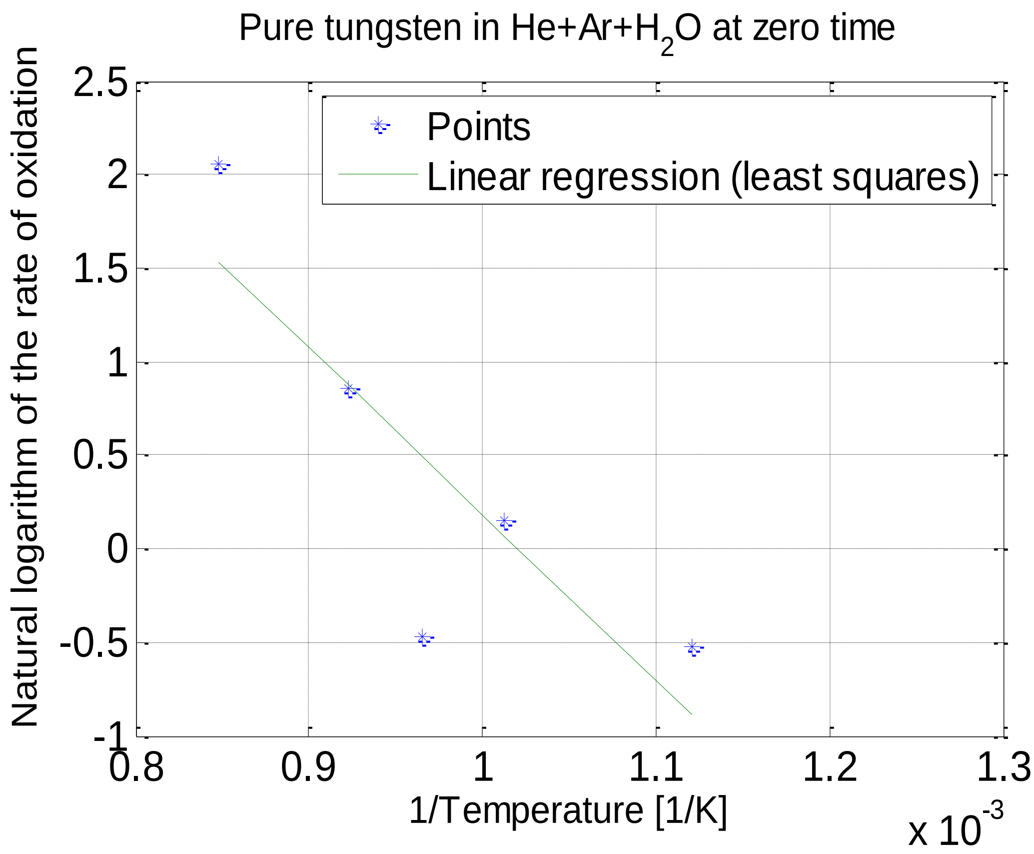

Figure 5.29 *Arrhenius plot*

The results from the experiment at ~400° and ~500°C have not been taken into account when constructing the plot above due to the uncertainty of the values at this low temperature.

The activation energy for the diffusion controlled oxidation at temperatures below 750°C has been found to be ca. *183000 J/mol*. The values from the 522°, 619° and 714°C runs have been used for this Arrhenius plot. For the combined mechanisms at temperatures above the volatilization temperature there is another value for the activation energy. It has been calculated from the 763°, 811° and 906°C experiments. The value for this activation energy is *44000 J/mol.*

5.5 TGA, two hours in Dry Helium (oxygen partial pressure ≤ $5 \cdot 10^{-6}$ atm.)

Experiments at two different temperatures were run in dry helium containing a maximum impurity of an oxygen partial pressure of ~$5 \cdot 10^{-6}$ atmospheres. As seen in Figure 5.30 below, the experiment at 621°C shows a clear increase in weight and a slightly parabolic shaped curve. The first experiment at ~500°C showed a negative slope and was therefore redone; the second try at 513°C was more successful. The detailed plot can be found in the appendix.

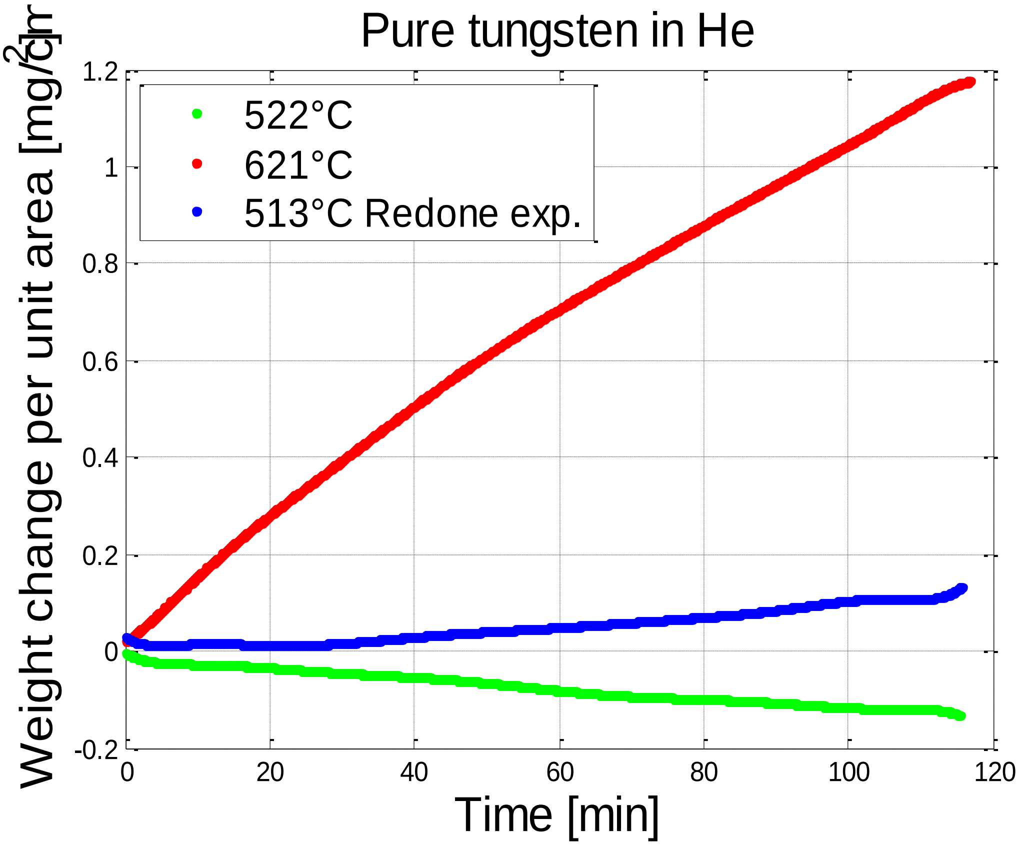

Figure 5.30 *Results from the experiment with pure dry helium in the TGA.*

In the table below the temperatures, surface areas, weight gains, and structures of the samples are shown.

Table 5.5 *Summary of results from the TGA runs with pure dry helium*

TGA, two hours, Dry Helium (partial pressure of oxygen ≤ $5 \cdot 10^{-6}$ atm.)			
Temp. [°C]	**Surface area [mm^2]**	**Total weight gain [mg/cm^2]**	**Color and texture**
513*	822.5305	0.156	Matte black
522	817.8613	-0.146	Shiny dark grey
621	815.2938	1.21	Light grey layer

* The second try of the 500° C experiment

The following pictures were taken after the oxidation experiments. The lower temperature shows a matte black oxide and the higher temperature shows a lighter grey oxide.

Figure 5.31 *Photographed samples. 522°-621°C, TGA 2h, He*

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6. MODELLING

A suitable model for the low temperature range (400°-750°C) which will be used in this thesis which takes both linear and parabolic oxidation kinetics into consideration is a power law on the form:

$$\frac{\Delta m}{A} = kt^n \quad (6.1)$$

Δm is the mass change, A is the surface area, k is the oxidation rate constant, t is the exposure time and n the rate exponent.

The oxidation rate constant k is a function of temperature according to the Arrhenius equation:

$$k = k(T) = k_0 * exp^{(\frac{-Q}{RT})} \quad (6.2)$$

k_0 is a constant, Q is the activation energy for a certain type of oxidation mechanism, R is the gas constant and T is the absolute temperature.

A combination of Eq. (6.2) and Eq. (6.1) results in:

$$\frac{\Delta m}{A} = kt^n = k_0 * exp^{\left(\frac{-Q}{RT}\right)} * t^n \quad (6.3)$$

A power law of the form like in Eq. (6.1) is fitted against the data points from the four first TGA runs with Helium + 0.5 % Oxygen. The results are shown in Table 6.1 below:

Table 6.1 *Tabulated values of the constants extracted with the power law from the experiments with oxygen*

Temperature [°C]	Time range [min]	*k*	*n*	Kinetics
422	0-120	0.0014	0.50	Parabolic
522	0-120	0.015	0.63	Almost parabolic
618	0-120	0.018	0.91	Linear
716	0-120	0.117	0.81	Almost linear

As seen in the table above, the values of the oxidation rate constant and the rate exponent varies greatly with temperature.

In the same manner a power law of the form in Eq. (6.1) is fitted against the results from the TGA experiments that were conducted below the volatilization temperature. The oxidation atmosphere was Helium, Argon and water vapour. The results are shown in Table 6.2 below:

Table 6.2 *Tabulated values of the constants extracted with the power law from the experiments with water vapour*

Temperature [°C]	Time range [min]	*k*	*n*	Kinetics
415	0-120	$1.2e^{-6}$	2.49	-
522	0-120	$2.1e^{-5}$	1.76	-
619	0-120	0.067	0.59	Almost parabolic
714	0-120	0.214	0.65	Almost parabolic

The two first values for the oxidation rate constant are very small compared to the ones from the TGA experiments with oxygen. However, the results from these two first experiments were not as clear as those at higher temperatures. The weight gain was very small in the order of the measuring errors, which makes them unreliable.

The higher temperature range from 700°-900°C requires a different kind of kinetic model due to the volatilization of tungsten trioxide. A more suitable kinetic model is the Tedmon model [42], which is a combination of a parabolic rate weight gain and a linear weight loss that occur at the same time:

$$\frac{dx}{dt} = \frac{K_p}{x} - K_v \tag{6.4}$$

x is the scale thickness, K_p is the parabolic rate constant for scale growth, K_v is the linear rate constant for loss of scale by volatilization.

Eq. (6.4) can also be written as, provided that $K_v/K_p < 1$:

$$x = K_v t + (K_v^2 t^2 + 2K_p t)^{1/2} \tag{6.5}$$

Considering the weight change per unit area instead leads to:

$$\Delta m = -K_v t + (K_v^2 t^2 + 2K_p t)^{1/2} \tag{6.6}$$

Unfortunately, due to time limitations, the work was only started but not finished.

7. CONCLUSIONS

The aim of this master´s thesis has been to investigate the oxidation behaviour of tungsten and understand the underlying mechanisms. In order to do so a great amount of theory on tungsten and tungsten oxidation has been reviewed and several experiments have been conducted in a wide temperature interval and with different gas atmospheres – focusing mainly on inert gases.

The effect of water vapor combined with high temperatures has been studied in this thesis, as well as the oxidizing effect of an alleged “pure and inert” gas. The gases used for these experiments, helium and argon, both contained less than 5 ppm of oxygen impurities. But as it turns out it they are far from pure enough for tungsten, even at low temperatures. The study involving tungsten foil kept at 500°-550°C in argon showed a definite increase in weight due to oxidation despite the “inert” atmosphere. In the table below is a summary of the results from the STA.

Table 7.1 *Summary of results from the forty-eight hour STA experiments*

			Weight gain		
			[%]	**[mg]**	**[mg/cm^2]**
Dry Argon $p_{O2} \leq 5 \cdot 10^{-6}$ atm.	550°C	1st	3.19	0.345	0.726
		1st at 12h	*1.05*	*0.114*	*0.240*
		2nd (12h)	*1.80*	*0.164*	*0.345*
		*2nd at 48h**	*7.43*	*0.677*	*1.425*
	500°C	1st	0.34	0.037	0.078
		2nd	5.33	0.510	1.073
		3rd	5.31	0.475	1.000
Humid Argon $p_{H2O} \sim 6.6 \cdot 10^{-3}$ atm.	550°C		2.85	0.275	0.579
	500°C		2.36	0.225	0.473

*The twelve hour long 2nd run was extrapolated to forty-eight hours.

From this table it is clear that even a fifty degrees difference in temperature affects the rate of oxidation; the higher the temperature, the greater the oxidation rate. For the experimental runs in humid argon the resulting weight gains are 0.579 mg/cm^2 and 0.473 mg/cm^2, for 550° and 500°C respectively. Compared to the second and third try conducted in dry gas at 500°C, the values from the experiments in moist gas are only about half the amount – and even less if compared to the results from the 550°C run in dry gas. The resulting weight gain for the twelve hour run at 550°C in dry gas is quite high when considering the results from the experiments with moist gas, which have been oxidized four times longer.

The most important conclusion drawn from the STA set up is that even the smallest amount of oxygen impurity will without a doubt cause oxidation of tungsten at temperatures from 500°C and above. Another realization is that even though the oxygen partial pressure was much less in the dry set up than the water vapour partial pressure in the moist set up, the oxidation rate was still higher for the experiments with pure dry argon. In other words, at this temperature oxygen impurity in the inert atmosphere is far more detrimental to tungsten than moisture at the same partial pressure.

In the TGA, the samples were much bigger: eighteen grams as compared to the nine milligram samples used in the STA. Because the experiments were carried out for a shorter period of only two hours the gas atmospheres were slightly modified. The first sets of experiments were done in helium containing 0.5% oxygen. The results can be seen in the table below where a summary of all the resulting mass changes from the TGA experiments are presented. These mass gain values can be compared with the corresponding values for the moist inert gas mixture of helium, argon and water vapour (with a partial pressure of ~ $7.8 \cdot 10^{-3}$ atm). The same conclusion can be drawn here – the oxidation rate is greater when oxygen is present then when water vapour is.

A third set up with only pure and dry helium was used for two experiments at low temperatures. The dry helium contained a maximum impurity of oxygen with a partial pressure of $5 \cdot 10^{-6}$, but this was enough to oxidize the samples at 513° and 621°. In fact, the 621° sample showed a greater mass gain than the 619°C sample in the moist atmosphere. Also, the TGA experiments show that tungsten oxidizes even at temperatures as low as 400°C when in these specific atmospheres.

Table 7.2 *Summary of results from the 2h TGA experiments*

Gas atmosphere	Temperature [°C]	Total weight gain [mg/cm^2]
He-0.5% O_2 $p_{O2} \sim 5 \cdot 10^{-3}$ atm.	422	0.0444
	522	0.380
	618	1.407
	716	4.953
	763	6.450
	811	12.21
	907	17.93
Dry Helium $p_{O2} \leq 5 \cdot 10^{-6}$ atm.	513*	0.156
	522	*-0.146*
	621	1.21
He-Ar-H_2O $p_{H2O} \sim 7.8 \cdot 10^{-3}$ atm.	415*	0.1567
	419	*-0.5793*
	522	0.1249
	619	1.107
	714	4.453
	763	5.797
	811	7.627
	906	10.69

*New redone experiments

The results from these runs were plotted and are presented in both the appendix and in the results chapter. When comparing the shapes of the mass change curves one can conclude that for the forty-eight hour runs the oxidation rate becomes more linear, whilst the shorter two hour runs shows a more parabolic behaviour. Additionally, the oxidation rates in the two hour runs are parabolic at lower temperatures and tend to flatten out to a more linear shape at higher temperatures.

The oxide scales that formed during the experiments were photographed and can be seen in appendix. It is clear that two different types of oxides layers have formed on the surface. For temperatures between 700° and 900°C the outermost oxide is porous and green/yellow. It is most probably the tungsten trioxide. At lower temperatures the scale is dark, adherent and thin. The composition of this scale is unknown but is assumed to be a mixture of lower nonstoichiometric tungsten oxides.

Activation energies for both the He-0.5% O_2 and the He-Ar-H_2O gas mixtures were determined with the help of an Arrhenius plot. For the phase boundary limited reaction the values were found to be 64 and 74 kJ/mol, respectively. The activation energies for the diffusion limited reactions for these respective gas mixtures were determined as approximately 95 and 183 kJ/mol.

Finally, an attempt was made to create a model for the oxidation. The model which is valid for the lower temperature range of 400°-700°C is a power law on the form:

$\frac{\Delta m}{A} = kt^n$ where Δm is the mass change, A is the surface area, k is the oxidation rate constant, t is the time and n is the rate exponent.

At higher temperatures, around 750°C the volatilization of tungsten trioxide is starting; two mechanisms are taking place at the same time both volatilization of tungsten trioxide and growth of the oxide scale. A suitable model which takes a parabolic weight gain and a linear loss by volatilization into account has been proposed by Albina [42]. An attempt was made to fit the data points to this particular model, but due to lack of time, this was not finished.

8. FUTURE WORK AND IMPROVEMENTS

Due to the limited amount of time, there are some stages that unfortunately were left out. An x-ray diffraction study was planned to identify the different oxides and thus gain a deeper understanding of the oxidation mechanisms. Also, a scanning electron microscopy study would have given valuable information about the structure of the oxides.

For future work a study at different partial pressures of both oxygen and water vapour is suggested. Furthermore some previous research [43] has been focused on determining the amount of trioxide that has been volatilized. This technique involves measuring the amount of oxygen that is let in a closed system versus the amount of oxygen in the oxide scale. From the difference one can derive the amount of volatilization of tungsten trioxide. This type of measurement would complement the kinetic model presented in this thesis.

Shorter steps between the different oxidation temperatures would have given a more accurate analysis. Some reports suggest that longer oxidation times results in an almost linear oxidation rate as opposed to parabolic oxidation rates at shorter times. This would have been interesting to investigate on a larger scale.

One of the more important improvements of the experimental work involves the STA. During this project there have been contradictions in the results. Two of the four experiments in the STA have been redone more than once to ensure correct results. If not for the time constraints, all four experiments would have been redone. Moreover the amount of humidity in the argon gas had to be kept very low because of the sensitivity of the balance.

The samples used in this project were electro-polished. However the quality of the polishing was not satisfactory. According to Arslambekov and Gorbunova [44] different types of polishing will lead to a difference in oxidation activation energies.

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APPENDIX 1

The results from the experiments in the STA are shown below:

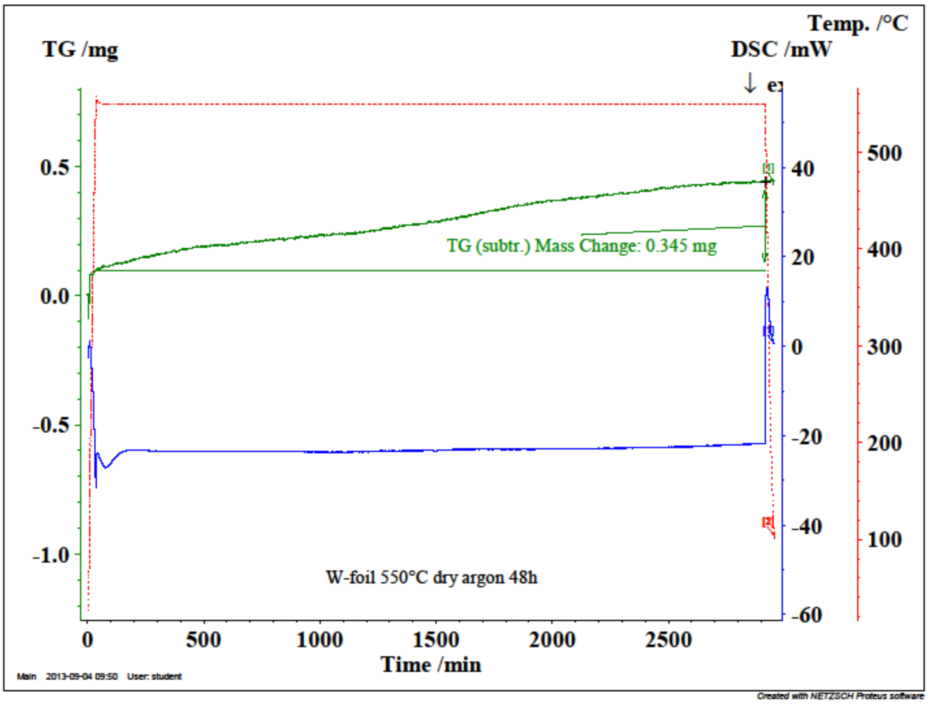


Figure A1.1 *STA results from the first dry 550°C run*

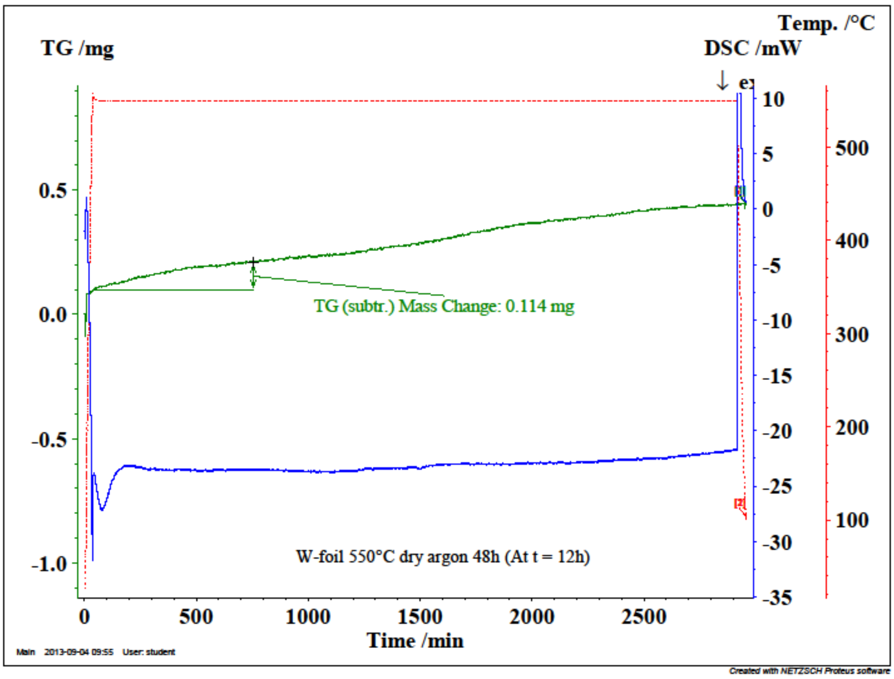


Figure A1.2 *STA results from the first dry 550°C run at t = 12 hours*

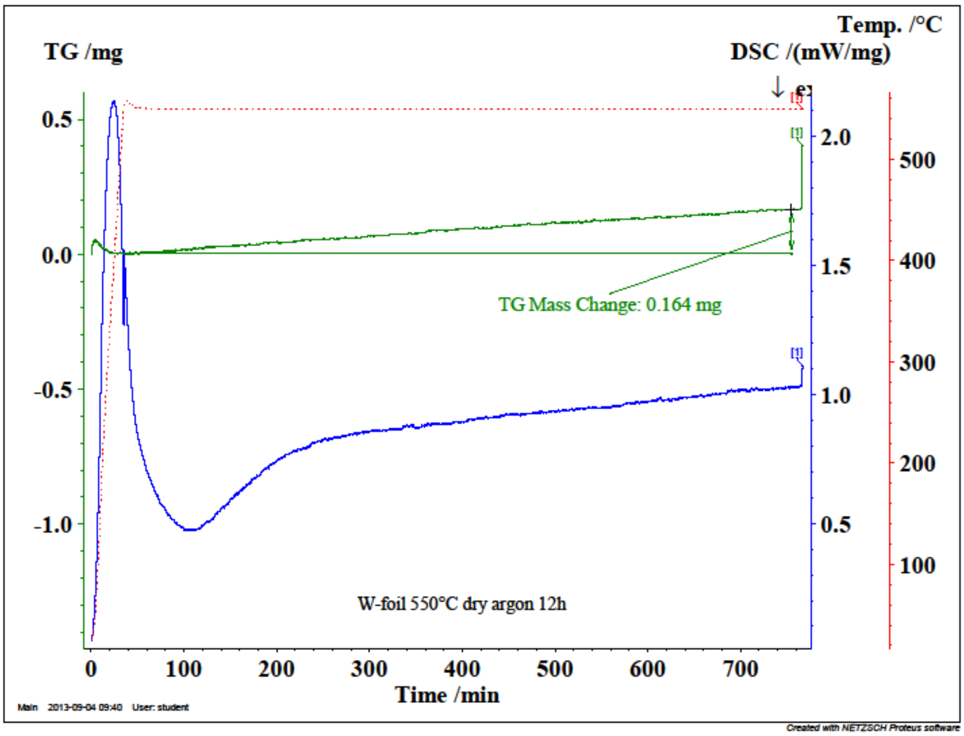


Figure A1.3 *STA results from the second dry 550°C run*

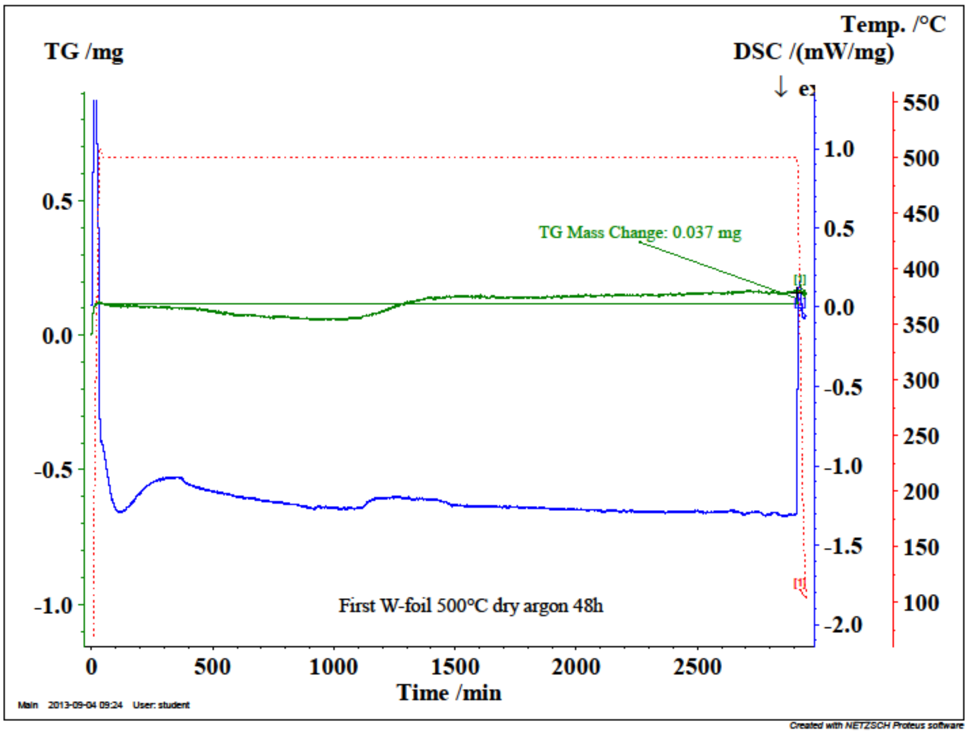


Figure A1.4 *STA results from the first dry 500°C run*

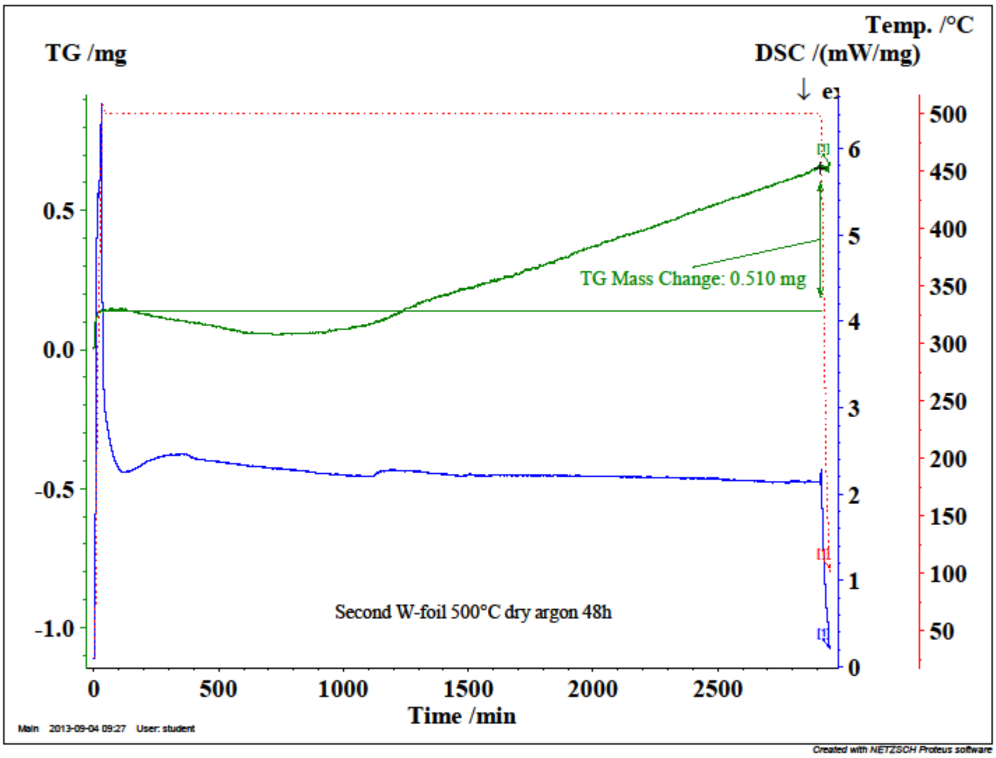


Figure A1.5 *STA results from the second dry 500°C run*

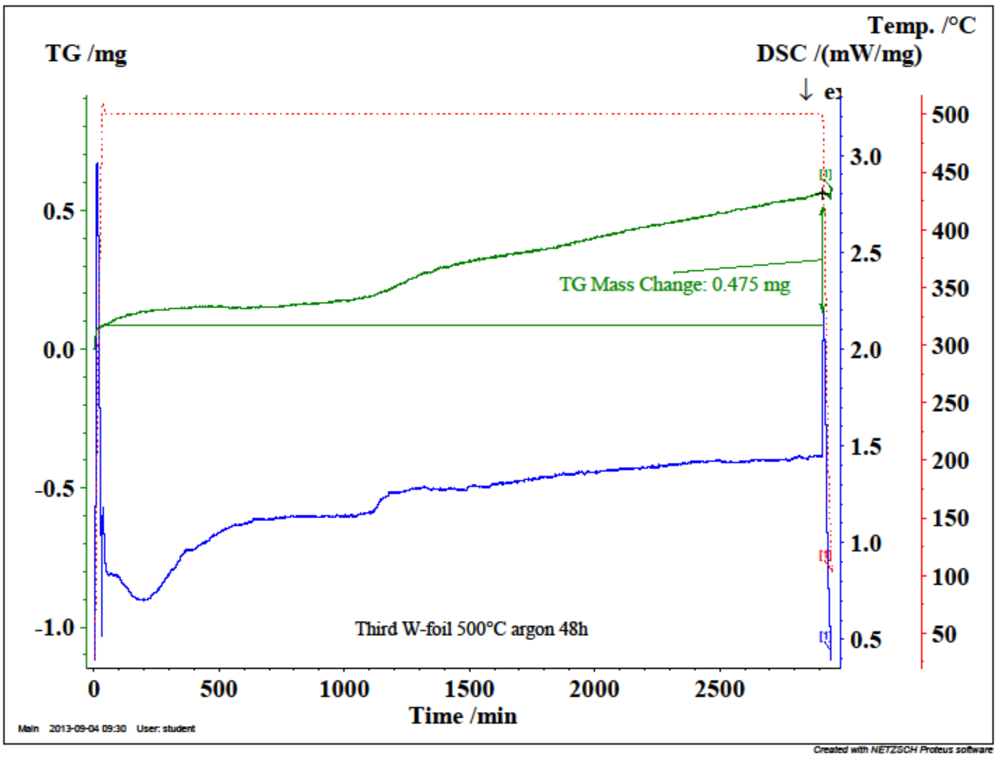


Figure A1.6 *STA results from the third dry 500°C run*

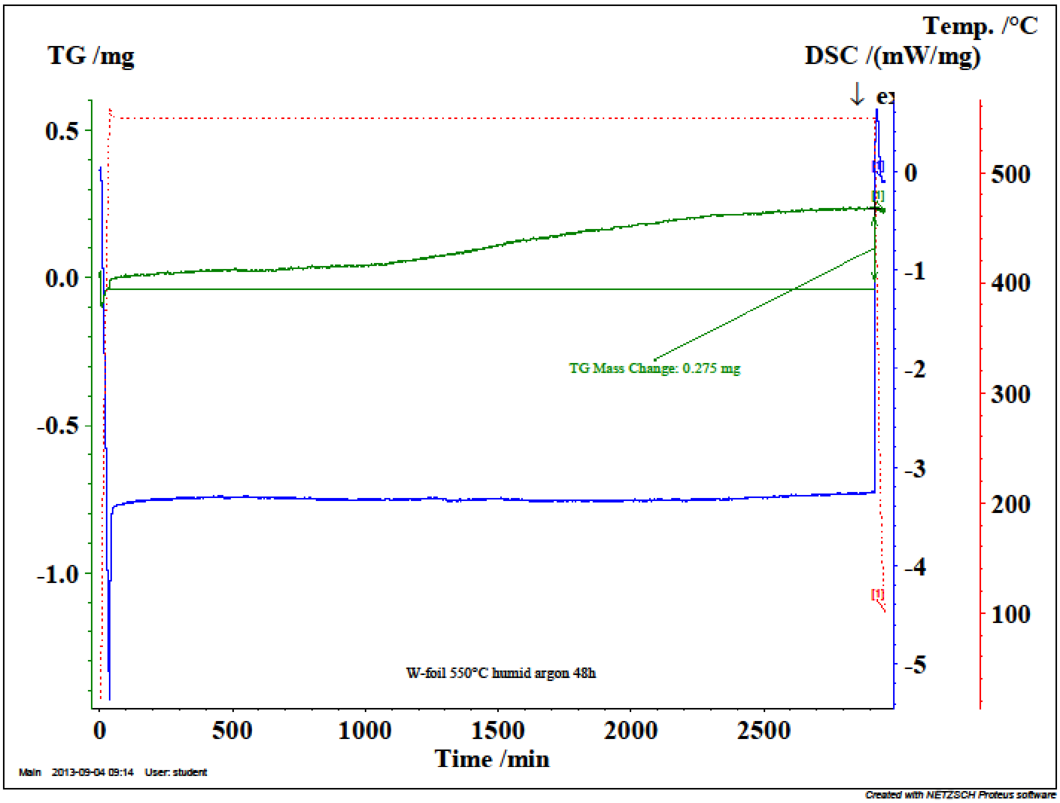


Figure A1.7 *STA results from the humid 550°C run*

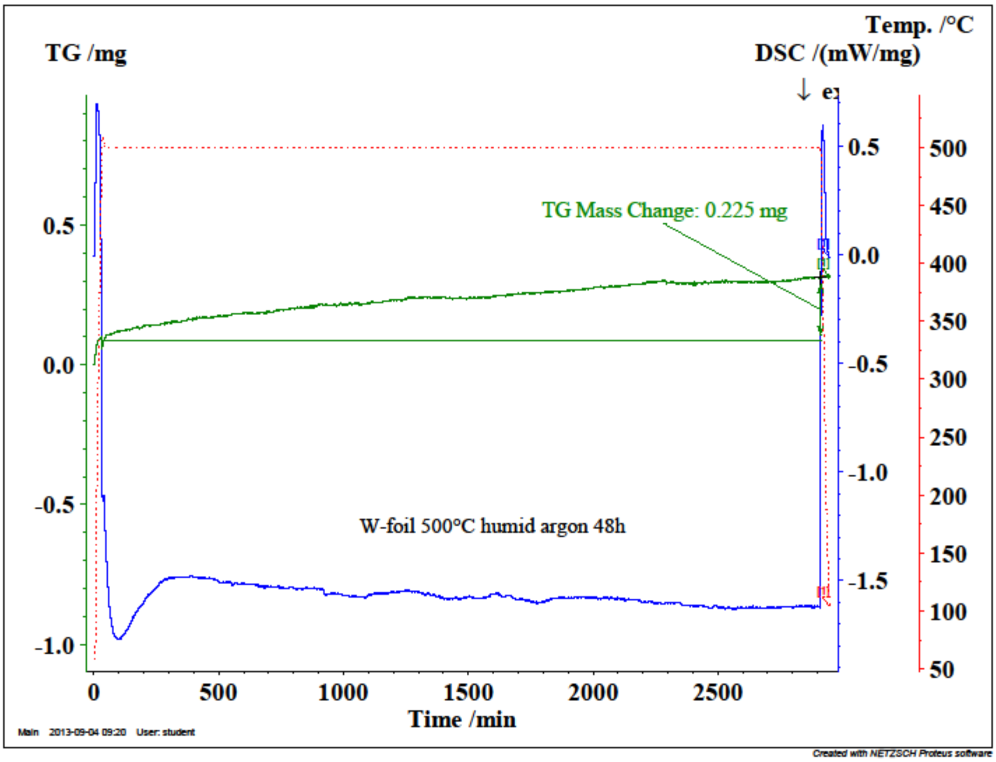


Figure A1.8 *STA results from the humid 500°C run*

APPENDIX 2

Pictures taken in the light microscope are shown below:

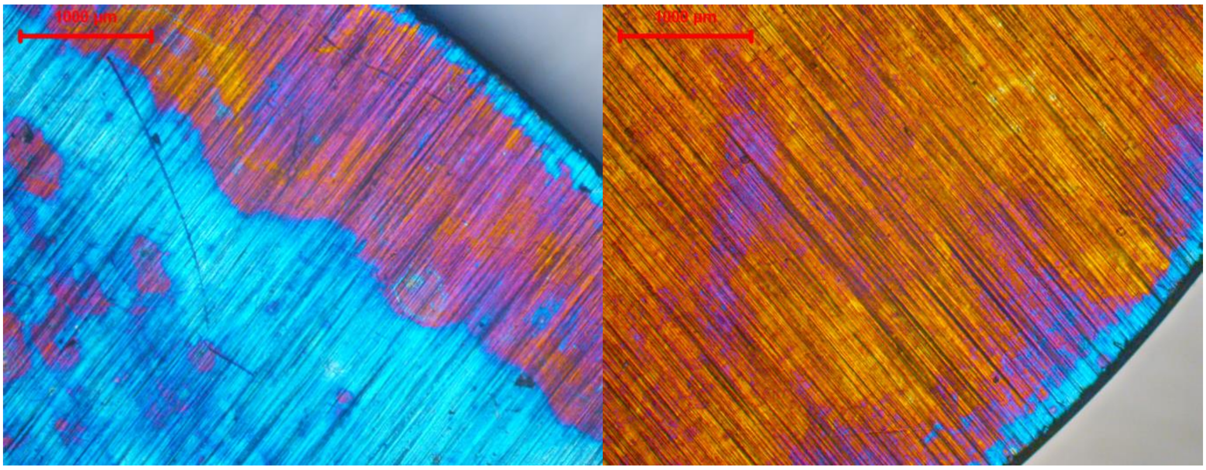


Figure A2.1 *Optical microscope 50 x magnification*

400°, 2h, Ar+He+H_2O

The oxide layer on the 400°C sample exposed to a humid argon/helium mixture is very thin. The machining marks are still very visible. The colors of this sample are very shiny and shift between blue, purple and orange. The picture below is taken at a greater magnification and shows the colors and texture in detail.

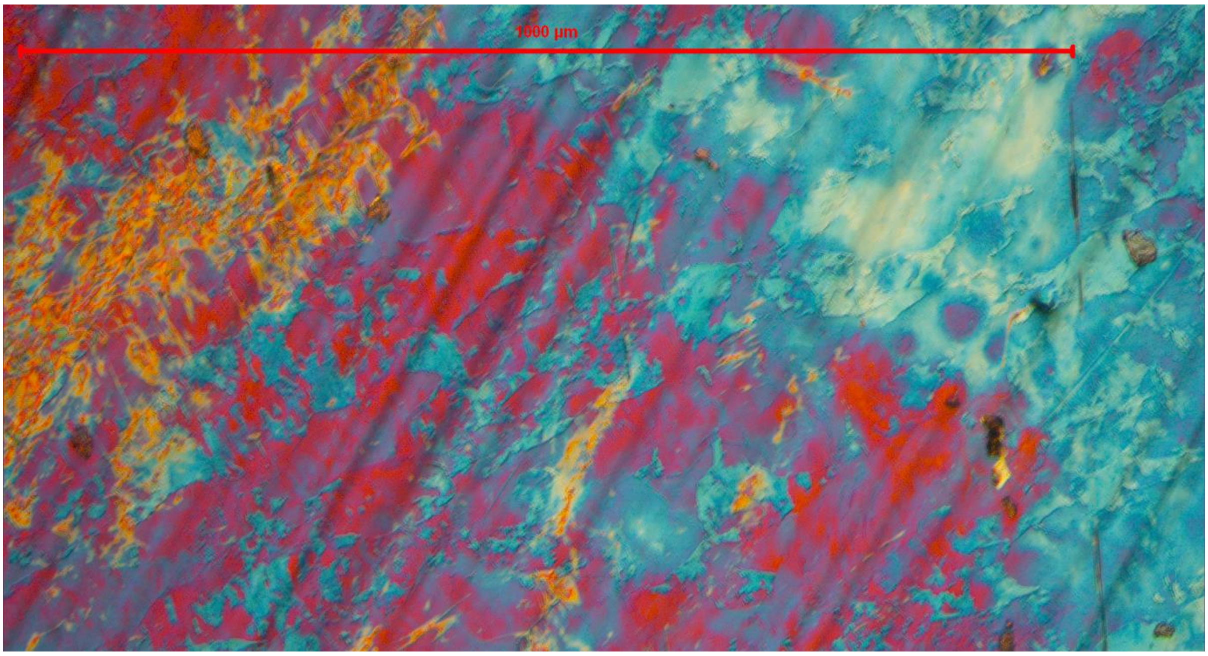


Figure A2.2 *Optical microscope 100 x magnification*

400°C, 2h, Ar+He+H_2O

The oxide on the 400°C sample oxidized in the helium/oxygen mixture is shown below. It does not have the same golden and purple color – it is all blue.

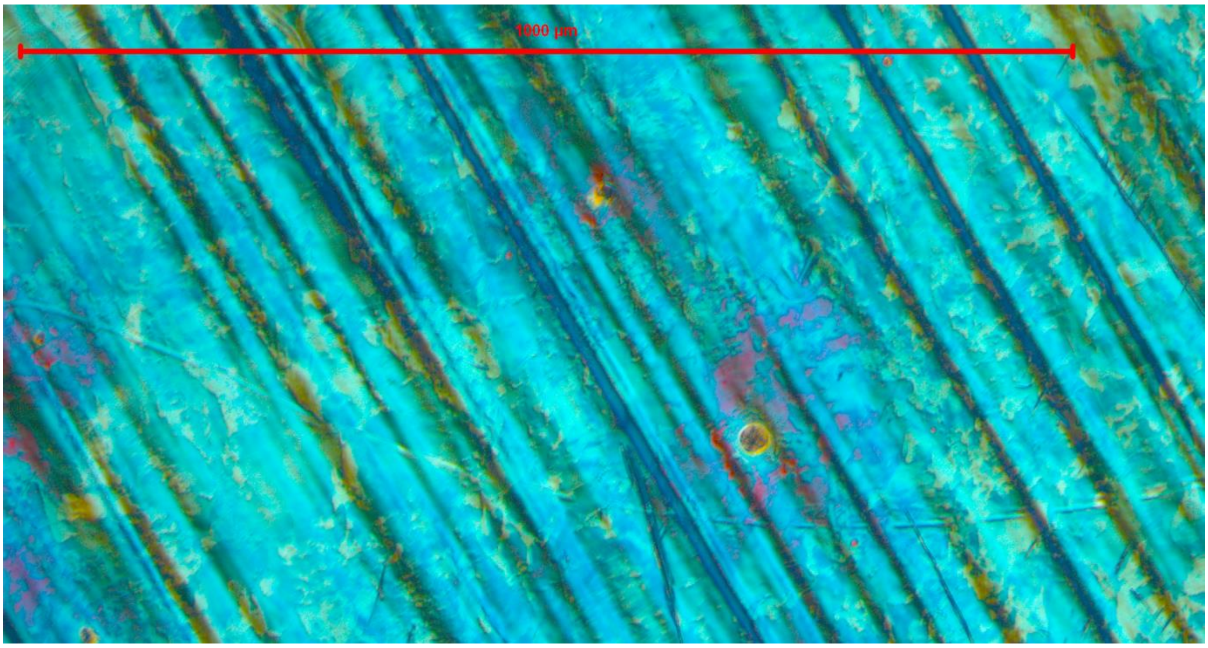


Figure A2.3 *Optical microscope 100 x magnification*

400°C, 2h, He+0.5% O_2

At 500°C the appearance of the surface has changed. There seems to have formed some sort of coating on top of the sample, though the surface is not completely covered. The first two pictures below (one for each gas mixture) show the surface in a 100 x magnification. The third picture is taken in a polarized light to elucidate the details of the humid gas mixture sample.

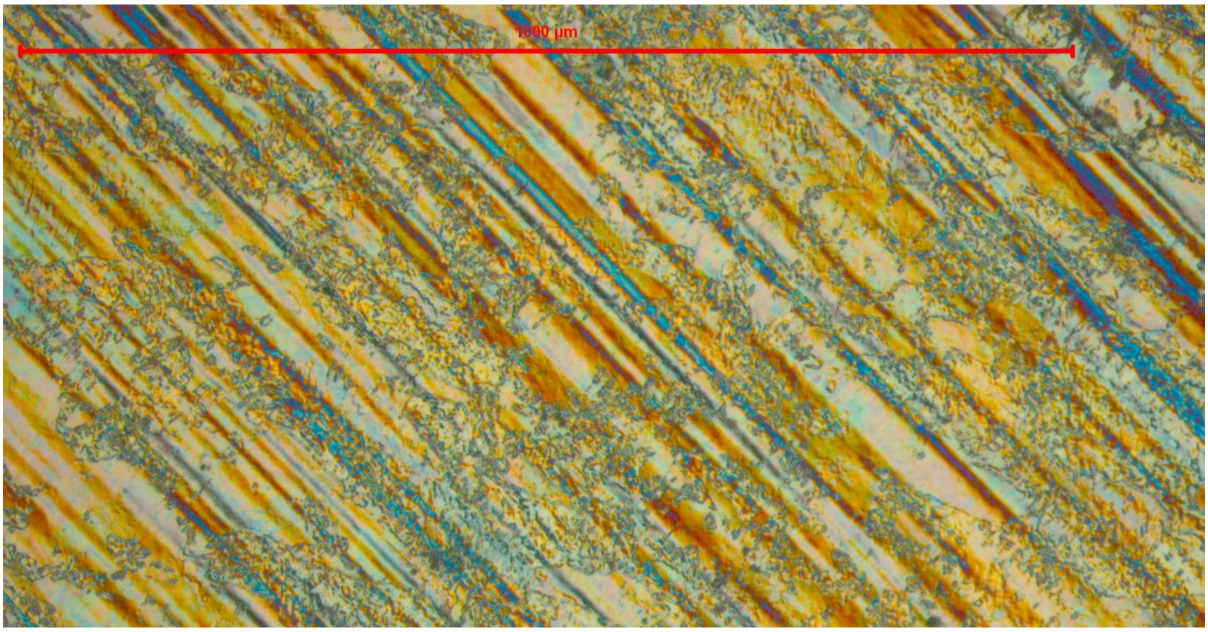


Figure A2.4 *Optical microscope 100 x magnification*

500°C, 2h, Ar+He+H_2O

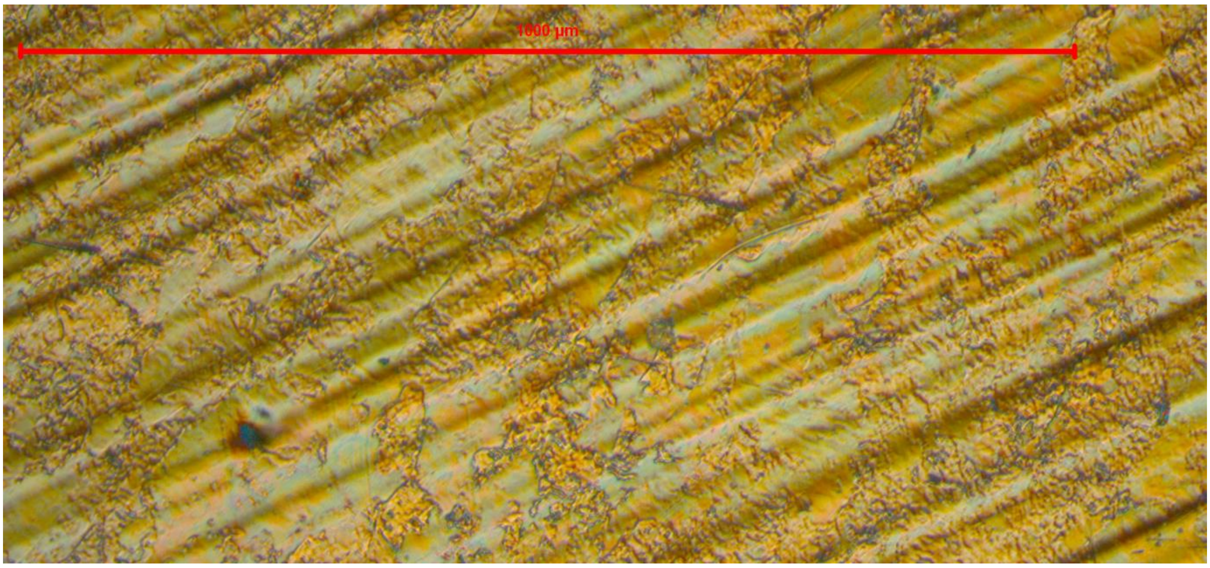


Figure A2.5 *Optical microscope 100 x magnification*

500°C, 2h, He+0.5% O_2

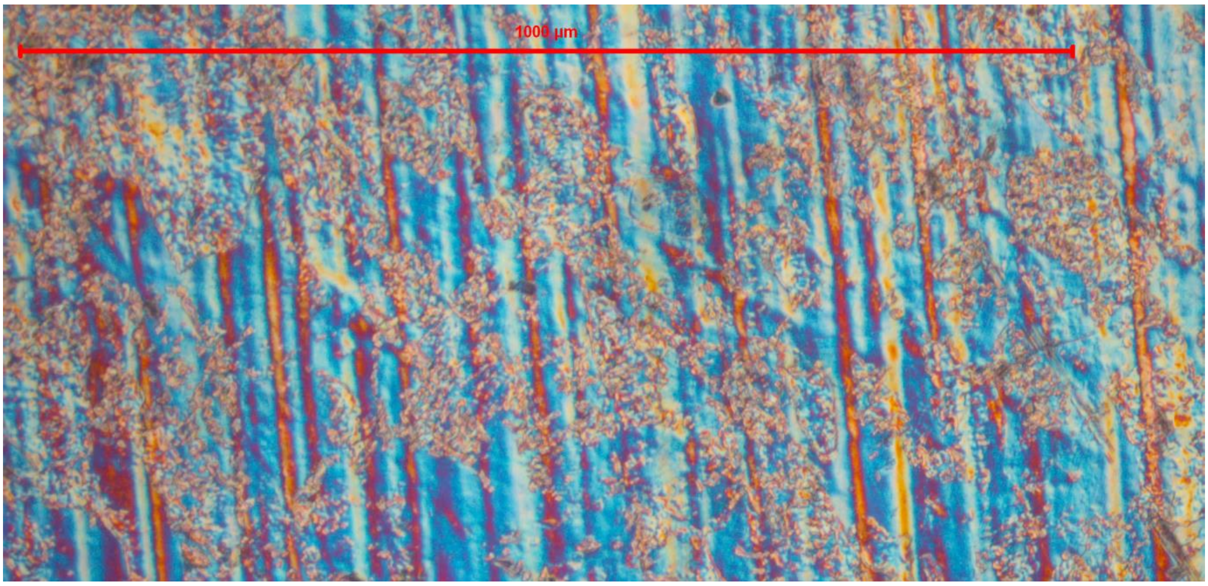


Figure A2.6 *Optical microscope 100 x magnification, polarized light*

500°C, 2h, Ar+He+H_2O

The appearance and thickness of the oxide layer has again changed when the sample is oxidized at an even higher temperature. The 600°C samples are presented below. Here the marks from the machining are no longer visible and the oxide layer has completely covered the sample, it seems compact and adherent. The texture of the oxide appears to be the same all over the sample. The oxide looks oily and glossy on top, with a darker color underneath.

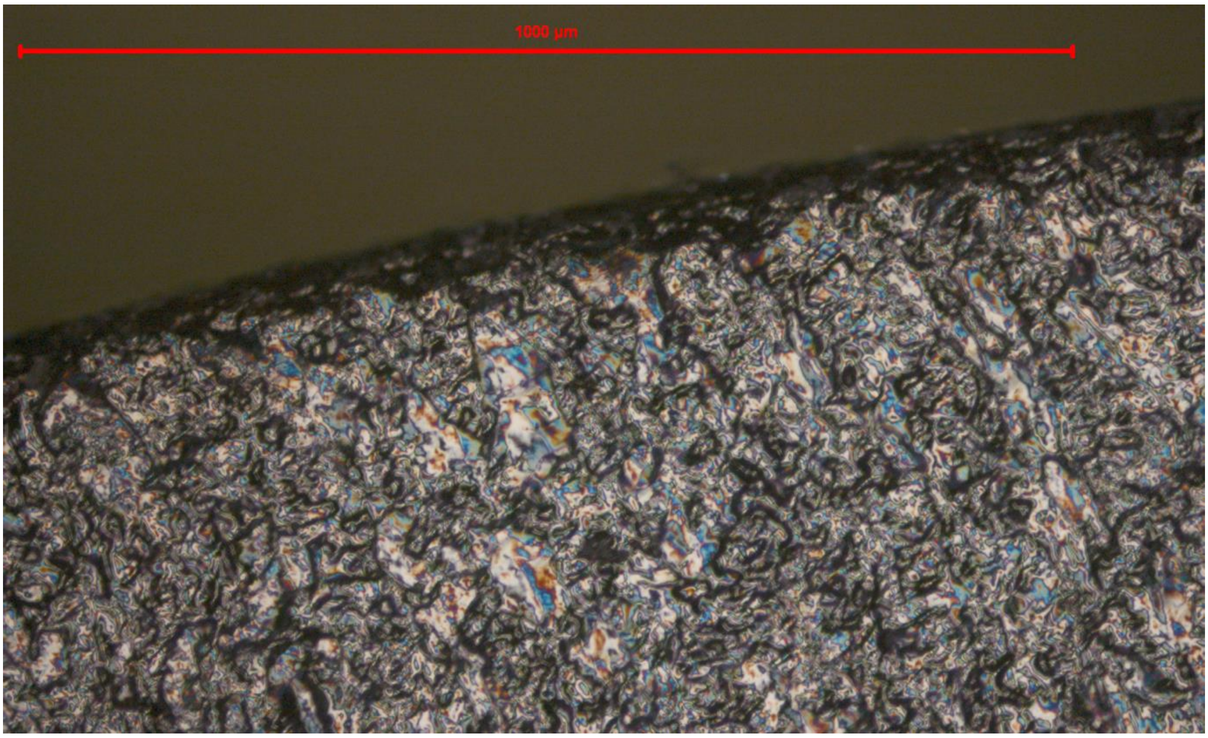


Figure A2.7 *Optical microscope 100 x magnification 600°C, 2h, Ar+He+H_2O.*

The sample oxidized in the humid gas mixture looks roughly the same.

When looking at same sample in a greater magnification and in a polarized light one can see a rough surface with small cracks, see figure below.

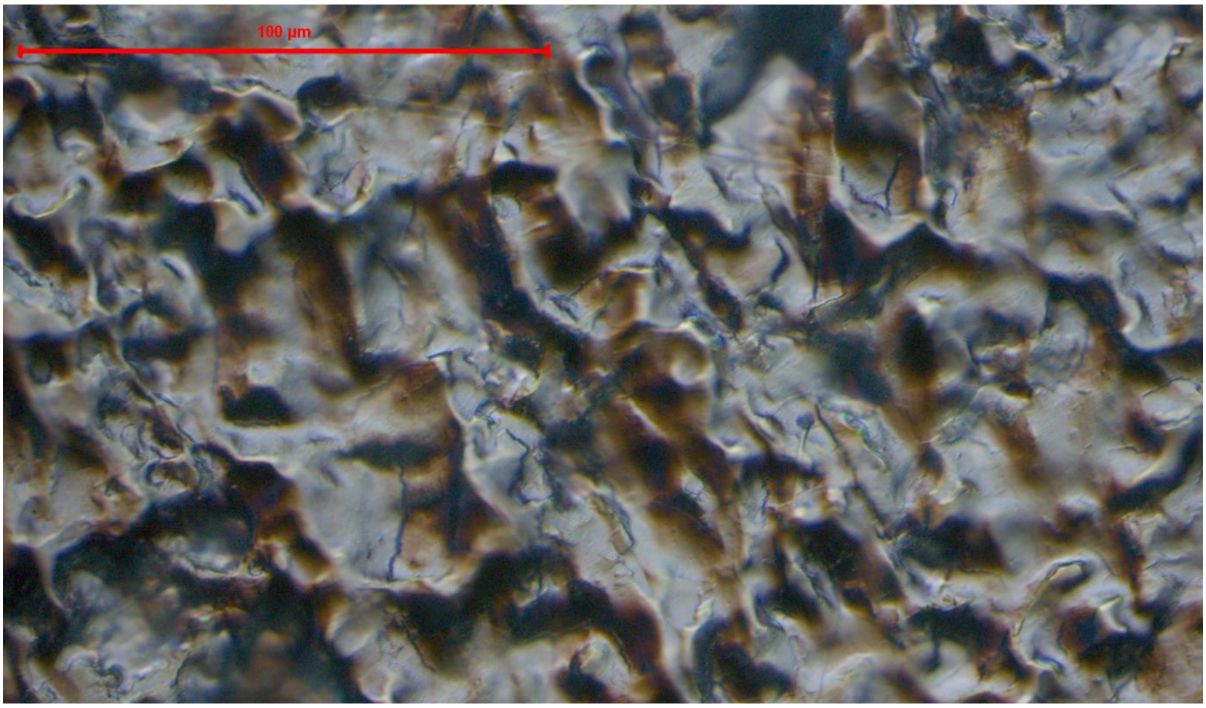


Figure A2.8*Optical microscope 200 x magnification, polarized light*

600°C, 2h, Ar+He+H_2O

At 700°C the oxide has become markedly thicker, the color has turned yellow/green and the surface is more porous than in the previous samples. The second picture is a 200 x magnification of the same surface as in the first picture below.

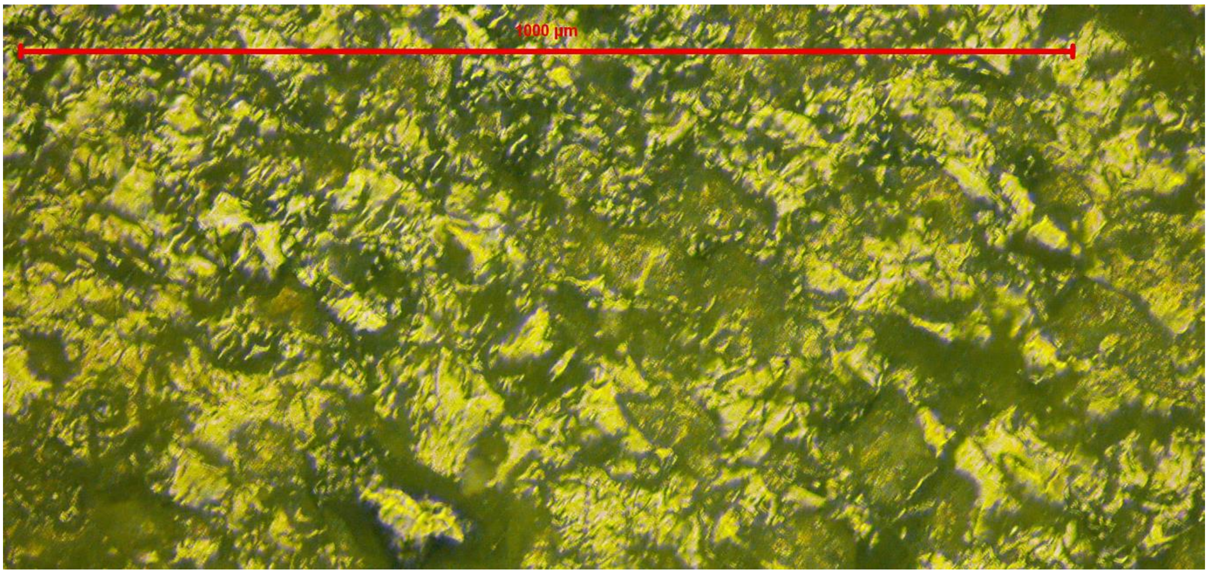


Figure A2.9 *Optical microscope 100 x magnification*

600°C, 2h, He+0.5% O_2

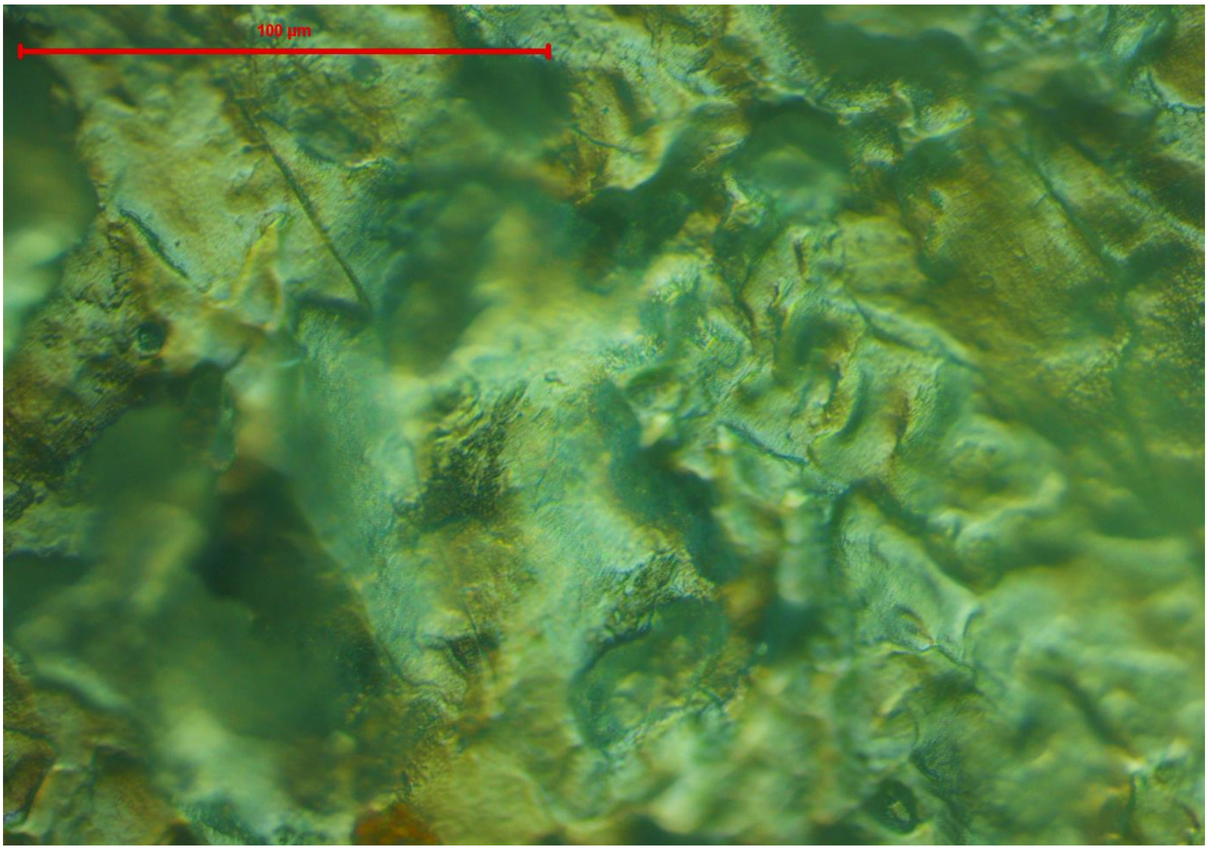


Figure A2.10 *Optical microscope 200 x magnification*

700°C, 2h, He+0.5% O_2

The volatilization of tungsten trioxide should theoretically begin at 750°C. A picture of the sample oxidized at this temperature is shown below. The oxide layer is now of a darker green color and there seems to have appeared lines running across the surface again.

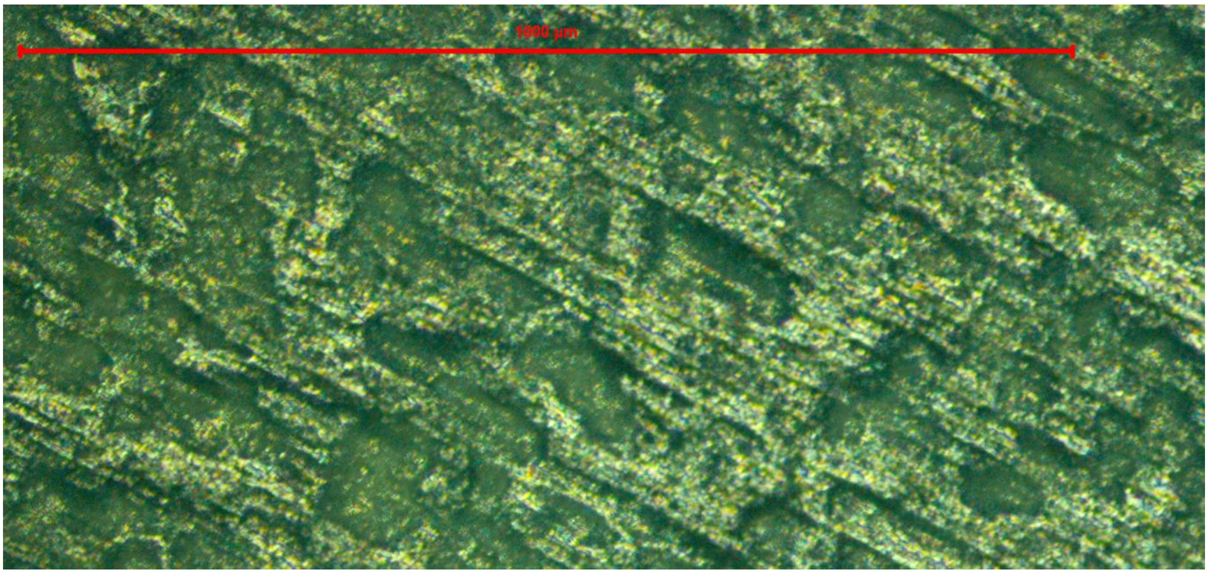


Figure A2.11 *Optical microscope 100 x magnification*

750°C, 2h, Ar+He+H_2O

A magnification of the surface (see figure below) shows a very porous green oxide.

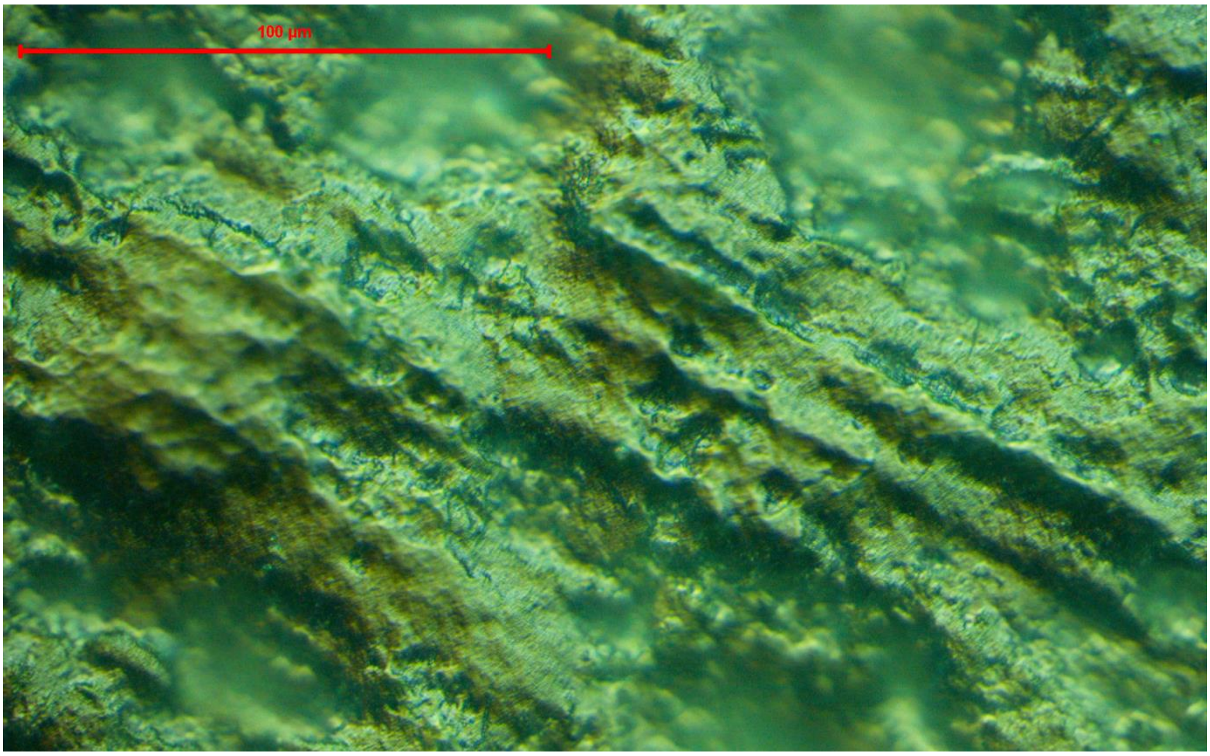


Figure A2.12 *Optical microscope 200 x magnification, polarized light*

750°C, 2h, Ar+He+H_2O

The sample oxidized in the helium/oxygen mixture at 750°C is far more porous and the surface looks more even compared to the pictures above. The lines across the surface are also less visible. Sharp pictures of higher magnification were not possible to take because of the porous surface.

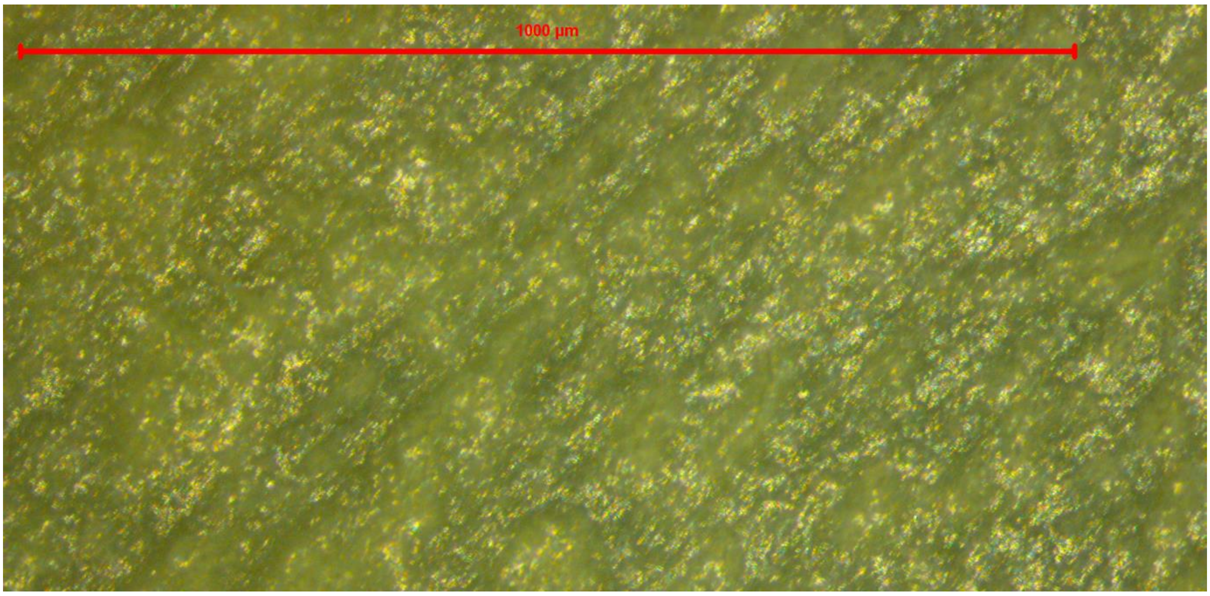


Figure A2.13 *Optical microscope 100 x magnification*

750°C, 2h, He+0.5% O_2

Below, samples from the 800°C run are shown. To the left is the sample oxidized in the humid atmosphere and to right is the sample oxidized in the helium/oxygen mixture. Both samples are of the same magnification. There is a distinct difference between these two surfaces; the surface to the right is thicker and more even. The surface to the left still shows some rough areas and is of a darker colour.

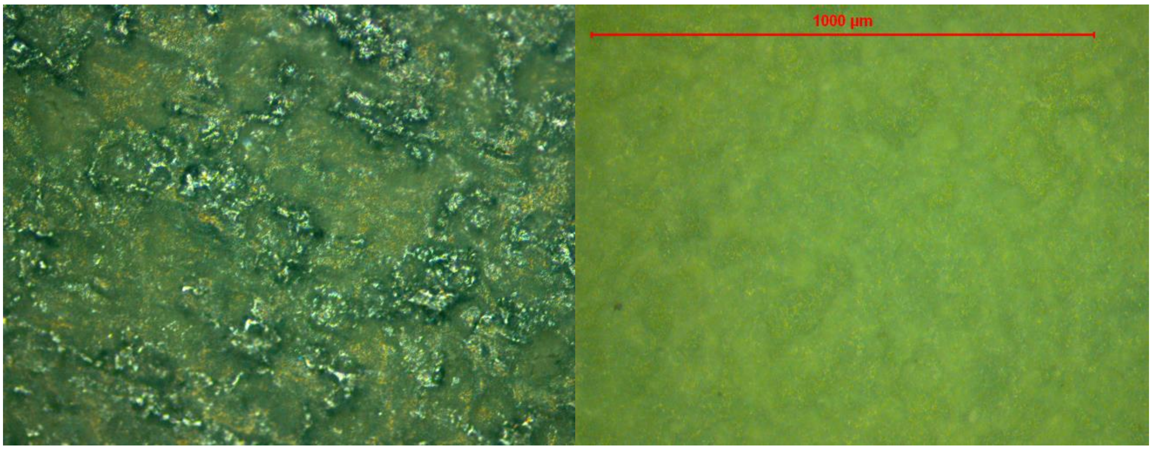


Figure A2.14 *Optical microscope, 100 x magnification, 800°C, 2h,*

Left: Ar+He+H_2O. Right: He+0.5% O_2

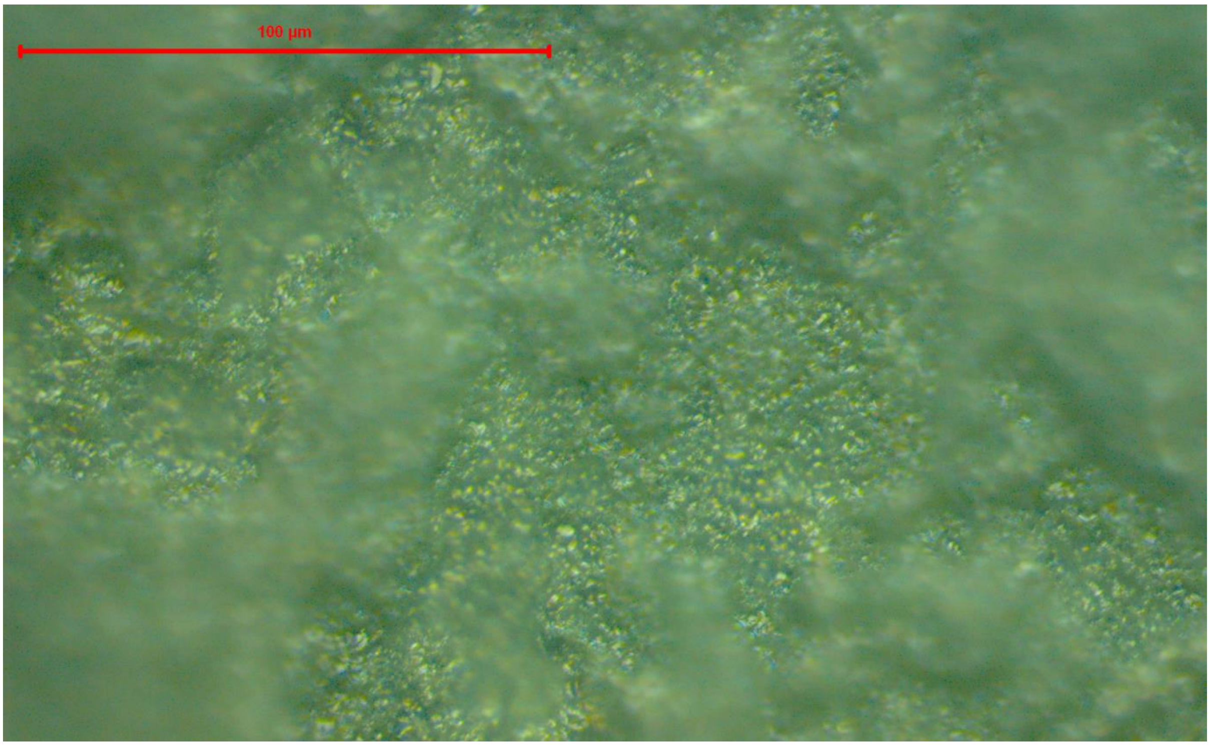


Figure A2.15 *Optical microscope, 200 x magnification*

900°C, 2h, Ar+He+H_2O

The surface for the humid oxidation has become smoother at 900°C and there are no signs left of the lines seen in the previous pictures. Below is the corresponding picture (though at a lower magnification) for the sample run in the helium/oxygen gas mixture.

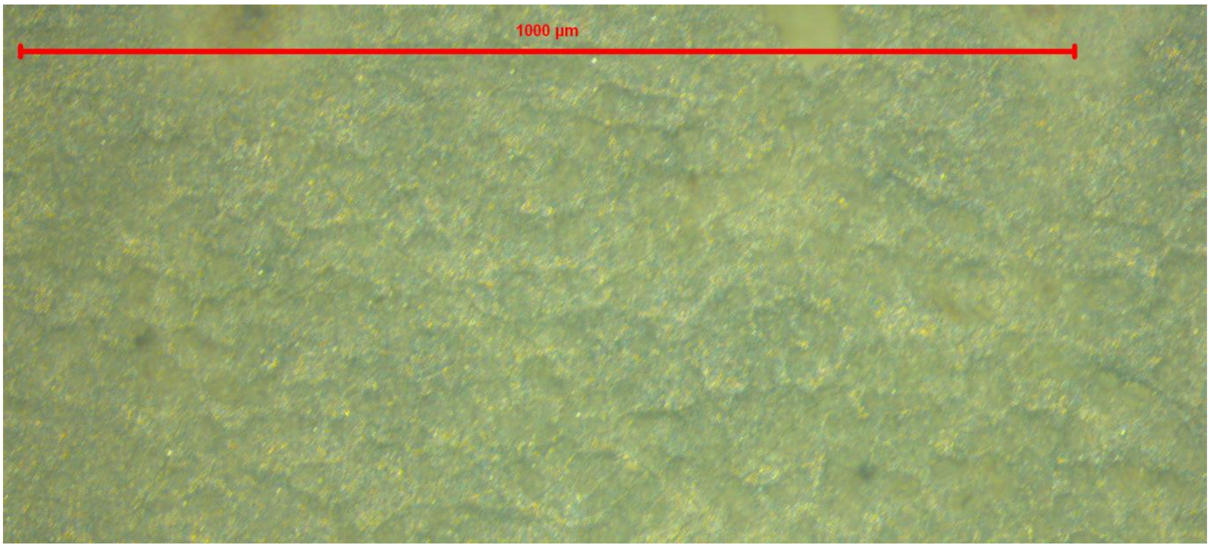


Figure A2.16 *Optical microscope, 100 x magnification*

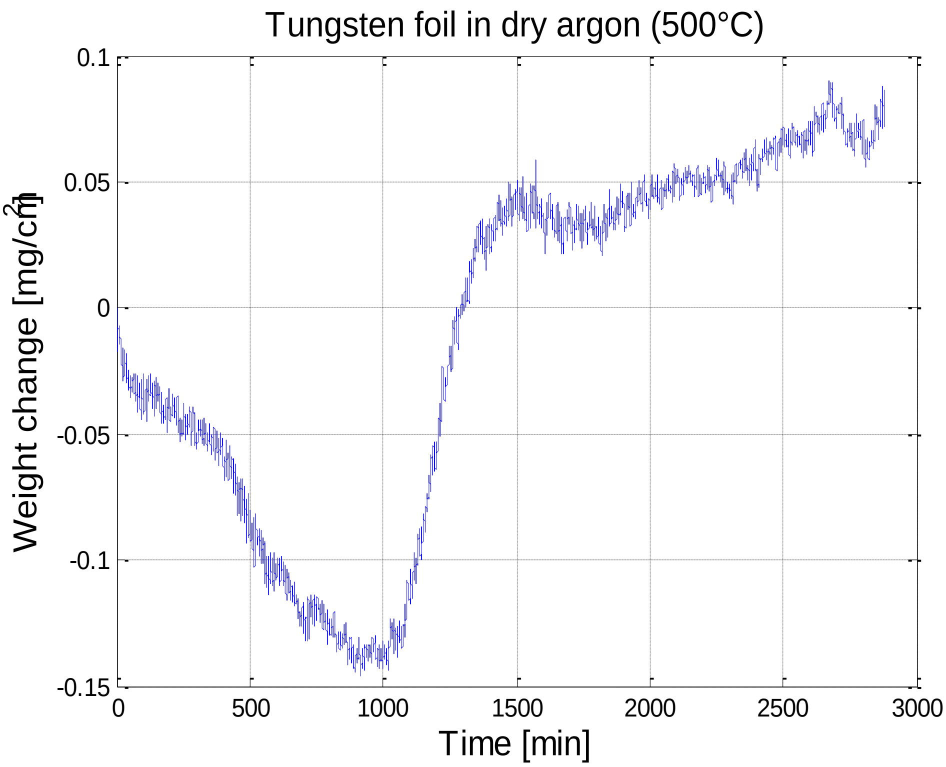
900°C, 2h, He+0.5% O_2

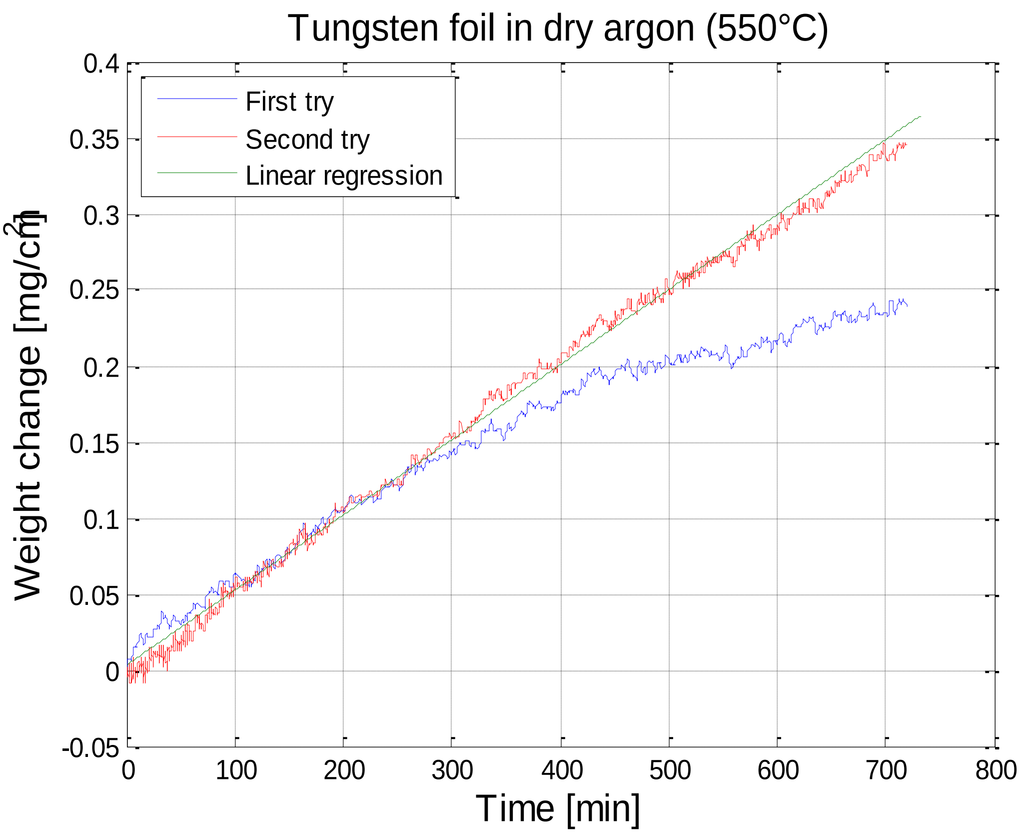
This surface is thicker, less green and more even. A picture at a higher magnification was not possible due to the porosity of the surface.

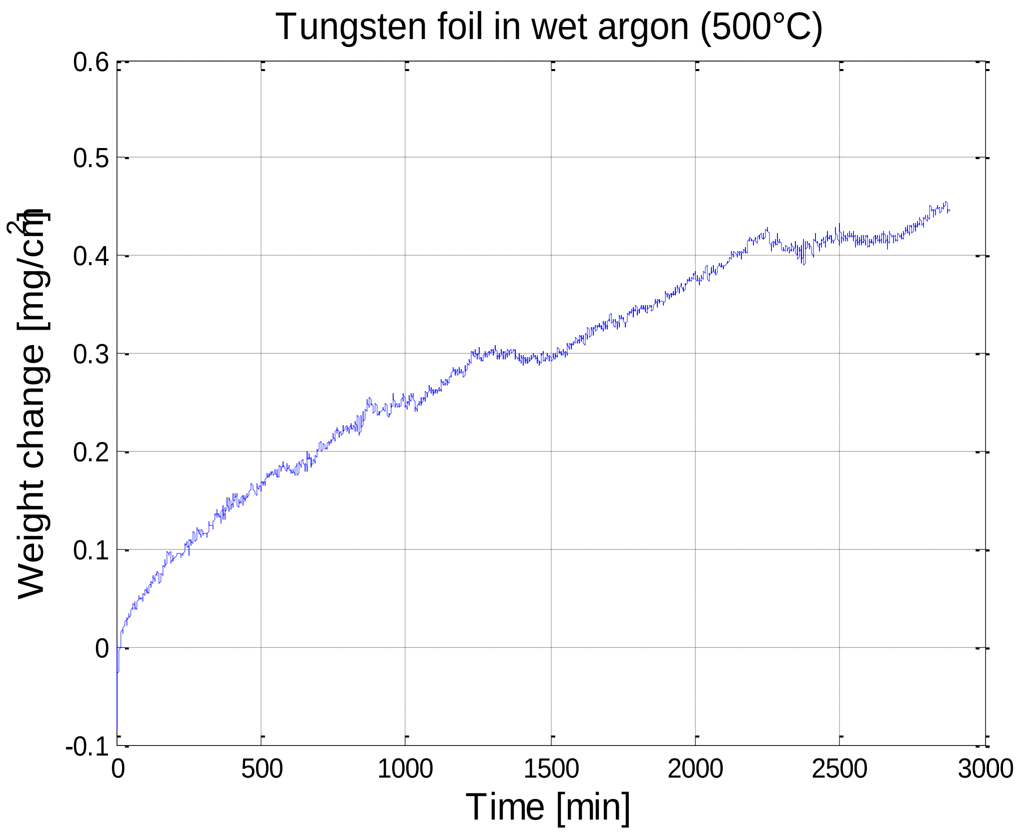
APPENDIX 3

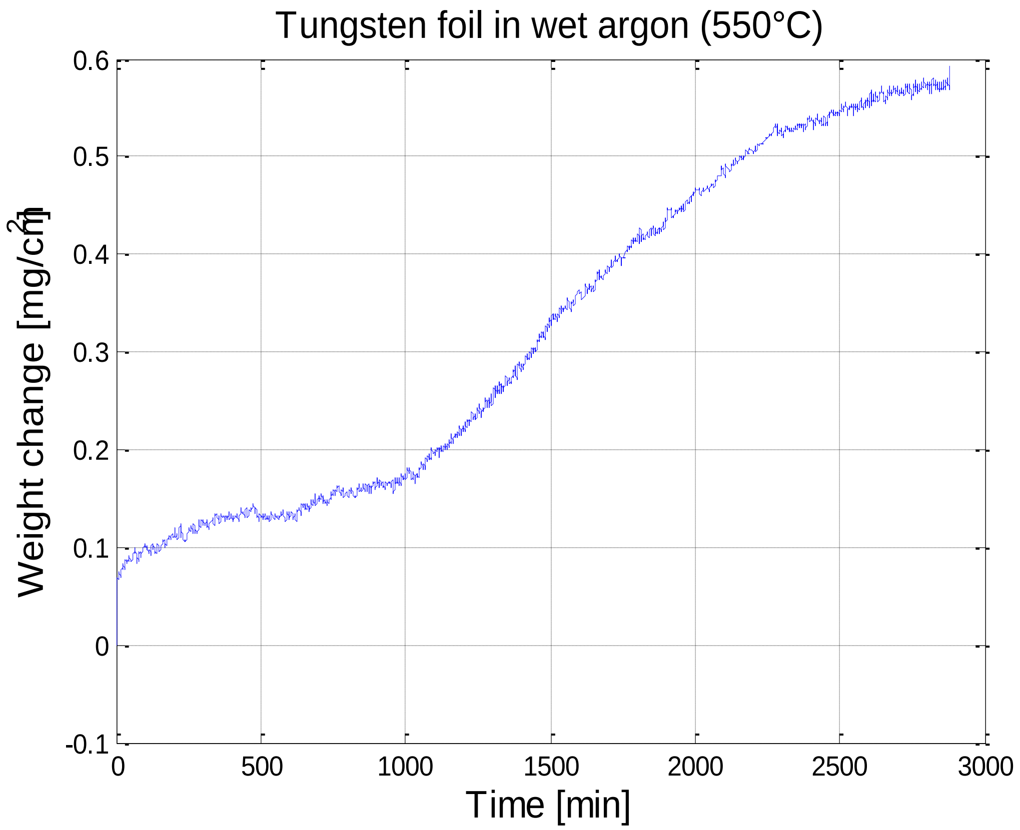
Matlab plots and figures are shown below.

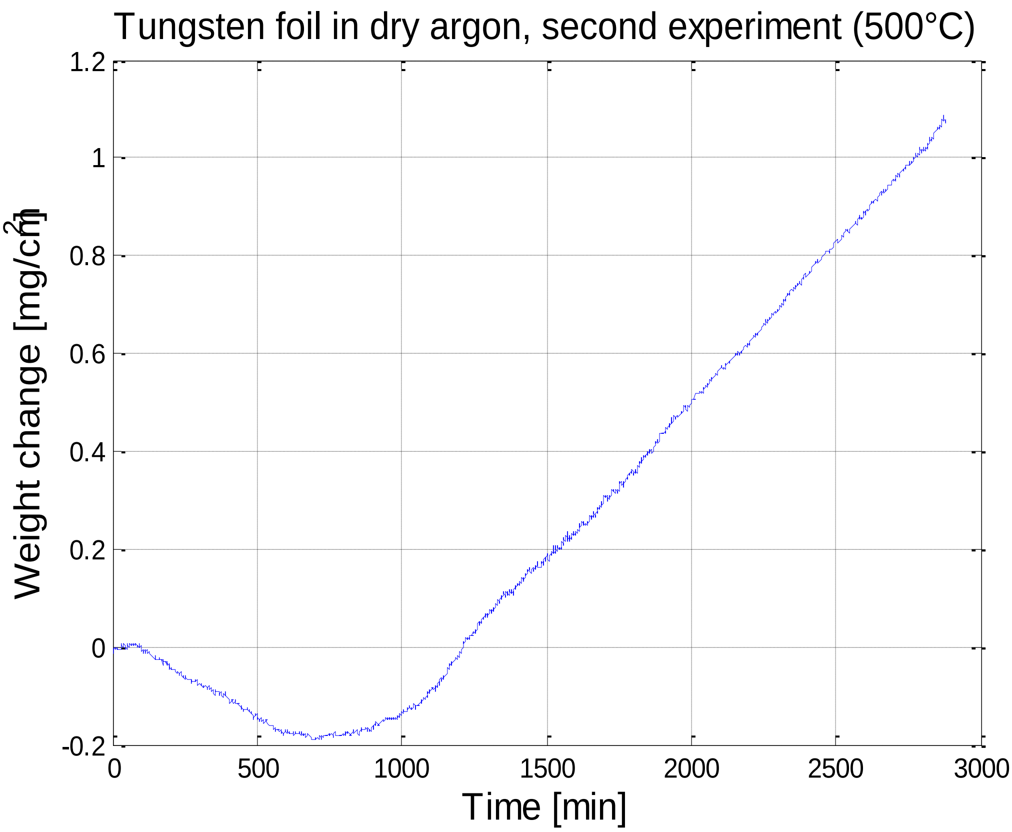
The results from the STA are shown below:



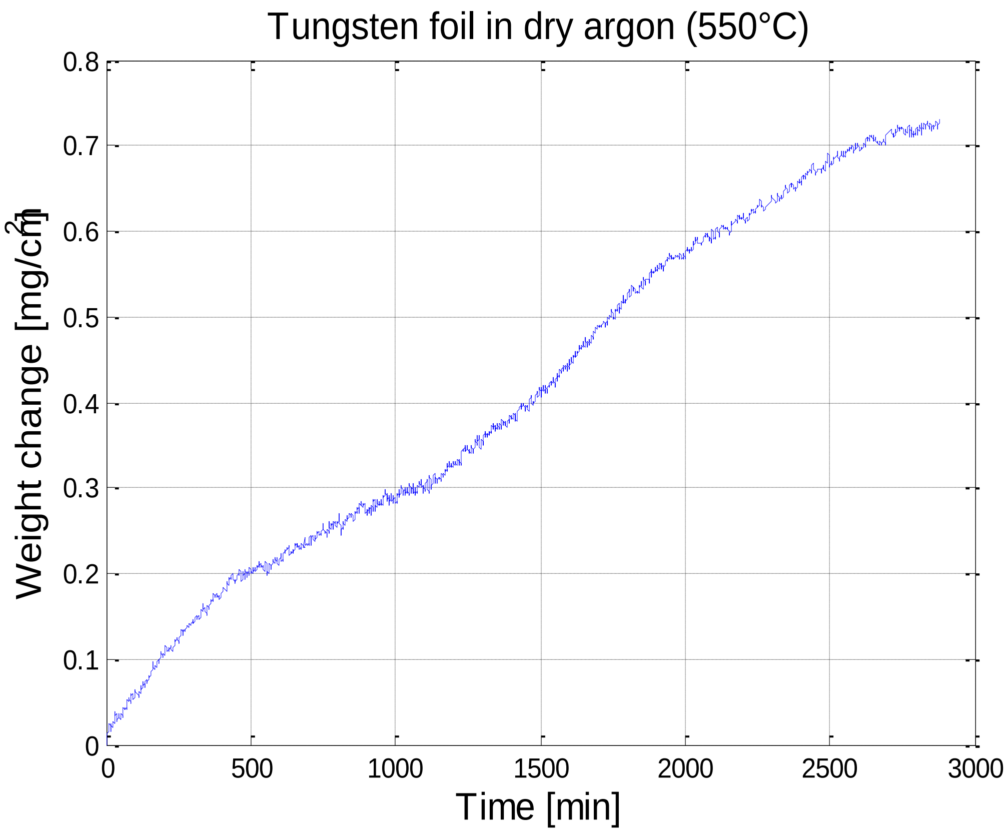


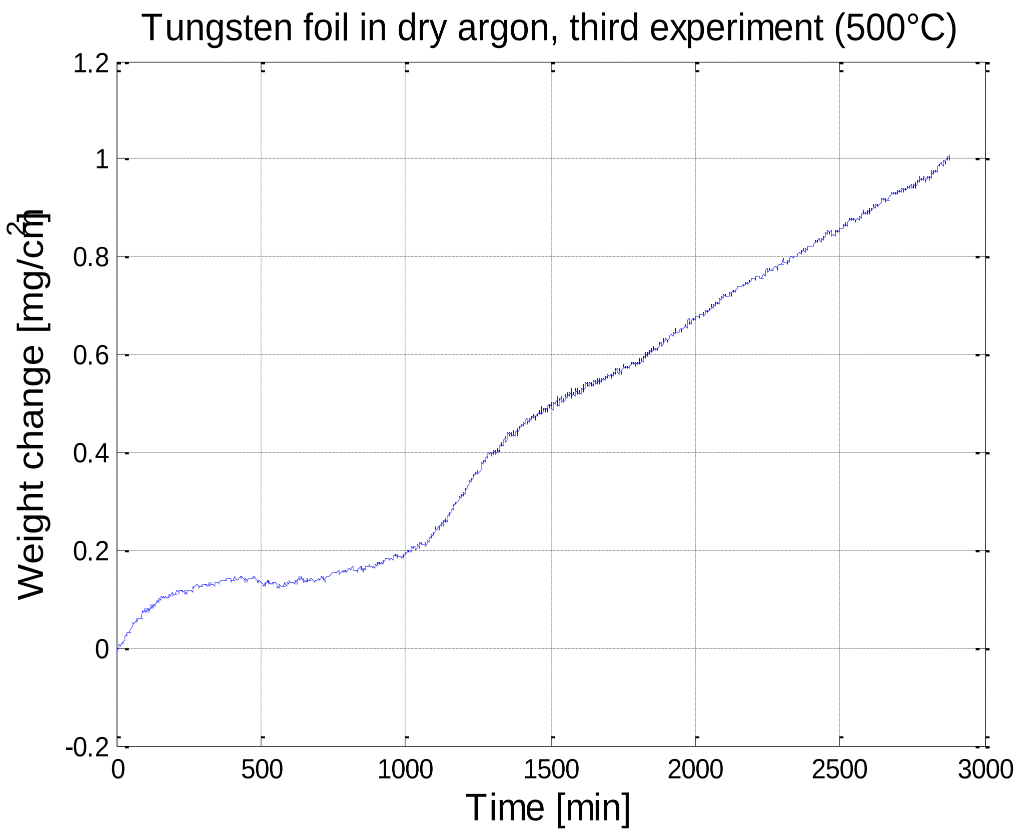

Tungsten foil in wet argon (500°C)
Weight change [mg/cm2]
Time [min]
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
500
1000
1500
2000
2500
3000

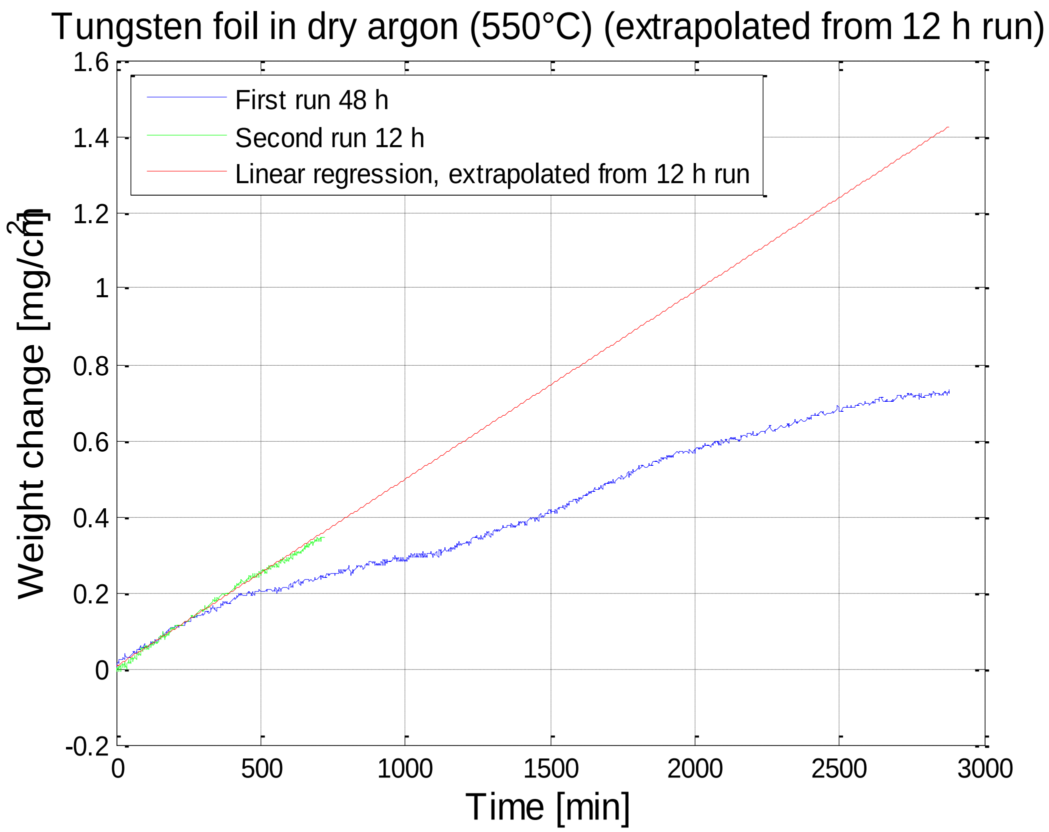

Tungsten foil in wet argon (550°C)
Weight change [mg/cm2]
Time [min]
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
500
1000
1500
2000
2500
3000



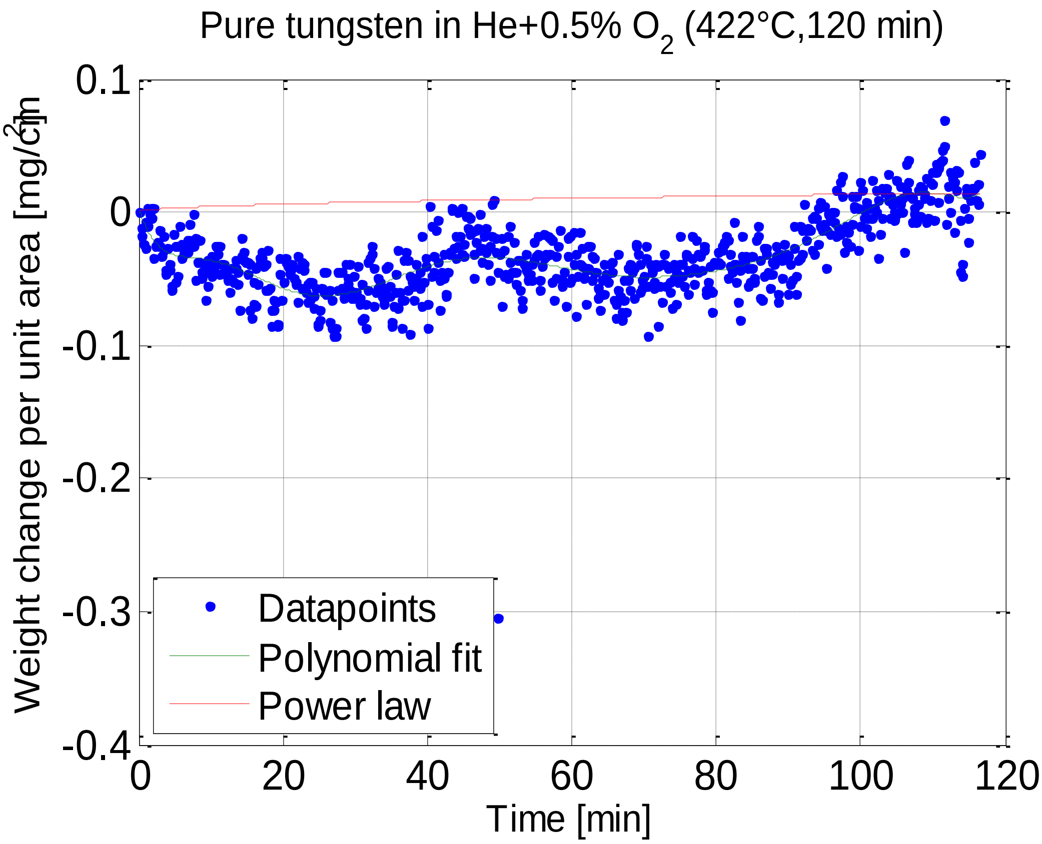
Tungsten foil in dry argon, second experiment (500°C)
Weight change [mg/cm2]
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
500
1000
1500
2000
2500
3000
Time [min]

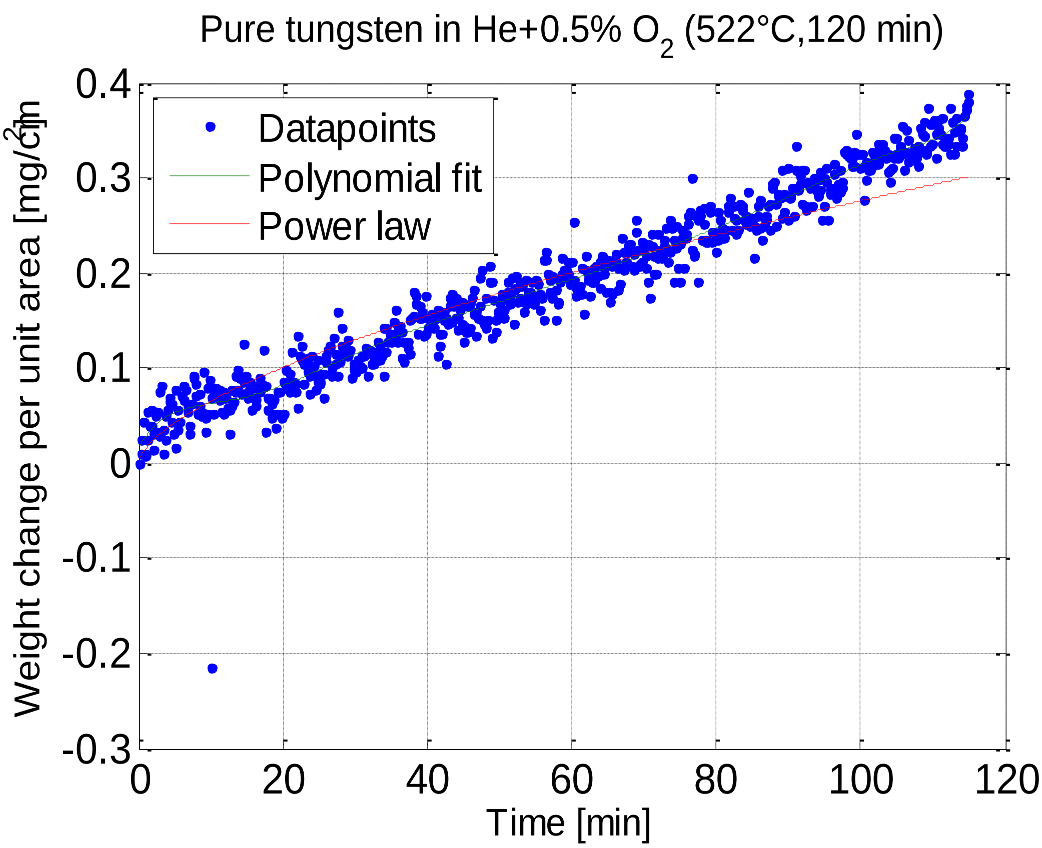

Tungsten foil in dry argon (550°C)
Weight change [mg/cm2]
Time [min]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
2500
3000

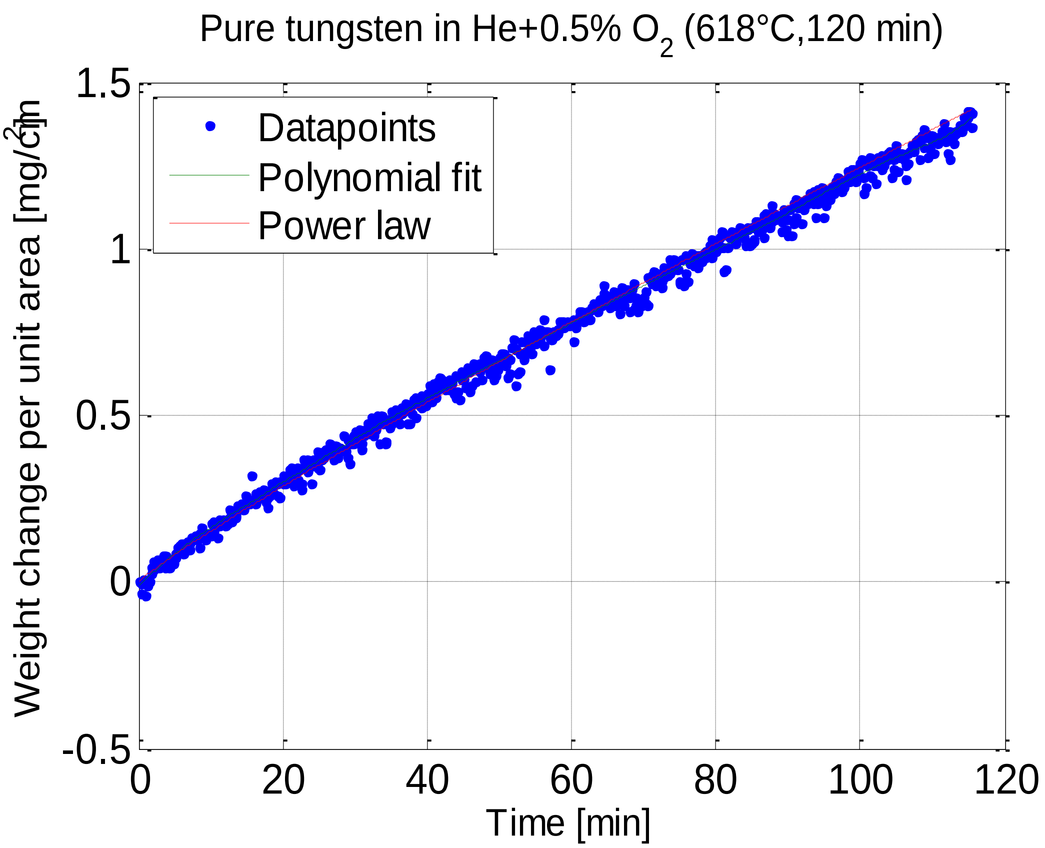

Tungsten foil in dry argon, third experiment (500°C)
Weight change [mg/cm2]
Time [min]
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
500
1000
1500
2000
2500
3000

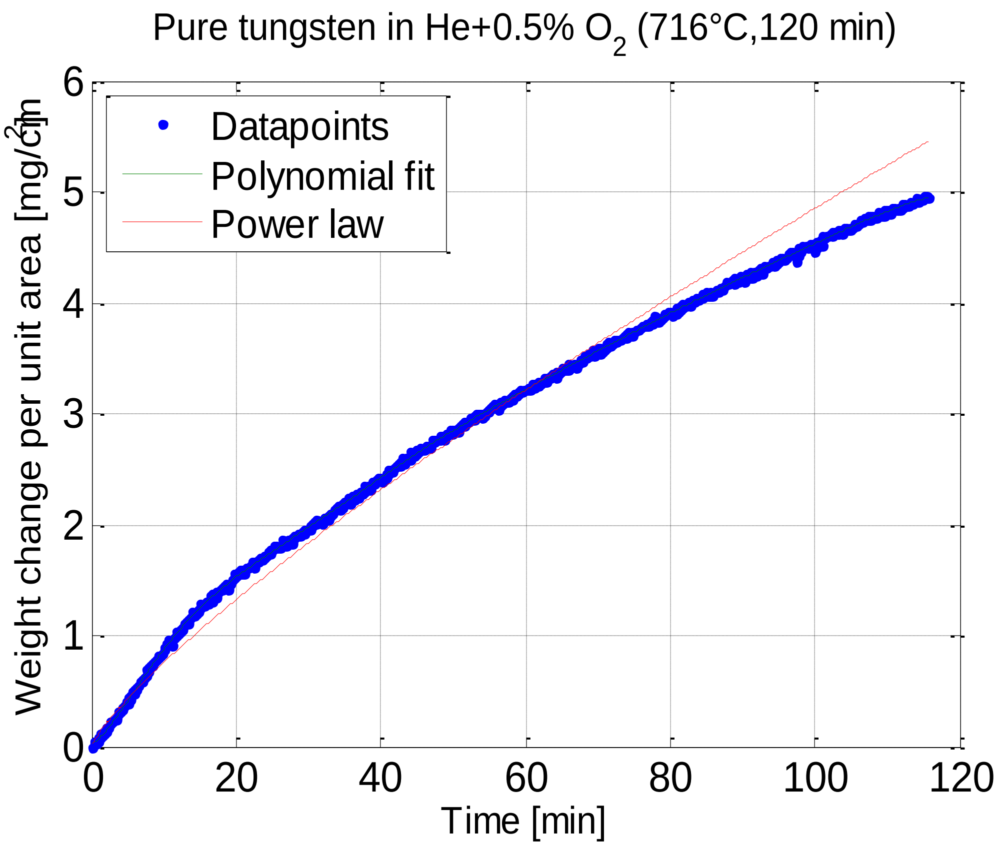

Tungsten foil in dry argon (550°C) (extrapolated from 12 h run)
First run 48 h
Second run 12 h
Linear regression, extrapolated from 12 h run
Weight change [mg/cm2]
Time [min]
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
500
1000
1500
2000
2500
3000

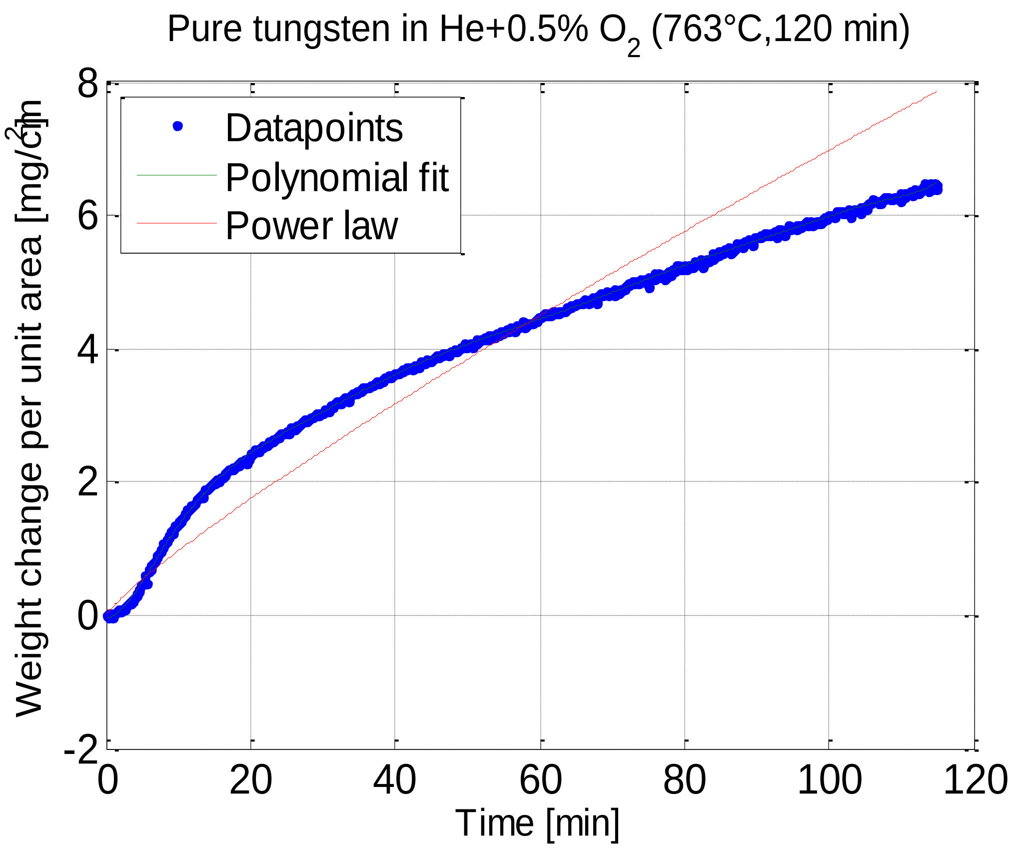
Figures and plots from the experiments in the TGA with Helium and 0.5% Oxygen are shown below:



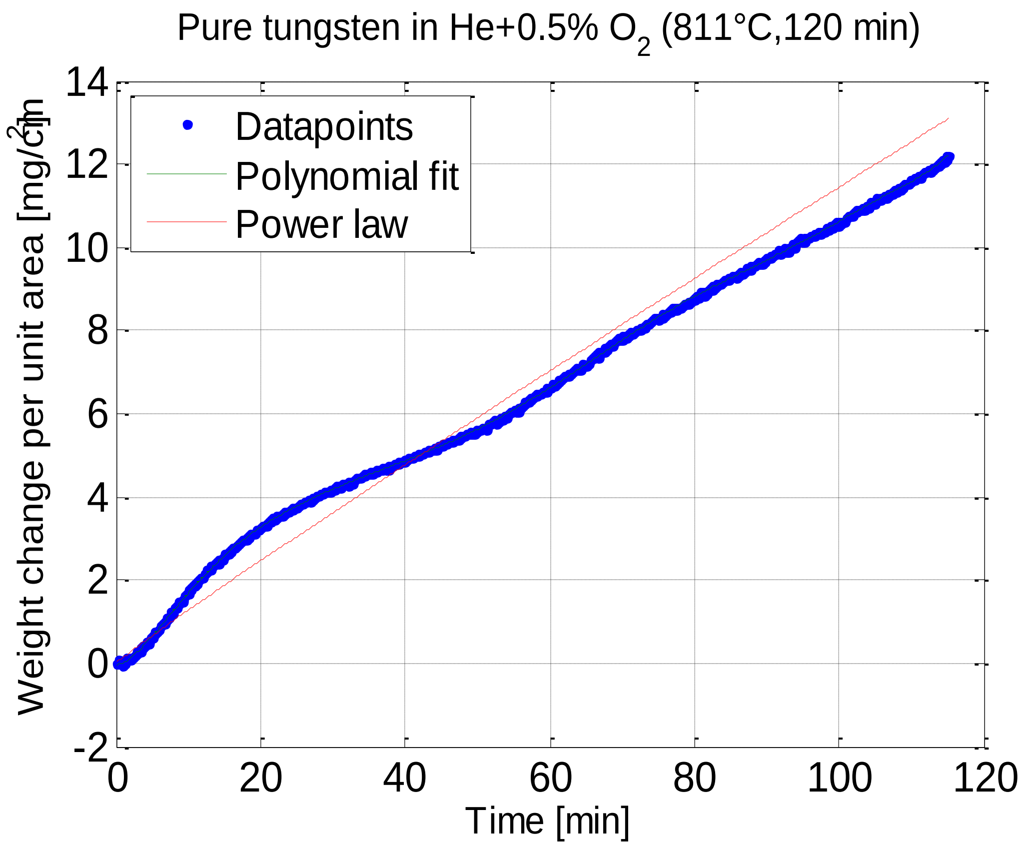



Pure tungsten in He+0.5% O_2 (618°C,120 min)
Datapoints
Polynomial fit
Power law
Weight change per unit area [mg/cm²]
Time [min]
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
120

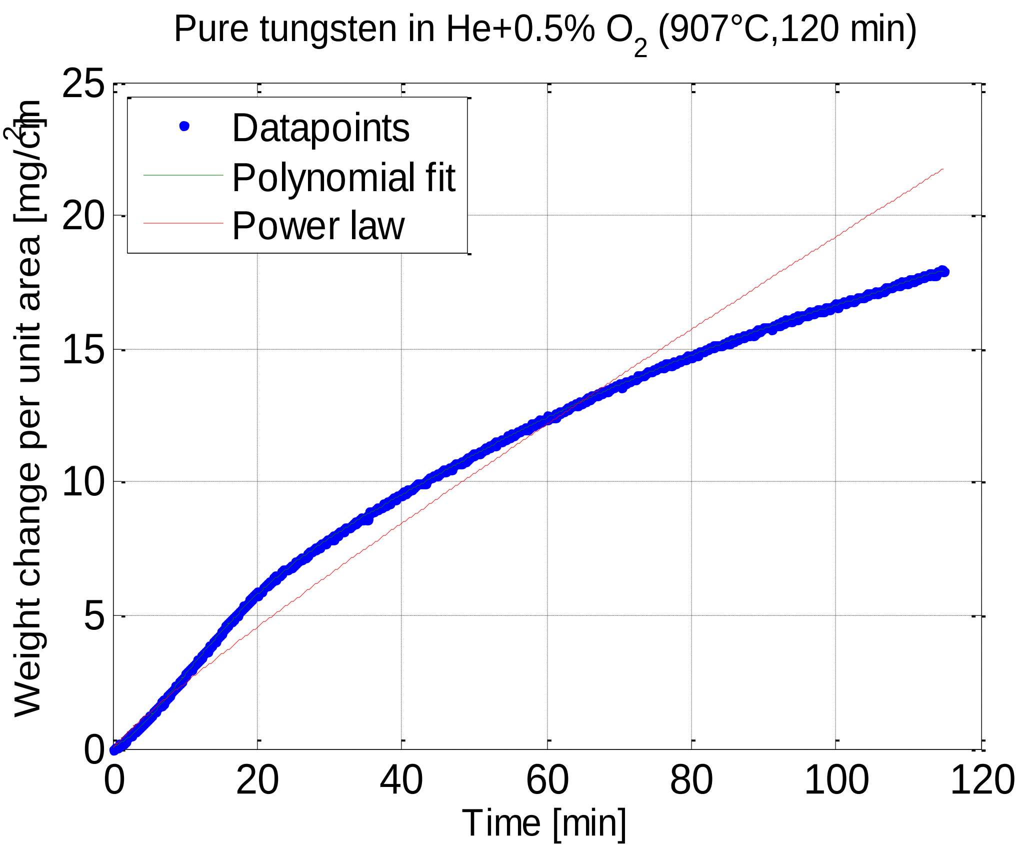

Pure tungsten in He+0.5% O_2 (716°C,120 min)
Datapoints
Polynomial fit
Power law
Weight change per unit area [mg/cm²]
Time [min]
6
5
4
3
2
1
0
0
20
40
60
80
100
120



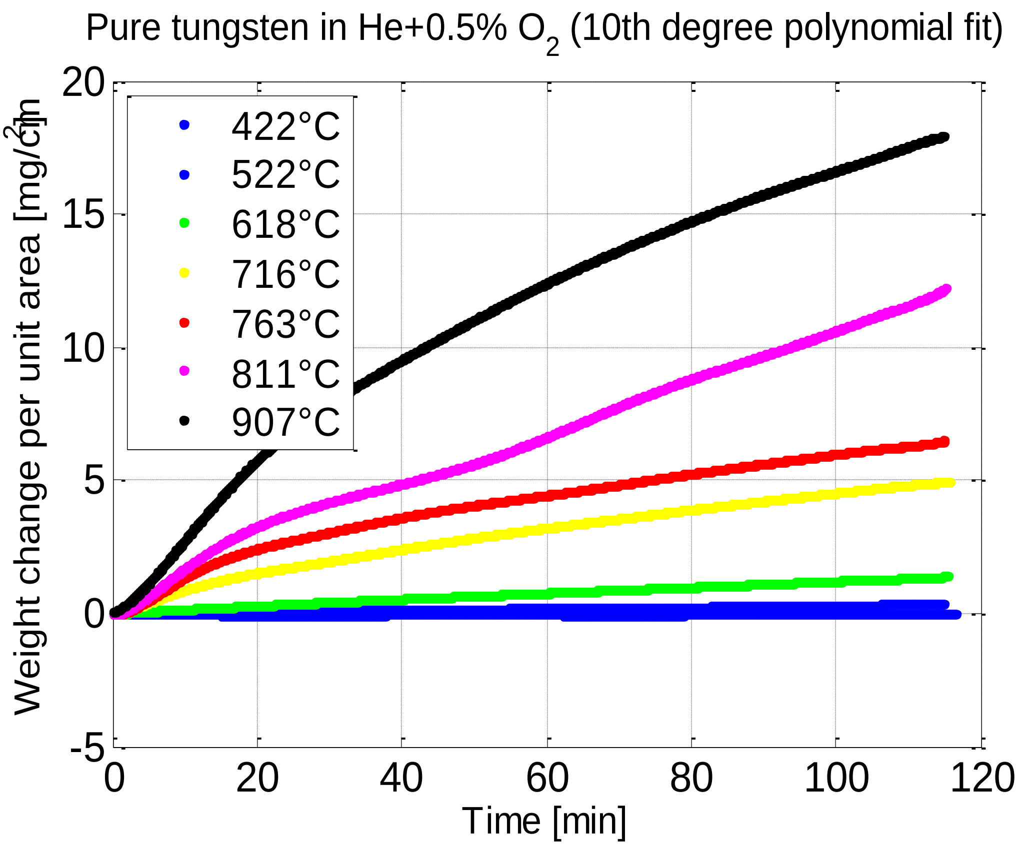
Pure tungsten in He+0.5% O2 (763°C,120 min)
Datapoints
Polynomial fit
Power law
Weight change per unit area [mg/cm2]
Time [min]



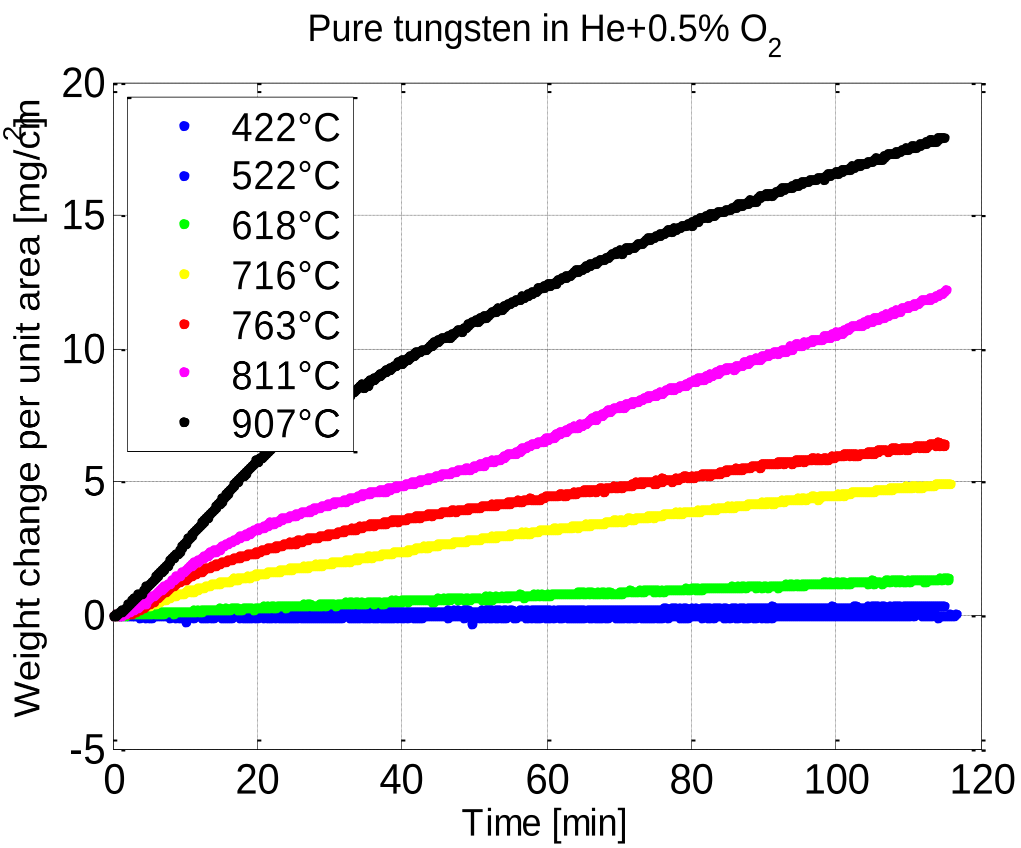
Pure tungsten in He+0.5% O2 (811°C,120 min)
Datapoints
Polynomial fit
Power law
Weight change per unit area [mg/cm2]
Time [min]

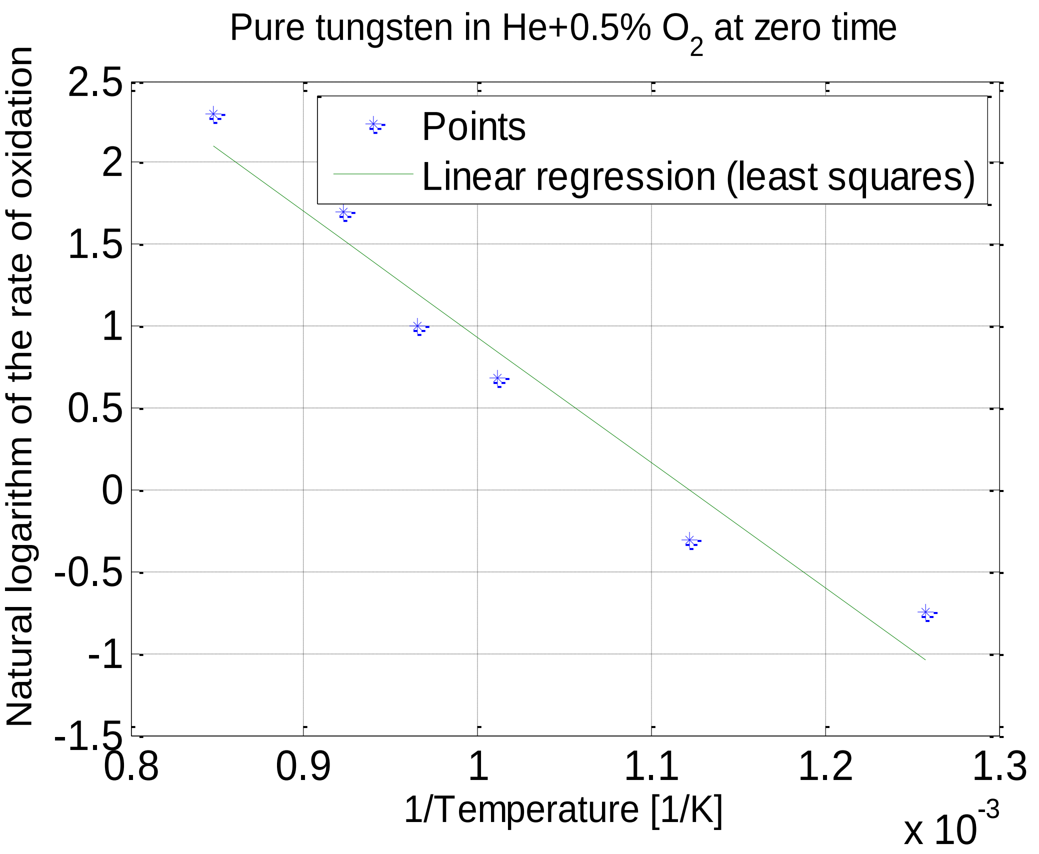


Pure tungsten in He+0.5% O2 (907°C,120 min)
Datapoints
Polynomial fit
Power law
Weight change per unit area [mg/cm2]
Time [min]

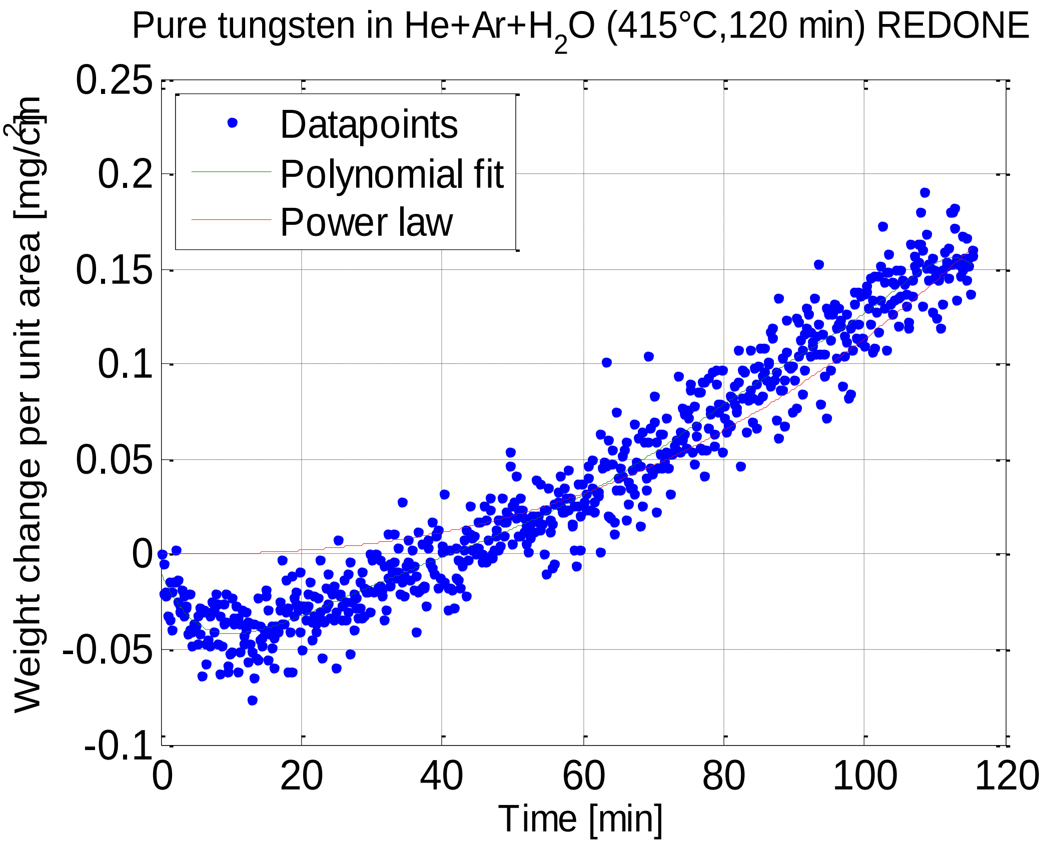


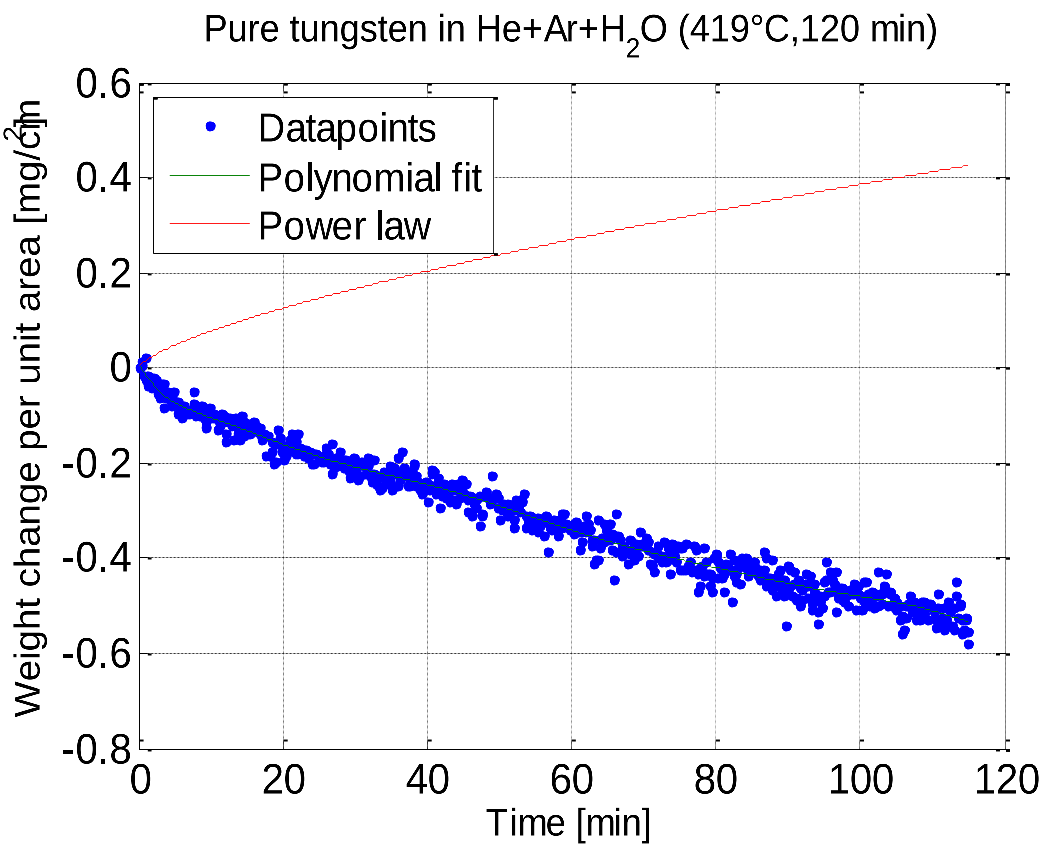
Pure tungsten in He+0.5% O2 (10th degree polynomial fit)
422°C
522°C
618°C
716°C
763°C
811°C
907°C
Weight change per unit area [mg/cm2]
Time [min]

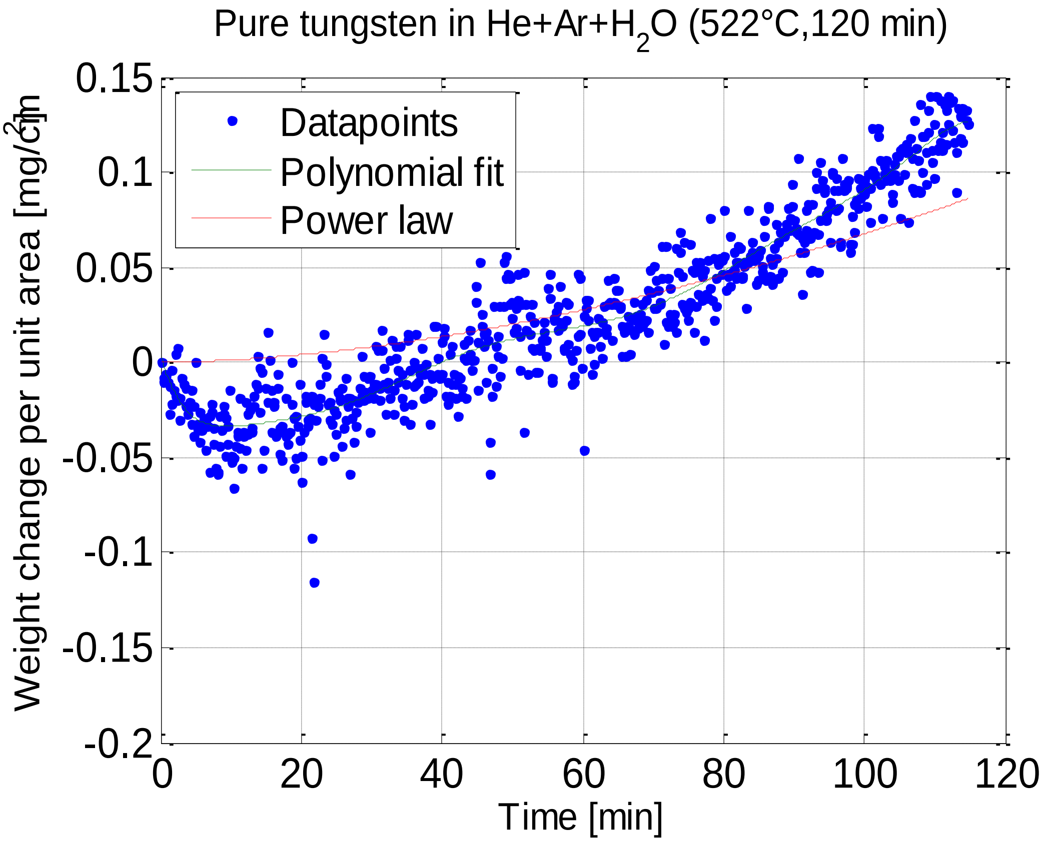

Pure tungsten in He+0.5% O2
Weight change per unit area [mg/cm2]
Time [min]
422°C
522°C
618°C
716°C
763°C
811°C
907°C
20
15
10
5
0
-5
0
20
40
60
80
100
120

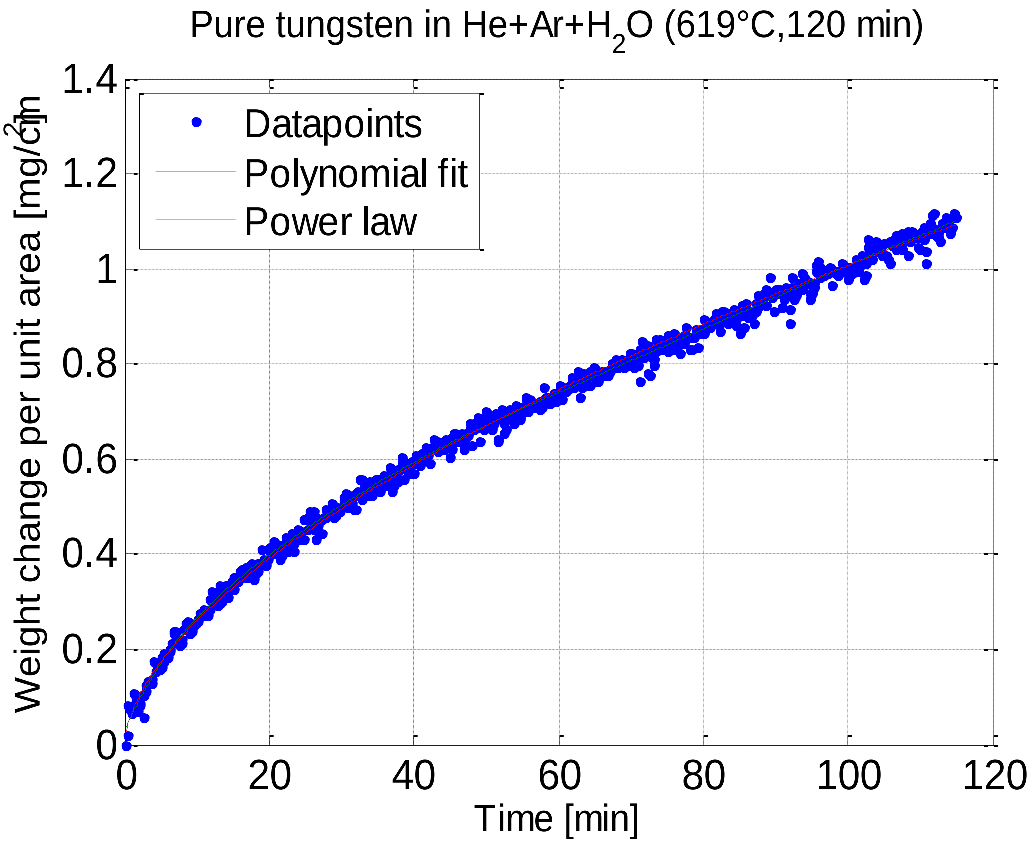

Pure tungsten in He+0.5% O2 at zero time
Natural logarithm of the rate of oxidation
1/Temperature [1/K]
x 10-3
Points
Linear regression (least squares)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0.8
0.9
1
1.1
1.2
1.3

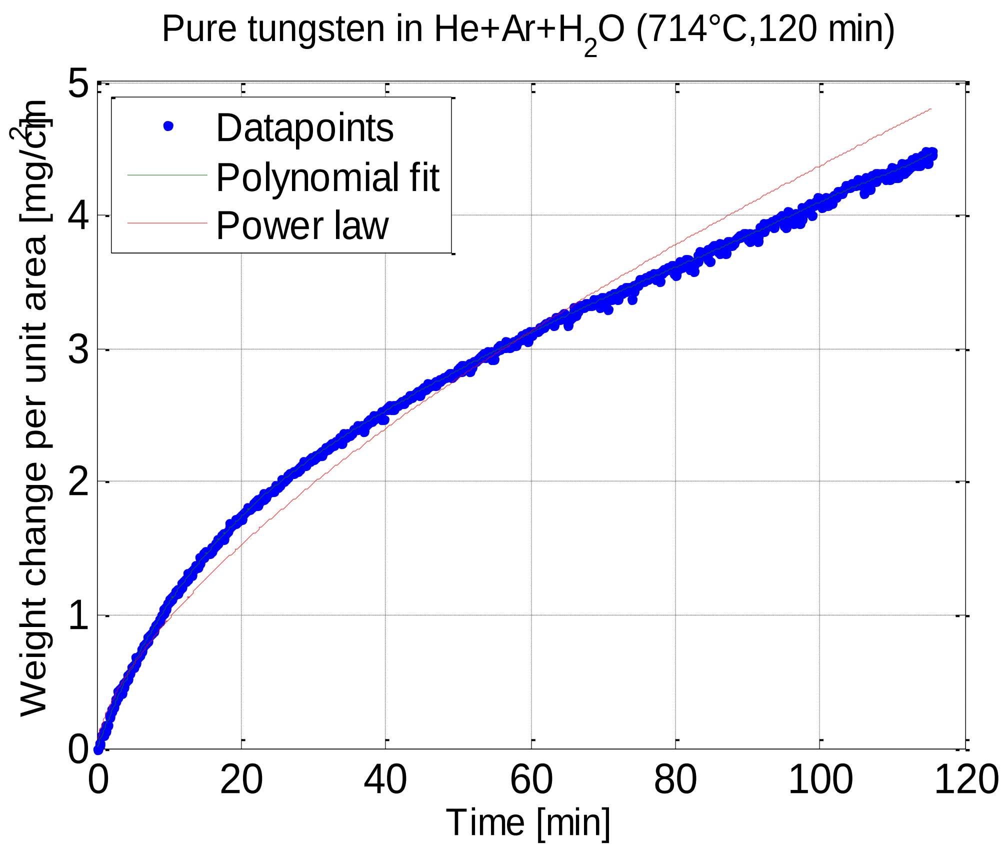
Figures and plots from the experiments in the TGA with Helium, Argon and water vapour are shown below:

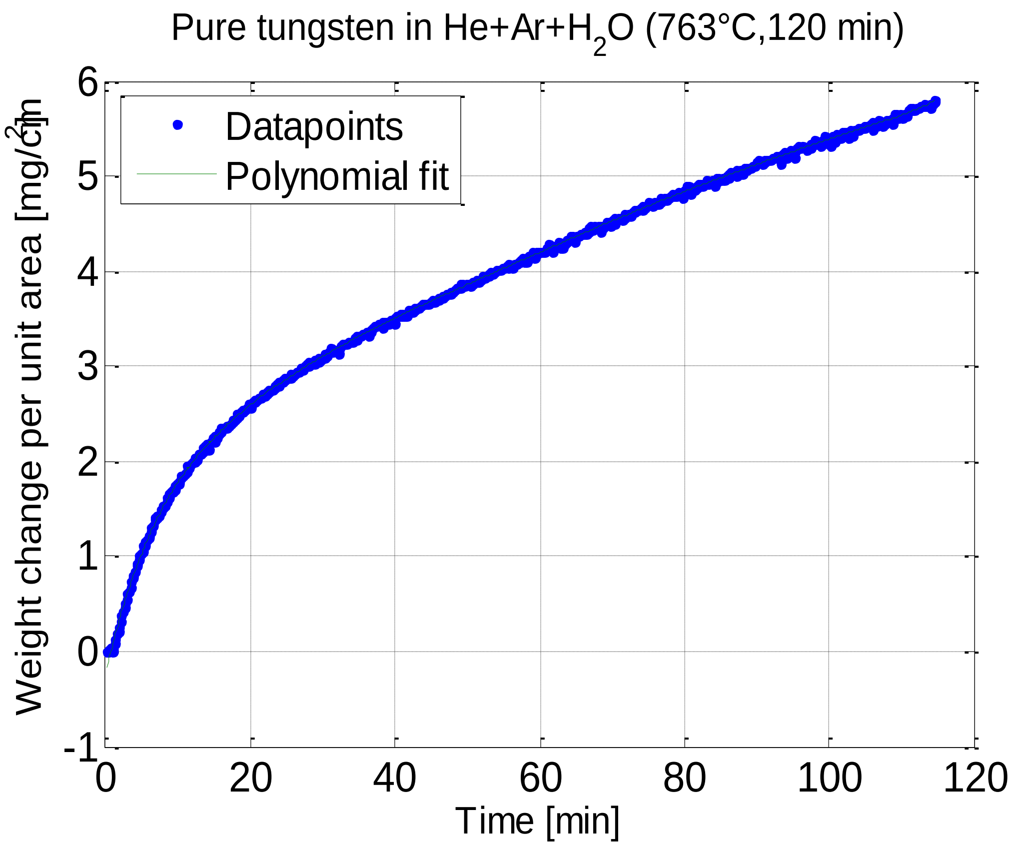


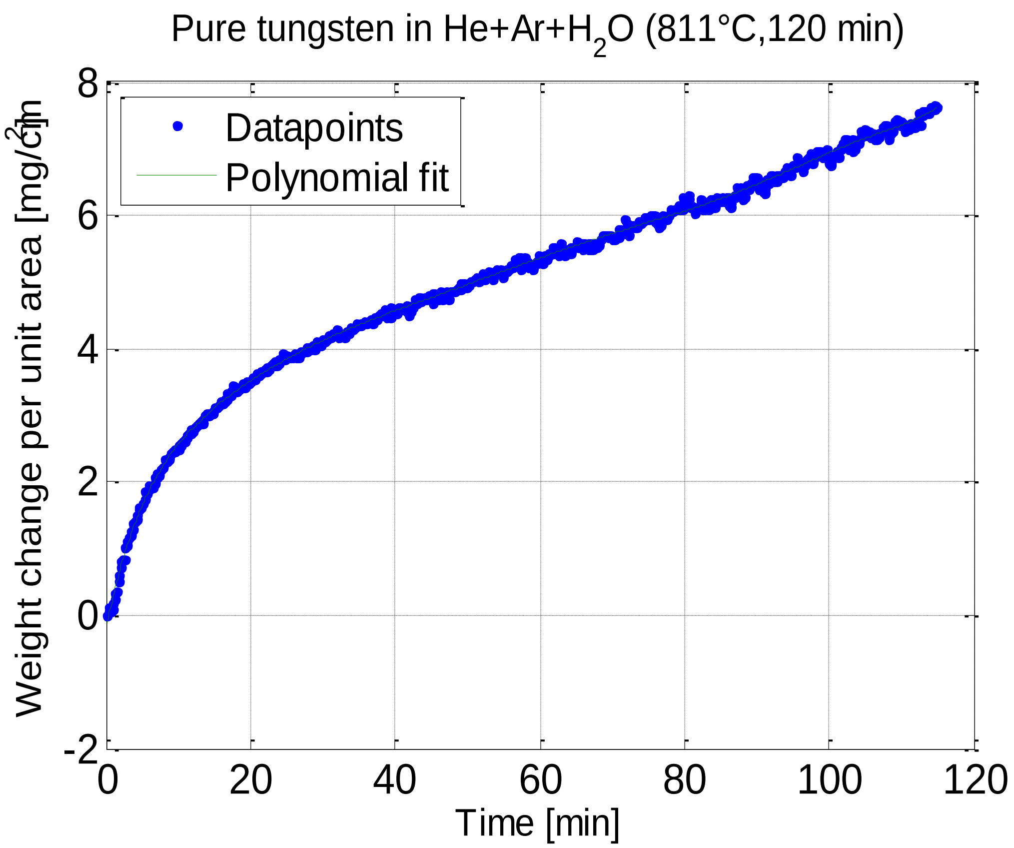



Pure tungsten in He+Ar+H2O (522°C,120 min)
Datapoints
Polynomial fit
Power law
Weight change per unit area [mg/cm2]
Time [min]
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
20
40
60
80
100
120

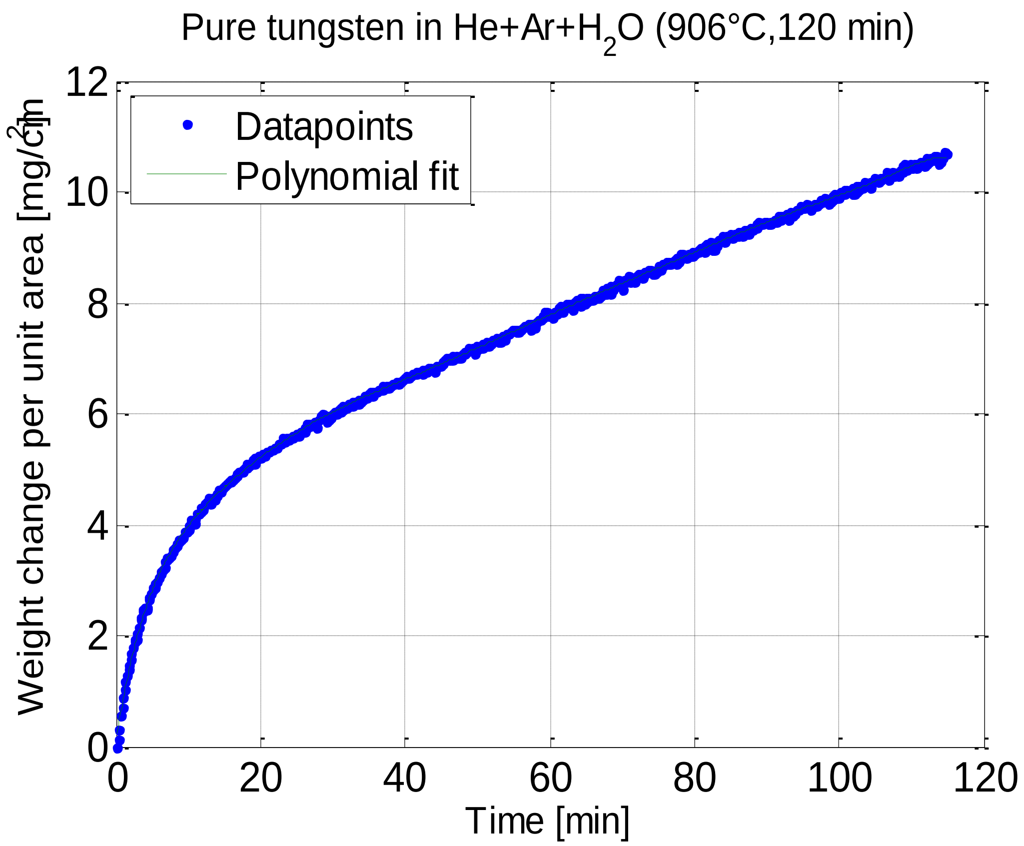

Pure tungsten in He+Ar+H2O (619°C,120 min)
Datapoints
Polynomial fit
Power law
Weight change per unit area [mg/cm2]
Time [min]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120


Pure tungsten in He+Ar+H2O (714°C,120 min)
Datapoints
Polynomial fit
Power law
Weight change per unit area [mg/cm2]
Time [min]
0
1
2
3
4
5
0
20
40
60
80
100
120

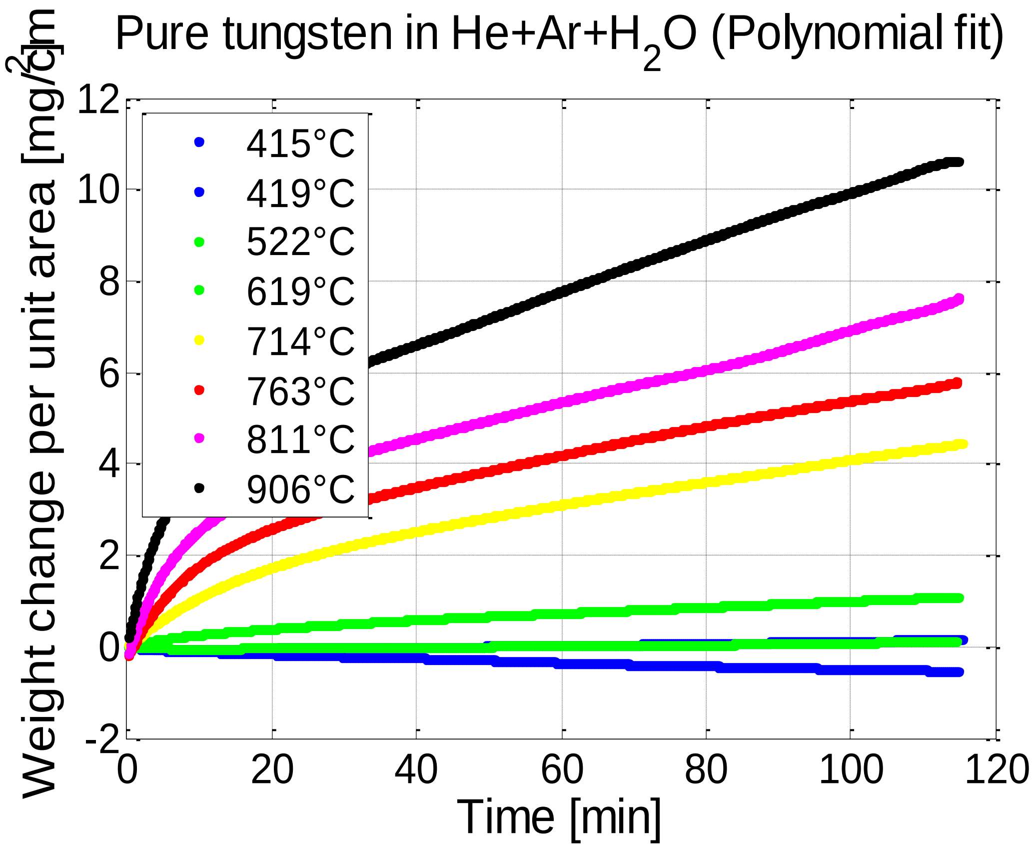

Pure tungsten in He+Ar+H2O (763°C,120 min)
Datapoints
Polynomial fit
Weight change per unit area [mg/cm2]
Time [min]
-1
0
1
2
3
4
5
6
0
20
40
60
80
100
120

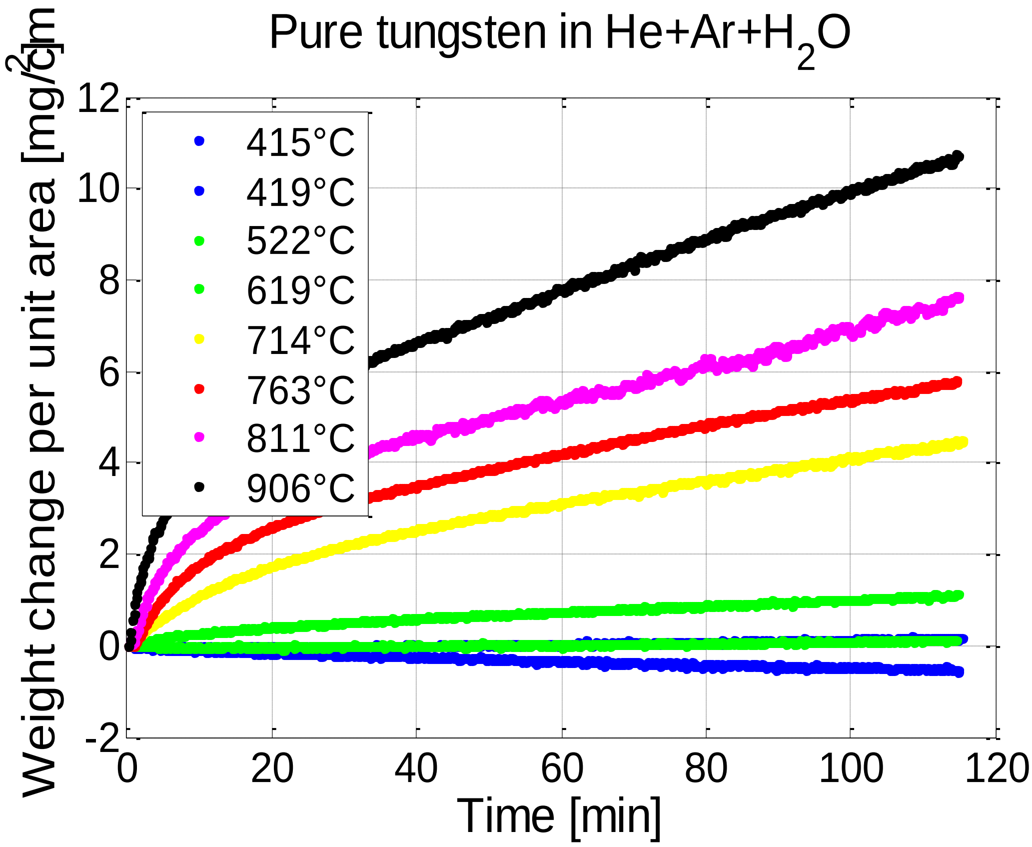


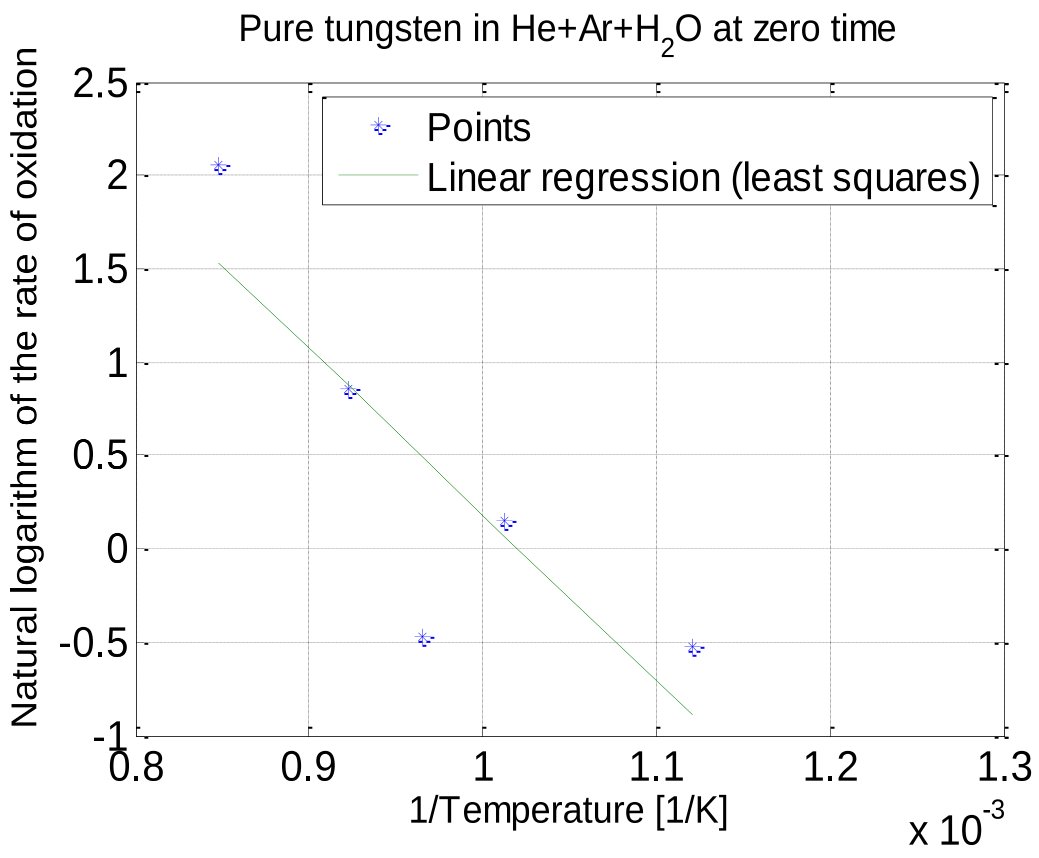
Pure tungsten in He+Ar+H2O (811°C,120 min)
Datapoints
Polynomial fit
Weight change per unit area [mg/cm2]
Time [min]



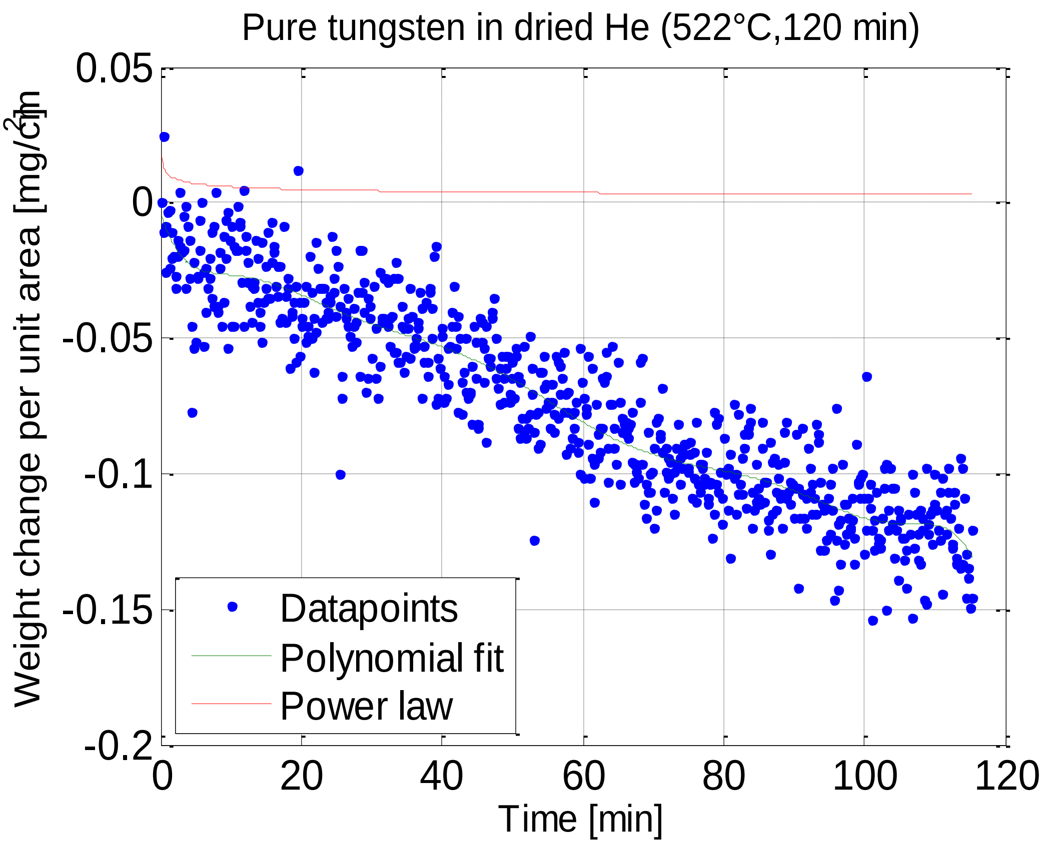
Pure tungsten in He+Ar+H2O (906°C,120 min)
Datapoints
Polynomial fit
Weight change per unit area [mg/cm2]
Time [min]

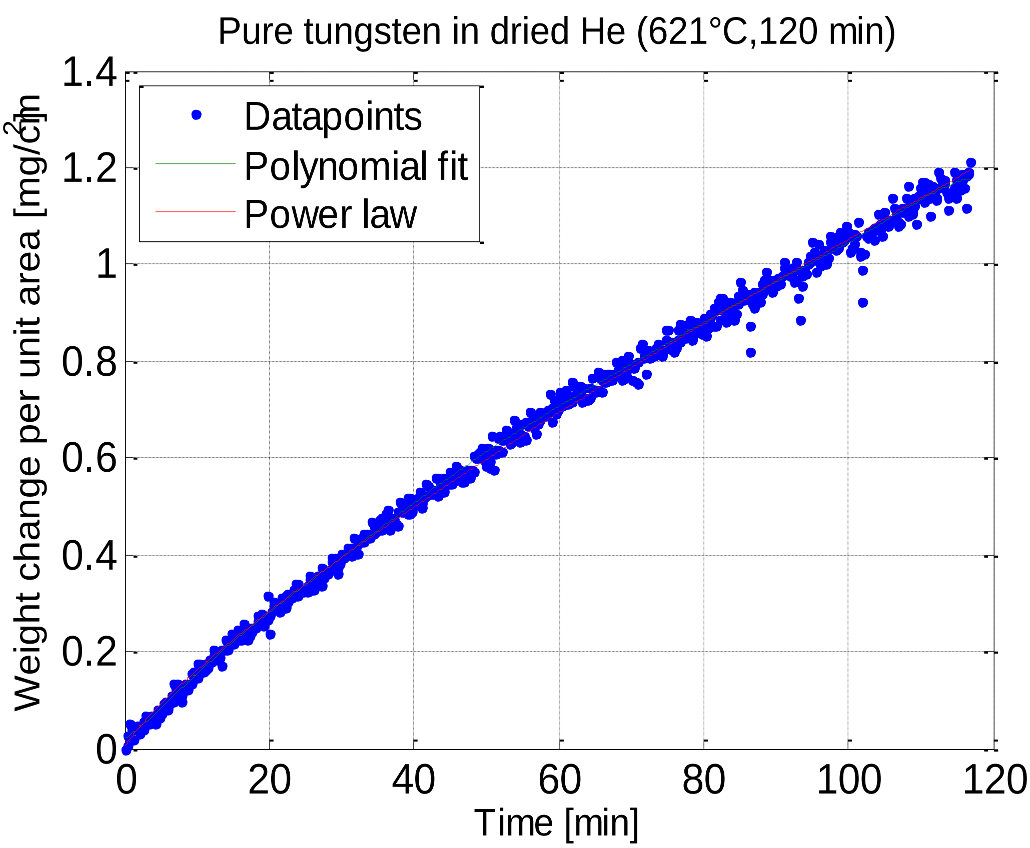

Pure tungsten in He+Ar+H2O (Polynomial fit)
Weight change per unit area [mg/cm2]
Time [min]
415°C
419°C
522°C
619°C
714°C
763°C
811°C
906°C
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120

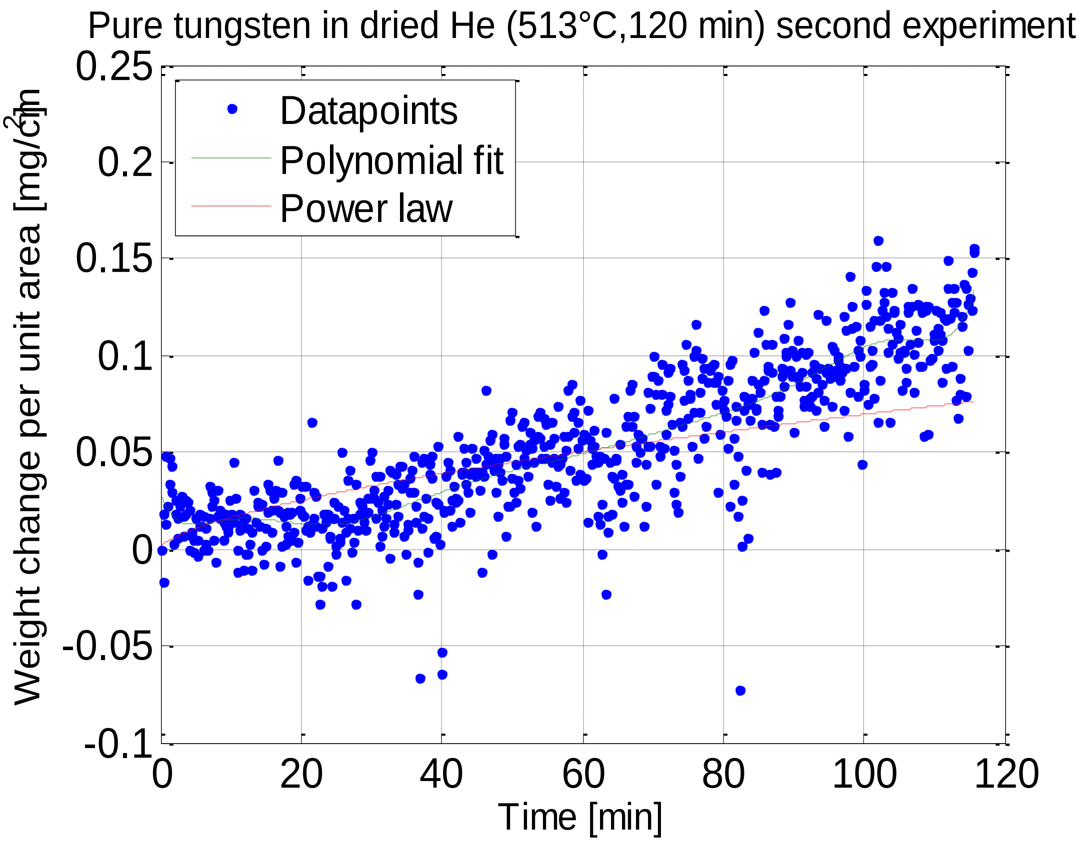

Pure tungsten in He+Ar+H2O
Weight change per unit area [mg/cm2]
Time [min]
415°C
419°C
522°C
619°C
714°C
763°C
811°C
906°C
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120

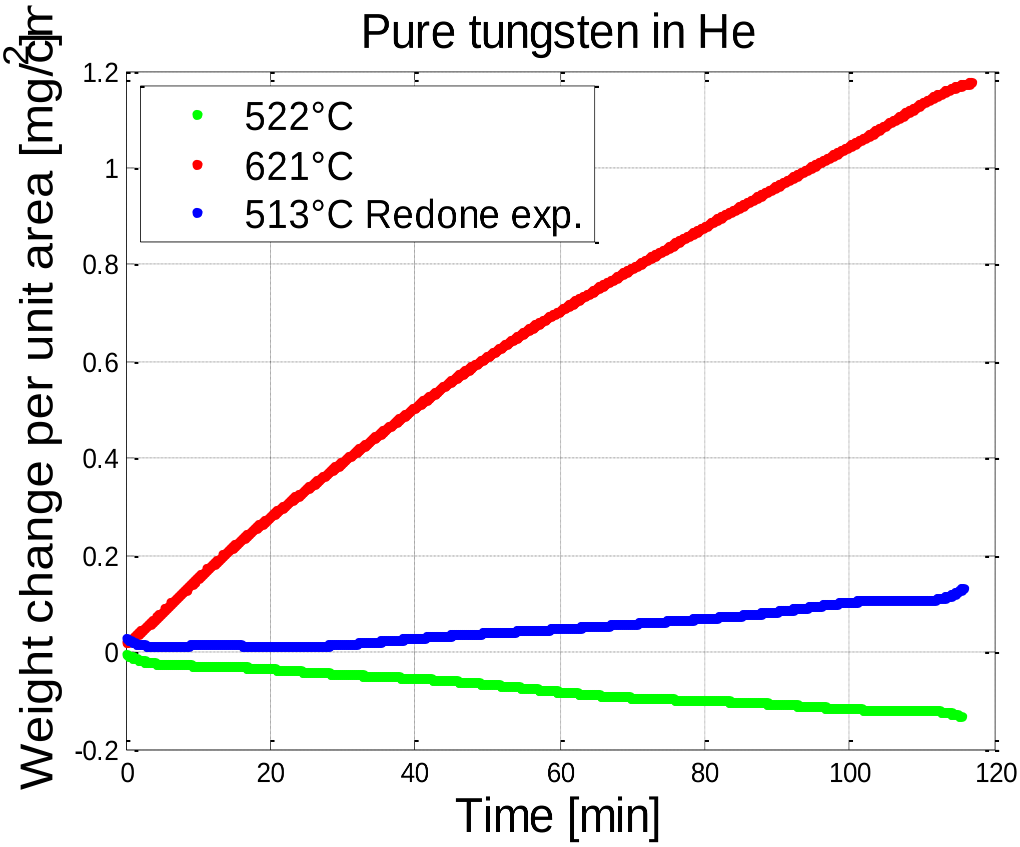

Pure tungsten in He+Ar+H2O at zero time
Natural logarithm of the rate of oxidation
2.5
2
1.5
1
0.5
0
-0.5
-1
0.8
0.9
1
1.1
1.2
1.3
1/Temperature [1/K]
x 10-3
Points
Linear regression (least squares)

The results from the experiments in the TGA with pure Helium are shown below:






Pure tungsten in dried He (513°C,120 min) second experiment
Datapoints
Polynomial fit
Power law
Weight change per unit area [mg/cm2]
Time [min]
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
0
20
40
60
80
100
120


Pure tungsten in He
522°C
621°C
513°C Redone exp.
Weight change per unit area [mg/cm2]
Time [min]
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
20
40
60
80
100
120

APPENDIX 4

The coefficients from the tenth degree polynomials from the TGA experiments with Helium and 0.5 % Oxygen are shown below:

poly400 =

Columns 1 through 4

0.000000000000000 -0.000000000000002 0.000000000000641 -0.000000000093154

Columns 5 through 8

0.000000008248505 -0.000000455803529 0.000015454404981 -0.000304738517122

Columns 9 through 11

0.003209807774624 -0.017221085608417 0.003462231298863

poly500 =

Columns 1 through 4

0.000000000000000 0.000000000000000 -0.000000000000026 0.000000000007618

Columns 5 through 8

-0.000000001067788 0.000000085781821 -0.000004117640135 0.000115225073013

Columns 9 through 11

-0.001714165896465 0.013674312335765 0.015521456987834

poly600 =

Columns 1 through 4

0.000000000000000 -0.000000000000001 0.000000000000263 -0.000000000031133

Columns 5 through 8

0.000000002126862 -0.000000081945397 0.000001482711200 0.000001816026378

Columns 9 through 11

-0.000550566887613 0.022023874757551 -0.014745483564188

```
poly700 =

  Columns 1 through 4

   0.000000000000000  -0.000000000000006   0.000000000001605  -0.000000000251644

  Columns 5 through 8

   0.000000024221512  -0.000001469127609   0.000055239589440  -0.001202154202830

  Columns 9 through 11

   0.012299313224762   0.039873496897227   0.021327646229993


poly750 =

  Columns 1 through 4

   0.000000000000000  -0.000000000000023   0.000000000005947  -0.000000000877038

  Columns 5 through 8

   0.000000079547213  -0.000004565434435   0.000163981315020  -0.003481823438667

  Columns 9 through 11

   0.036835654771541  -0.007483932260129  -0.039843087361299


poly800 =

  Columns 1 through 4

   0.000000000000000  -0.000000000000023   0.000000000005662  -0.000000000783314

  Columns 5 through 8

   0.000000066962403  -0.000003687461693   0.000131720023548  -0.002920377668125

  Columns 9 through 11

   0.033493067227702   0.029247016135304  -0.045681901662860
```

poly900 =

Columns 1 through 4

-0.000000000000000   0.000000000000009 -0.000000000001951   0.000000000218288

Columns 5 through 8

-0.000000011907918   0.000000097317102   0.000024631441183 -0.001338774456003

Columns 9 through 11

0.025420533007739   0.128288950361051   0.015713990545563

The coefficients from the tenth degree polynomials from the TGA experiments with Helium, Argon and water vapour are shown below:

poly400_H2O =

Columns 1 through 4

0.000000000000000 -0.000000000000002   0.000000000000522 -0.000000000077004

Columns 5 through 8

0.000000006950420 -0.000000394811558   0.000014025336119 -0.000301342701224

Columns 9 through 11

0.003708035942093 -0.029172975031694   0.011334260706556

poly400_H2O_redo =

Columns 1 through 4

-0.000000000000000   0.000000000000000   0.000000000000004 -0.000000000001897

Columns 5 through 8

0.000000000279727 -0.000000022860228   0.000001168844373 -0.000038939790451

Columns 9 through 11

0.000828651376318 -0.008637143306413 -0.009104353777187

poly500_H2O =

Columns 1 through 4

0.000000000000000 -0.000000000000000   0.000000000000126 -0.000000000021177

Columns 5 through 8

0.000000002133800 -0.000000133700469   0.000005210634024 -0.000123816485753

Columns 9 through 11

0.001744696794751 -0.012909335772423   0.004025317600543 poly600_H2O =

Columns 1 through 4

0.000000000000000 -0.000000000000000   0.000000000000069 -0.000000000008151

Columns 5 through 8

0.000000000503279 -0.000000010298951 -0.000000625483022   0.000050085020826

Columns 9 through 11

-0.001554976317433   0.034956842599619   0.029077525417773

poly700_H2O =

Columns 1 through 4

0.000000000000000 -0.000000000000001   0.000000000000333 -0.000000000040574

Columns 5 through 8

0.000000002913425 -0.000000120869461   0.000002202566571   0.000042100276668

Columns 9 through 11

-0.003905547187558   0.143215826902993 -0.009548466288166

poly750_H2O =

Columns 1 through 4

0.000000000000000 -0.000000000000001   0.000000000000193 -0.000000000011719

Columns 5 through 8

-0.000000000861843   0.000000201515310 -0.000015787451256   0.000687412151370

Columns 9 through 11

-0.018197959736151   0.326841343972724 -0.217491228145541 poly800_H2O =

Columns 1 through 4

-0.000000000000000   0.000000000000003 -0.000000000001185   0.000000000220323

Columns 5 through 8

-0.000000024554809   0.000001723927184 -0.000077610554561   0.002242592605118

Columns 9 through 11

-0.041502504966423   0.530001486251244 -0.208734325861153

poly900_H2O =

Columns 1 through 4

-0.000000000000000   0.000000000000024 -0.000000000006403   0.000000000953466

Columns 5 through 8

-0.000000088286221   0.000005272193995 -0.000204310609292   0.005077563717323

Columns 9 through 11

-0.079561460207568   0.835944911637526   0.091441388021696

The coefficients from the tenth degree polynomials from the TGA experiments with pure Helium are shown below:

poly500_He =

Columns 1 through 4

0.000000000000000	-0.000000000000000	0.000000000000084	-0.000000000015372

Columns 5 through 8

0.000000001640393	-0.000000106672579	0.000004237175437	-0.000099594252532

Columns 9 through 11

0.001280672670448	-0.008505936776870	-0.003383773900601

poly500_He_2 =

Columns 1 through 4

0.000000000000000	-0.000000000000002	0.000000000000440	-0.000000000060774

Columns 5 through 8

0.000000005139262	-0.000000273412844	0.000009040063355	-0.000176807457852

Columns 9 through 11

0.001871815546675	-0.009147679706399	0.028763824410385

poly600_He =

Columns 1 through 4

0.000000000000000	-0.000000000000000	0.000000000000044	-0.000000000009458

Columns 5 through 8

0.000000001122941	-0.000000078744873	0.000003278028496	-0.000077219946957

Columns 9 through 11

0.000869107799517	0.009900038537837	0.019006170981848

APPENDIX 5

Raw data values from the TGA experiment with Helium and 0.5 % Oxygen are shown below:

400 O2	500 O2	600 O2	700 O2	750 O2	800 O2	900 O2
3.26004	9.54453	3.25713	3.25711	3.25701	3.25656	3.25737
3.26007	9.54467	3.25708	3.25711	3.25701	3.25719	3.25745
3.26007	9.54467	3.25718	3.25701	3.25704	3.25718	3.2574
3.2601	9.54458	3.25714	3.25706	3.25698	3.25729	3.25739
3.26014	9.54462	3.25711	3.25704	3.25695	3.25719	3.2573
3.26013	9.54455	3.25712	3.25707	3.25703	3.25715	3.25741
3.26013	9.54454	3.25705	3.25698	3.25701	3.25719	3.25732
3.26006	9.54461	3.25715	3.25707	3.25704	3.25714	3.25743
3.26	9.54455	3.25707	3.25707	3.25699	3.25719	3.25751
3.25995	9.54457	3.25707	3.25706	3.25704	3.25714	3.25736
3.26	9.54465	3.25698	3.25714	3.25702	3.25709	3.25734
3.26003	9.54456	3.2571	3.25714	3.2569	-0.00001	3.2575
3.26006	9.54463	3.25704	3.25712	3.25692	-0.00005	3.2575
3.26006	9.5446	3.25695	3.25713	3.25695	0	3.25751
3.26007	9.54467	3.25692	3.25713	3.2569	-0.37363	3.2573
3.26017	9.5446	3.25696	3.2571	3.25704	5.68434	0.00158
3.26008	9.54471	3.25702	3.25699	3.25692	6.89828	0.00337
3.26005	9.5446	3.25698	3.25708	3.25693	27.84445	0.00021
3.26011	9.54469	3.25705	3.25706	3.25703	27.80748	6.21524
3.26009	9.54455	3.25705	3.25703	3.25705	27.80764	6.21567
3.26009	9.54454	3.25702	3.25703	3.25693	27.80753	6.21611
3.25993	9.54456	3.25704	3.25704	3.25699	27.80763	6.21635
3.26011	9.54468	3.25706	3.25695	3.257	27.80756	6.21648
3.26009	9.54451	3.25713	3.25711	3.25708	27.80773	6.21665
3.26005	9.54457	3.25698	3.25698	3.25686	27.80766	6.2165
3.25997	9.54471	0.11953	3.25702	3.25689	27.80766	6.21663
3.26003	9.54469	0.00009	3.25707	3.25699	27.80785	6.2168
3.25998	9.54467	0.00007	3.25704	3.25704	5.68213	6.21691
3.25987	9.54459	0	3.25689	3.25684	5.68403	6.38583
3.25996	9.54461	0	3.25693	3.25685	5.684	5.68414
3.25991	9.54466	5.80463	3.25695	3.25676	5.68394	5.68386
3.26005	9.5447	5.68414	3.25692	3.25679	5.684	5.68397
3.26006	9.54463	9.0363	3.25695	3.25686	5.68412	5.68345
3.26003	9.54472	9.64162	3.25692	3.25681	9.49499	5.68324
3.26015	9.54467	9.64156	3.25686	1.7105	9.495	5.683
3.26005	9.54459	9.64164	3.25692	0.00014	9.49497	5.68306
3.26004	9.54458	9.64173	3.25681	0	9.49502	5.68236
3.26007	9.5445	9.64175	3.25684	0	9.49505	5.68092
3.26002	9.54453	9.64183	3.25691	5.68441	9.49511	5.68169
3.25999	9.54459	9.64167	3.25735	5.70894	9.49507	5.68294
3.25998	9.54453	9.64182	9.54113	6.13513	9.49495	5.68324
3.25999	9.54453	9.64182	9.52383	9.46051	9.4948	5.68339

3.25998	9.54458	9.64171	9.52374	9.46328	5.68415	5.68179
3.26006	9.54472	9.64176	9.52364	9.46336	5.68389	5.68084
3.26007	9.54466	9.64176	9.52366	9.4634	5.68414	5.68143
3.26001	9.54467	9.64186	9.52353	9.46334	5.68416	5.68189
3.25996	9.54463	9.64173	9.5236	9.46335	5.68424	43.05586
3.26006	9.54464	5.68419	9.52356	9.46336	5.6841	42.9712
3.26002	9.54464	5.68411	9.52363	9.4634	5.68396	24.54991
3.26013	9.54473	5.68411	9.52364	9.46344	5.38365	24.54897
3.26009	9.54463	5.68414	9.52368	9.46332	31.59544	24.54939
3.2599	9.54469	5.68408	9.52375	9.4631	24.55033	24.54977
3.26001	9.54458	5.68405	9.52376	8.7687	24.55043	24.55185
3.25993	9.54455	5.68405	9.52368	5.68386	24.55032	24.5529
3.25991	9.54464	5.68411	9.52374	5.68401	24.55032	24.55306
3.25998	9.54466	5.68417	9.52367	5.6839	24.5504	24.55365
3.26003	9.54469	5.68413	9.52353	5.68399	24.55032	24.55393
3.25993	9.54459	27.98493	9.31511	5.68409	24.55035	24.55396
3.25995	9.54453	27.98477	3.25693	5.68405	24.55033	24.55441
3.25997	9.54459	27.9849	0.86523	5.68404	24.55042	24.55426
3.25993	9.54463	27.98481	-0.00017	5.68409	24.55039	24.55431
3.25995	9.54469	27.98496	0	5.68408	24.55047	24.55419
3.25996	9.54466	27.98482	0	5.68392	24.55045	24.5545
3.25996	9.54454	27.98489	3.64199	5.68399	24.5504	24.55451
3.25999	9.54465	27.98491	5.68413	5.68397	24.55028	24.55462
3.25999	9.54459	27.98489	5.68386	5.68411	24.55036	24.55429
3.25998	9.54467	27.98493	5.68401	5.68397	24.55031	24.55401
3.25996	9.54475	26.17846	5.6824	5.68577	24.55043	24.55391
3.26012	9.54459	5.68423	27.90675	27.77143	24.55033	24.55456
3.26005	9.54468	5.68392	27.92622	27.74462	24.55046	24.55469
3.25998	9.54455	5.68414	27.92621	27.74437	24.55042	24.55459
3.26008	9.54457	5.68406	27.92621	27.74434	24.55033	24.55474
3.26005	9.54462	5.68403	27.92628	27.7443	24.55034	24.55476
3.25991	9.54468	5.68401	27.9262	27.74427	24.55036	24.55468
3.25991	9.54473	5.684	27.92617	27.74443	24.55032	24.55465
3.25988	9.54458	5.71429	27.92615	27.74443	24.55032	24.55471
3.25994	9.54465	8.96053	27.92619	27.74439	24.5503	24.55485
3.25999	9.54452	24.728	27.92626	27.74463	24.55039	24.55477
3.26	9.54472	24.72791	27.92622	27.74441	24.55036	24.55477
3.25995	9.54455	24.7277	22.73063	27.74451	24.5506	24.55468
3.25993	9.54464	24.72789	5.68402	27.74432	24.5504	24.55486
3.25988	9.54456	24.72786	5.68397	27.74443	24.5503	24.55488
3.25984	9.54461	24.72791	5.68404	27.74454	24.55038	24.55472
3.25989	9.54465	24.72787	5.68398	27.74443	24.55035	24.55489
3.25996	9.54465	24.72768	5.60724	27.74442	24.55051	24.55477
3.2599	9.54452	24.72769	18.21356	27.74456	24.55045	24.55493
3.25994	9.54451	24.72787	24.66921	27.74448	24.55041	24.55494
3.25995	9.5447	24.72741	24.66917	27.74459	24.55048	24.55491

3.25996	9.54458	24.72756	24.66922	27.74443	24.55041	24.55483
3.26009	9.54464	24.72806	24.66921	27.74429	24.55047	24.55482
3.26012	9.54455	24.72792	24.66918	25.4996	24.55047	24.55482
3.25999	9.54465	24.72782	24.66915	5.68407	24.55041	24.55477
3.25993	9.54456	24.72797	24.66923	5.68382	24.5504	24.55491
3.25983	9.54467	24.72789	24.66923	5.68387	24.55039	24.55495
3.25996	9.54473	24.72792	24.66925	5.68396	24.55033	24.55477
3.25982	9.54461	24.72792	24.66932	5.68394	24.55042	24.55479
3.25982	9.54469	24.72791	24.66924	5.68393	24.55036	24.55494
3.25991	9.54467	24.728	24.66919	5.68392	24.55031	24.55494
3.25989	9.54462	24.72787	24.66929	5.64822	24.55048	24.55484
3.2599	9.54463	24.72793	24.66933	3.492	24.55049	24.5549
-0.21055	9.54468	24.72789	24.66923	40.39263	24.5504	24.55483
-0.00007	9.54475	24.72801	24.66925	24.4868	24.55046	24.55511
0	9.54465	24.728	24.66925	24.48729	24.55045	24.55491
0	9.54467	24.72792	24.66925	24.48722	24.55041	24.55494
0	9.54463	24.7279	24.66926	24.48702	24.55038	24.55499
3.56232	9.54466	24.72791	24.66928	24.48727	24.55043	24.55482
5.68247	9.54463	24.72789	24.6692	24.48736	24.55042	24.55485
2.26769	9.54453	24.7279	24.66931	24.48732	24.55044	24.55486
-0.08026	9.54461	24.72789	24.66916	24.48732	24.5505	24.55486
5.68285	9.54464	24.72803	24.66926	24.4873	24.55043	24.55484
5.68252	9.54461	24.72789	24.66925	24.48728	24.55042	24.5549
5.6826	9.54459	24.72787	24.66924	24.4962	24.55054	24.55493
5.68249	9.54454	24.72801	24.66928	24.48723	24.55052	24.5548
5.6827	9.54467	24.72787	24.66918	24.48726	24.55044	24.55488
10.6205	9.54467	24.72796	24.66925	24.48737	24.55044	24.55498
9.55681	9.54469	24.72787	24.66916	24.48731	24.55046	24.55496
9.55692	9.54464	24.72782	24.66935	24.48733	24.55053	24.555
9.55691	8.8102	24.72794	24.66925	24.48727	24.55048	24.55498
9.55704	0.00038	24.7279	24.66929	24.48719	24.55048	24.55501
9.55707	0.00032	24.72793	24.66929	24.48733	24.55046	24.55492
9.5569	0.00031	24.72792	24.6693	24.4874	24.5505	24.55493
9.557	0.00026	24.72802	24.66935	24.4874	24.55054	24.55494
9.55711	0.00027	24.72803	24.66928	24.48731	24.55052	24.55509
9.55692	3.25758	24.7281	24.66929	24.48721	24.55047	24.55503
9.55682	3.25767	24.72801	24.66936	24.48729	24.55053	24.5551
9.55694	3.25801	24.72816	24.66925	24.48718	24.5505	24.55495
9.55696	3.25758	24.72793	24.66927	24.48732	24.55064	24.55491
9.55698	3.25764	24.72792	24.66934	24.48731	24.55058	24.55487
9.55707	3.25761	24.72801	24.66937	24.48728	24.55052	24.55491
9.557	0.20883	24.72814	24.66928	24.48736	24.55056	24.55501
9.55715	0.0003	24.72795	24.66937	24.48721	24.55053	24.55494
9.55709	0.00031	24.72789	24.6693	24.48728	24.55049	24.55506
9.55705	0.00029	24.72795	24.66952	24.48744	24.55056	24.55518
8.43096	0.0003	24.72803	24.66942	24.48728	24.5507	24.55502

5.68251	7.50049	24.72784	24.66945	24.48754	24.55053	24.55488
5.68252	8.94164	24.72802	24.66942	24.48746	24.55059	24.5549
5.68247	8.94175	24.72807	24.66935	24.48743	24.55058	24.55497
5.68246	8.94177	24.7281	24.6694	24.48733	24.55061	24.55488
5.68242	8.94175	24.7281	24.66936	24.48741	24.55067	24.55508
5.6825	8.94198	24.72796	24.66941	24.48751	24.55077	24.55512
5.68271	5.68447	24.72814	24.66932	24.4874	24.55063	24.5549
5.68262	5.68447	24.7281	24.66944	24.48747	24.55066	24.5549
5.6826	5.68443	24.72792	24.6694	24.48754	24.55058	24.55496
5.68254	5.68452	24.72806	24.66946	24.48744	24.55054	24.55502
5.6826	5.68443	24.72799	24.66923	24.48746	24.55053	24.5549
5.6824	5.68444	24.72817	24.66934	24.4875	24.5505	24.55493
5.6825	5.68442	24.72801	24.66941	24.48742	24.55056	24.55489
5.68229	5.68359	24.72808	24.66938	24.48733	24.55055	24.55497
5.68749	5.68546	24.7281	24.66938	24.48746	24.55061	24.55508
27.9033	27.86939	24.72809	24.66929	24.48736	24.55053	24.555
27.89885	27.88171	24.72804	24.66926	24.48739	24.55059	24.55502
27.89882	27.88169	24.72812	24.6695	24.48737	24.55056	24.55498
27.89859	27.88182	24.72799	24.66923	24.48743	24.55054	24.55504
27.89858	27.88184	24.72797	24.66922	24.48736	24.55061	24.55502
27.89873	27.88191	24.72803	24.66935	24.48733	24.55046	24.55496
27.8989	27.88181	24.72797	24.66926	24.48732	24.55041	24.55492
27.89906	5.68459	24.72802	24.66936	24.48736	24.5505	24.55483
27.89893	5.68447	24.72804	24.66934	24.48748	24.55047	24.55494
27.89898	5.68449	24.72813	24.66925	24.4874	24.5505	24.55496
27.8989	5.68434	24.72795	24.66937	24.48753	24.55049	24.555
27.89883	11.59693	24.728	24.66934	24.48735	24.55049	24.55497
27.89875	24.62457	24.72796	24.6692	24.48745	24.55058	24.55495
27.89872	24.6243	24.7279	24.66923	24.48761	24.55048	24.55499
27.89889	24.62449	24.72804	24.66918	24.4875	24.5505	24.55496
27.89877	24.62452	24.72805	24.66926	24.48739	24.55049	24.5548
27.89878	24.62459	24.72803	24.66919	24.48737	24.55054	24.555
27.89886	24.62468	24.72794	24.66918	24.48736	24.55045	24.55493
27.89877	24.62454	24.72804	24.66925	24.48751	24.55037	24.55487
27.89876	24.62453	24.72791	24.66909	24.48742	24.5504	24.555
27.89885	24.62458	24.72803	24.66916	24.48756	24.55035	24.55498
27.89895	24.62454	24.72813	24.66928	24.48743	24.55054	24.55494
27.89907	24.62463	24.72805	24.66927	24.48756	24.55027	24.55495
27.89903	24.6246	24.72803	24.66913	24.48749	24.55041	24.55486
27.89895	24.62461	24.72816	24.66914	24.48742	24.55045	24.55489
5.68256	24.62474	24.7279	24.66921	24.48745	24.5504	24.55483
5.68241	24.62461	24.72798	24.66921	24.48741	24.55051	24.55483
5.68268	24.62466	24.728	24.66916	24.48746	24.55041	24.55492
24.64023	24.62473	24.72793	24.66919	24.48745	24.55044	24.55486
24.63854	24.62465	24.72793	24.66919	24.48744	24.55044	24.55497
24.63887	24.62467	24.72802	24.66923	24.48739	24.55031	24.5549

24.63886	24.62484	24.72807	24.66918	24.48742	24.55044	24.55496
24.63904	24.62476	24.72799	24.66917	24.48734	24.55042	24.55493
24.63882	24.62475	24.72804	24.66922	24.48741	24.55036	24.55502
24.64466	24.62486	24.72799	24.66919	24.48737	24.55039	24.55512
24.63885	24.62466	24.72803	24.66922	24.48747	24.55041	24.55514
24.63896	24.62471	24.72802	24.66918	24.4874	24.55049	24.55512
24.63908	24.62471	24.72804	24.66906	24.48747	24.55047	24.55494
24.63878	24.62476	24.72806	24.66907	24.48752	24.55045	24.55503
24.63896	24.62477	24.72814	24.66919	24.4875	24.55045	24.55499
24.63912	24.62475	24.72786	24.66908	24.48742	24.5505	24.55498
24.63903	24.62487	24.72792	24.66898	24.48749	24.55042	24.55504
24.63917	24.62477	24.72801	24.66909	24.48752	24.5505	24.5549
24.63905	24.62479	24.72798	24.66916	24.48748	24.55039	24.55511
24.63906	24.62468	24.72798	24.6692	24.48738	24.55046	24.55487
24.639	24.62475	24.72795	24.66927	24.48748	24.55048	24.55498
24.63904	24.62483	24.72792	24.66908	24.48744	24.55046	24.55495
24.63908	24.62486	24.72796	24.66911	24.48743	24.5505	24.55488
24.63914	24.62484	24.72807	24.66914	24.48745	24.55038	24.55507
24.63903	24.62492	24.72802	24.66916	24.48743	24.5504	24.5549
24.6389	24.62487	24.72791	24.66918	24.48747	24.55019	24.55518
24.63898	24.62473	24.72803	24.66924	24.48734	24.55039	24.55512
24.63908	24.62474	24.72795	24.66914	24.48741	24.55026	24.55495
24.63906	24.62483	24.72798	24.66928	24.48731	24.55021	24.55505
24.63915	24.62485	24.72793	24.66918	24.48745	24.55019	24.5549
24.63915	24.62502	24.72786	24.66917	24.48743	24.55012	24.55497
24.63931	24.6248	24.72796	24.66902	24.48743	24.55023	24.55488
24.63931	24.62487	24.72805	24.66923	24.4875	24.55022	24.5548
24.63941	24.62482	24.72782	24.6691	24.48739	24.55042	24.5546
24.63929	24.62493	24.72784	24.66914	24.48741	24.55025	24.55479
24.6392	24.62488	24.7279	24.66914	24.48742	24.55031	24.55505
24.63905	24.62487	24.72802	24.66918	24.48731	24.55027	24.5554
24.63912	24.62481	24.728	24.66917	24.48739	24.55012	24.55494
24.63911	24.62488	24.72794	24.66907	24.48736	24.55008	24.55514
24.6391	24.62492	24.72801	24.66903	24.48747	24.55015	24.55473
24.63904	24.62492	24.72796	24.66911	24.48737	24.55025	24.55472
24.639	24.62499	24.728	24.66914	24.48753	24.55033	24.55474
24.63919	24.62487	24.72795	24.66903	24.48745	24.55028	24.55491
24.63925	24.62501	24.7279	24.66903	24.48738	24.5504	24.55485
24.63932	24.62501	24.72787	24.66905	24.48738	24.55046	24.55494
24.63932	24.62498	24.72785	24.66907	24.4873	24.55021	24.55499
24.63924	24.62494	24.72788	24.6691	24.48735	24.55024	24.55517
24.63923	24.62498	24.72783	24.66905	24.48736	24.55017	24.55501
24.63932	24.62507	24.72782	24.66905	24.48742	24.55022	24.55486
24.63933	24.62495	24.72787	24.66898	24.48736	24.5503	24.55493
24.63926	24.62509	24.72775	24.66898	24.48729	24.55026	24.55499
24.63932	24.62492	24.72786	24.66892	24.48735	24.55024	24.55505

24.63909	24.62503	24.7278	24.66896	24.48733	24.55022	24.555
24.63918	24.62498	24.72785	24.66904	24.48731	24.55014	24.55508
24.63916	24.62516	24.72784	24.66895	24.4873	24.55033	24.55485
24.63929	24.62505	24.72779	24.66898	24.48724	24.55007	24.55486
24.63927	24.62497	24.72777	24.66903	24.48723	24.55018	24.55498
24.63927	24.62496	24.72778	24.66886	24.48732	24.55013	24.5551
24.63916	24.62494	24.72788	24.66855	24.48736	24.55	24.55506
24.63926	24.62496	24.72772	24.66879	24.48735	24.54996	24.55519
24.63935	24.62496	24.72781	24.66872	24.48717	24.5502	24.55508
24.63905	24.62483	24.72775	24.66894	24.48735	24.55006	24.55506
24.63911	24.62499	24.72787	24.66884	24.4873	24.55019	24.55483
24.63911	24.62507	24.72793	24.66889	24.48734	24.55023	24.55507
24.63926	24.625	24.72781	24.6689	24.4873	24.5499	24.55498
24.63925	24.62507	24.72784	24.66892	24.48729	24.54994	24.55506
24.63928	24.62496	24.72784	24.66905	24.4873	24.54989	24.55499
24.63927	24.62498	24.72777	24.66882	24.48729	24.55008	24.55498
24.63932	24.62478	24.72776	24.66868	24.48729	24.5501	24.55503
24.6394	24.62466	24.72775	24.66886	24.48736	24.5499	24.55504
24.63933	24.62491	24.72782	24.66884	24.48732	24.55002	24.55516
24.63942	24.62511	24.72792	24.66859	24.48729	24.55001	24.55512
24.6395	24.62499	24.72791	24.66864	24.4873	24.55001	24.55504
24.63931	24.62513	24.72777	24.66882	24.48726	24.54997	24.55511
24.63937	24.62509	24.72788	24.66874	24.48722	24.55006	24.55512
24.63942	24.62502	24.7278	24.66872	24.48728	24.54969	24.55516
24.63947	24.62493	24.7279	24.6688	24.48721	24.54979	24.55491
24.63939	24.62507	24.7278	24.66884	24.48718	24.54999	24.55513
24.63937	24.62506	24.72769	24.66879	24.48729	24.54985	24.55501
24.63937	24.62513	24.72774	24.66881	24.4871	24.54996	24.55481
24.63935	24.62509	24.72777	24.66862	24.4872	24.54995	24.55452
24.63938	24.62502	24.72789	24.66867	24.48716	24.54989	24.54841
24.63943	24.62493	24.72784	24.66875	24.48712	24.55002	24.54984
24.63938	24.62388	24.7278	24.66879	24.4872	24.54982	56.9014
24.6394	24.62412	24.72769	24.66871	24.4871	24.54995	27.92843
24.63941	24.62454	24.72772	24.66872	24.48713	24.55	27.81001
24.63938	24.62503	24.72759	24.66879	24.48696	24.54991	27.80849
24.63939	24.62482	24.72761	24.66877	24.48702	24.54979	27.81173
24.63949	24.6242	24.72773	24.66868	24.48709	24.55001	27.81235
24.63924	24.62456	24.72759	24.66883	24.48699	24.5499	27.81259
24.63938	24.62457	24.72769	24.66876	24.48699	24.55013	27.81294
24.63933	24.62446	24.72767	24.66872	24.48692	24.55013	27.81315
24.63933	24.62448	24.72771	24.66865	24.48716	24.54998	27.81342
24.63949	24.62486	24.72766	24.66861	24.48695	24.55002	27.81374
24.63939	24.62475	24.72773	24.66878	24.48697	24.55007	27.81365
24.63946	24.62439	24.72774	24.66871	24.4868	24.55026	27.81403
24.63942	24.62443	24.72768	24.66865	24.48684	24.54963	27.8143
24.63946	24.62418	24.72764	24.66866	24.48687	24.54985	27.81472

24.63947	24.62425	24.72769	24.6686	24.48696	24.54998	27.81473
24.63948	24.62467	24.72772	24.66866	24.48706	24.5498	27.81495
24.63943	24.62484	24.72775	24.66859	24.48693	24.54976	27.81521
24.63939	24.62476	24.72777	24.66862	24.48704	24.54983	27.81566
24.63946	24.62429	24.7278	24.66855	24.48698	24.54999	27.81611
24.63935	24.6246	24.7277	24.66865	24.48686	24.54979	27.81654
24.63933	24.62454	24.72773	24.66859	24.48674	24.54985	27.81697
24.63945	24.62442	24.72786	24.66849	24.48689	24.54978	27.8173
24.63926	24.62464	24.72764	24.66857	24.48688	24.54968	27.81748
24.63956	24.62477	24.72774	24.66855	24.48707	24.54989	27.81806
24.63952	24.6249	24.72751	24.6686	24.48691	24.54993	27.81851
24.63952	24.6249	24.72762	24.66868	24.48703	24.54976	27.81881
24.63951	24.62473	24.72758	24.66855	24.48692	24.5497	27.81894
24.63931	24.6249	24.72776	24.66848	24.4868	24.54987	27.8192
24.63925	24.62478	24.7277	24.66869	24.4869	24.54986	27.81999
24.63939	24.62497	24.72745	24.66871	24.48677	24.54996	27.81986
24.63943	24.62483	24.72778	24.66859	24.48678	24.54972	27.81995
24.63926	24.62471	24.72765	24.66864	24.48697	24.54984	27.82027
24.63935	24.62453	24.72756	24.66875	24.48689	24.54992	27.82113
24.63929	24.62461	24.72765	24.66851	24.48689	24.55	27.82143
24.63934	24.62447	24.7277	24.66852	24.48692	24.54987	27.82196
24.63937	24.62449	24.72765	24.66851	24.48689	24.55003	27.82244
24.63929	24.62467	24.72765	24.66858	24.487	24.54987	27.82259
24.63933	24.62472	24.72756	24.66848	24.48691	24.54994	27.82294
24.63947	24.62474	24.72747	24.6686	24.48708	24.54979	27.82346
24.63949	24.62469	24.7276	24.66851	24.48693	24.54989	27.82369
24.63955	24.62467	24.72744	24.6686	24.48693	24.54986	27.82366
24.63962	24.62494	24.72752	24.66858	24.4869	24.54965	27.8245
24.63943	24.62477	24.72769	24.66859	24.48696	24.55008	27.82497
24.63942	24.62491	24.72739	24.66842	24.48689	24.54986	27.82554
24.63929	24.62482	24.72743	24.66817	24.48671	24.54981	27.82588
24.63932	24.62486	24.72743	24.66836	24.48679	24.54996	27.8261
24.63939	24.62443	24.72768	24.66837	24.48675	24.54991	27.82672
24.63937	24.62469	24.72775	24.66838	24.48674	24.54989	27.82686
24.63938	24.62477	24.72747	24.66859	24.48664	24.54994	27.8276
24.6394	24.62477	24.72755	24.66824	24.48664	24.54994	27.82748
24.63949	24.62445	24.72744	24.66848	24.48673	24.54967	27.82821
24.63941	24.62479	24.72743	24.66837	24.48678	24.55001	27.82863
24.63958	24.62467	24.72762	24.66841	24.48671	24.54985	27.82899
24.63942	24.62472	24.72749	24.66847	24.48683	24.54995	27.82944
24.63933	24.62466	24.72756	24.66843	24.48671	24.5499	27.82981
24.63918	24.62484	24.72745	24.66863	24.48681	24.54963	27.83033
24.63936	24.62486	24.72743	24.66841	24.48684	24.54997	27.83086
24.63931	24.62485	24.72764	24.66839	24.48662	24.54992	27.83139
24.63933	24.62475	24.72731	24.66845	24.48661	24.55002	27.8318
24.63938	24.62479	24.72756	24.66828	24.48682	24.54981	27.83212

24.6394	24.62492	24.72754	24.66843	24.48687	24.54977	27.83254
24.63942	24.62453	24.7275	24.66829	24.48683	24.54979	27.83268
24.63937	24.62453	24.72759	24.66829	24.48688	24.54978	27.83328
24.6394	24.62465	24.72749	24.66827	24.48669	24.54977	27.83375
24.63947	24.6252	24.72751	24.6684	24.4866	24.54958	27.83424
24.63965	24.62426	24.72748	24.6685	24.48673	24.54988	27.8346
24.63945	24.62355	24.72753	24.66846	24.48686	24.54972	27.83529
24.63952	24.62442	24.72753	24.66822	24.48653	24.54957	27.8357
24.63926	24.62453	24.72745	24.66824	24.48679	24.54965	27.83613
24.63937	24.62439	24.72759	24.66838	24.48679	24.54977	27.83682
24.63937	24.6246	24.72742	24.66839	24.48684	24.54963	27.83709
24.63934	24.62469	24.72747	24.66826	24.48657	24.54954	27.8375
24.6394	24.62485	24.7275	24.66829	24.48657	24.54943	27.83795
24.63925	24.6244	24.7274	24.66823	24.48679	24.54946	27.83838
24.63955	24.62432	24.72759	24.66817	24.48678	24.54938	27.83886
24.63936	24.62472	24.72753	24.66816	24.48692	24.54973	27.839
24.6394	24.6246	24.72747	24.66832	24.48663	24.54973	27.83976
24.63927	24.62487	24.72758	24.66818	24.48664	24.54999	27.84039
24.63933	24.62486	24.72748	24.66818	24.48679	24.5497	27.84061
24.6395	24.6249	24.72747	24.66825	24.48652	24.54975	27.84097
24.63916	24.62434	24.72746	24.66832	24.48657	24.54981	27.84155
24.63938	24.62414	24.72739	24.66818	24.4867	25.05273	27.84203
24.63937	24.62472	24.72747	24.66834	24.48664	14.98162	27.84233
24.63938	24.62445	24.72762	24.66831	24.48671	20.03208	27.84283
24.63935	24.62474	24.72757	24.66818	24.48657	27.80712	27.84316
24.63959	24.62459	24.7274	24.66835	24.48675	27.8054	27.84323
24.6395	24.62482	24.7274	24.66792	24.48664	27.80617	27.84396
24.63944	24.62487	24.72729	22.15527	24.48672	27.80486	27.84448
24.63929	24.62471	24.72721	5.6817	24.48668	27.80706	27.84487
24.63939	24.62422	24.7274	5.68134	24.48641	27.80641	27.84528
24.63939	24.62444	24.72747	12.21183	28.37222	27.80566	27.84602
24.63935	24.62493	24.72728	24.97886	15.95143	27.80772	27.84602
24.63938	24.62506	24.72734	27.92621	18.21536	27.8078	27.84655
24.63938	24.62454	24.72738	27.926	27.83347	27.80778	27.84686
24.63937	24.62491	24.72741	27.92522	27.72512	27.80762	27.8475
24.63939	24.62465	24.72742	27.92528	27.74367	27.80836	27.84797
24.6393	24.6248	24.72734	27.92518	27.74397	27.80809	27.84836
24.63956	24.62448	24.72734	27.92583	27.74202	27.8075	27.84854
24.6395	24.6248	24.72741	27.92341	27.74296	27.80823	27.84934
24.63954	24.62443	24.72739	27.92604	27.74328	27.80785	27.84977
24.63958	24.62479	24.72735	27.92598	27.74373	27.80797	27.85029
24.63955	24.62491	24.72744	27.92597	27.7441	27.80873	27.85102
24.63945	24.62485	24.7273	27.92612	27.74414	27.80855	27.85107
24.63958	24.62492	24.72744	27.92613	27.74422	27.80849	27.85157
24.63961	24.62493	24.72477	27.92629	27.74401	27.80877	27.8521
24.63952	24.62487	15.83753	27.92647	27.74425	27.80871	27.85236

24.63948	24.62453	6.50055	27.92636	27.7441	27.80896	27.85277
24.63938	24.6246	5.93732	27.92647	27.74446	27.80926	27.85324
24.63951	24.62454	28.08829	27.92678	27.74448	27.80929	27.85378
24.63977	24.62467	27.98456	27.92683	27.74457	27.80956	27.85421
24.63953	24.62497	27.98438	27.92705	27.7441	27.80999	27.85442
24.63943	24.62484	27.98454	27.92694	27.74438	27.81001	27.85498
24.63955	24.62476	27.98435	27.9271	27.74449	27.81025	27.85575
24.63939	24.6249	27.98427	27.92725	27.74481	27.81077	27.85561
24.63933	24.62406	27.98474	27.92729	27.74472	27.81081	27.85628
24.63937	24.62419	27.98502	27.9275	27.74501	27.81114	27.8566
24.63946	24.62448	27.98492	27.92748	27.7448	27.81142	27.85714
24.63935	24.62454	27.98522	27.9278	27.74492	27.81147	27.85729
24.63937	24.62463	27.98509	27.92792	27.74494	27.81187	27.85719
24.6394	24.62489	27.98481	27.92797	27.74499	27.81202	27.85802
24.63936	24.62434	27.98507	27.928	27.74516	27.81167	27.85855
24.63941	24.62459	27.98515	27.92813	27.74535	27.81271	27.85905
24.63933	24.62406	27.98478	27.92819	27.74535	27.81301	27.8592
24.63924	24.62492	27.98516	27.92826	27.74562	27.81342	27.85963
24.63924	24.62485	27.985	27.92859	27.74573	27.81363	27.86016
24.63942	24.62445	27.985	27.92867	27.7459	27.814	27.86069
24.63926	24.6244	27.9851	27.92878	27.746	27.81392	27.86092
24.63927	24.62444	27.9853	27.92886	27.74616	27.81436	27.86066
24.6394	24.62414	27.98547	27.929	27.74639	27.81452	27.86147
24.63944	24.6246	27.98539	27.92908	27.7466	27.81502	27.86158
24.63925	24.62451	27.98561	27.92914	27.74682	27.81516	27.86157
24.63935	24.62495	27.98555	27.92942	27.7471	27.81565	27.86164
24.63941	24.62472	27.98548	27.92935	27.74737	27.81572	27.86253
24.63936	24.62448	27.98563	27.92973	27.74783	27.81605	27.86283
24.63943	24.62468	27.98562	27.92966	27.74804	27.81625	27.8632
24.63946	24.62461	27.98546	27.92995	27.74821	27.81681	27.86369
24.63938	24.62446	27.98563	27.93015	27.74853	27.81694	27.86379
24.63939	24.62414	27.98558	27.93004	27.74912	27.81759	27.86414
24.6394	24.62437	27.98574	27.93027	27.74823	27.81777	27.8645
24.63928	24.6245	27.98545	27.93038	27.74953	27.81754	27.86496
24.6394	24.62459	27.98576	27.93045	27.74977	27.81779	27.86529
24.63932	24.62455	27.98564	27.93065	27.74982	27.8187	27.86567
24.63946	24.62443	27.98554	27.93089	27.75035	27.81887	27.86555
24.63953	24.62448	27.98547	27.93088	27.75052	27.819	27.8663
24.63952	24.62361	27.98565	27.93095	27.75078	27.81955	27.86662
24.63925	24.62408	27.9856	27.93114	27.75097	27.81973	27.8667
24.63947	24.62408	27.98553	27.93119	27.75128	27.81992	27.86675
24.63951	24.6243	27.98569	27.93141	27.7515	27.82009	27.86737
24.63937	24.62346	27.98581	27.93176	27.75185	27.8203	27.86766
24.63949	24.62399	27.98593	27.93167	27.75206	27.82102	27.86815
24.6395	24.6246	27.98585	27.93201	27.75241	27.82109	27.86814
24.63943	24.62446	27.98601	27.93203	27.75255	27.82133	27.86841

24.6396	24.62386	27.98604	27.93212	27.75305	27.82167	27.86859
24.63955	5.6833	27.98588	27.93224	27.7532	27.82211	27.86882
24.63945	5.70034	27.98578	27.9324	27.75331	27.82239	27.86925
24.63946	5.78055	27.98603	27.93243	27.75359	27.82272	27.86908
24.63948	6.20446	27.98593	27.93254	27.75392	27.82308	27.86978
24.63962	27.85084	27.9861	27.93285	27.75411	27.82289	27.86939
24.6395	27.88228	27.98595	27.93275	27.75448	27.82341	27.87001
24.63939	27.88302	27.98604	27.93283	27.75439	27.82344	27.87086
24.63964	27.88289	27.98587	27.93284	27.75474	27.82401	27.87107
31.29556	27.88269	27.9862	27.93304	27.75499	27.82435	27.8709
32.38905	27.88289	27.98614	27.93339	27.75526	27.82461	27.87147
18.59413	27.88284	27.9862	27.93333	27.75539	27.82478	27.87173
27.89898	27.88303	27.98617	27.93354	27.75555	27.82466	27.87141
27.89874	27.88315	27.98622	27.93377	27.75574	27.82547	27.87211
27.89824	27.88265	27.98615	27.93402	27.7559	27.82544	27.87201
27.89968	27.88299	27.98628	27.93381	27.75616	27.82564	27.87216
27.90003	27.88281	27.98594	27.93368	27.75625	27.82611	27.87284
27.89996	27.88282	27.98642	27.93361	27.7566	27.82612	27.87313
27.8998	27.88298	27.9862	27.93401	27.75683	27.82612	27.87359
27.89985	27.88268	27.98624	27.93411	27.75699	27.82687	27.87375
27.89994	27.883	27.98627	27.93426	27.75735	27.82696	27.87394
27.89984	27.88182	27.98613	27.9346	27.75732	27.82714	27.87419
27.8998	27.88207	27.98624	27.93445	27.75752	27.82736	27.87435
27.89975	27.88157	27.98628	27.93468	27.75771	27.8276	27.87468
27.89972	27.88219	27.98626	27.93478	27.75766	27.82775	27.8749
27.89988	27.88218	27.98622	27.93482	27.75796	27.82754	27.87532
27.89986	27.88137	27.98655	27.93486	27.758	27.82809	27.87529
27.89996	27.88281	27.98631	27.93515	27.75853	27.82814	27.8757
27.89993	27.88243	27.98656	27.9354	27.75852	27.82824	27.87659
27.89997	27.88182	27.98649	27.93526	27.75865	27.82871	27.8765
27.8999	27.8824	27.98651	27.93527	27.75877	27.82904	27.87644
27.89996	27.88248	27.9862	27.93552	27.75905	27.82932	27.87641
27.89966	27.88275	27.98664	27.93562	27.75871	27.82945	27.8768
27.89974	27.883	27.98648	27.93584	27.75921	27.82954	27.87752
27.89976	27.88322	27.98653	27.93607	27.75962	27.82989	27.8776
27.89976	27.88295	27.98661	27.93572	27.75967	27.83003	27.8775
27.89974	27.88304	27.98657	27.93578	27.75985	27.82975	27.87794
27.89983	27.88291	27.9865	27.93599	27.75986	27.83056	27.87776
27.89967	27.88292	27.9866	27.93627	27.75988	27.83066	27.87772
27.89971	27.88287	27.98653	27.93606	27.76012	27.83039	27.87862
27.89979	27.88285	27.98687	27.93631	27.76041	27.83095	27.87884
27.89956	27.88263	27.98666	27.9366	27.76048	27.83109	27.87946
27.89959	27.88281	27.98668	27.93656	27.76057	27.83117	27.87901
27.89972	27.88288	27.98658	27.93648	27.76063	27.83176	27.87978
27.89963	27.88296	27.98684	27.93656	27.76084	27.83174	27.87985
27.89959	27.88308	27.98667	27.93664	27.76074	27.83193	27.8802

27.89949	27.88324	27.98672	27.93681	27.76093	27.83217	27.88018
27.89947	27.88295	27.98699	27.93673	27.76114	27.83209	27.88063
27.89981	27.88297	27.98688	27.93711	27.7612	27.83228	27.881
27.89973	27.88308	27.98694	27.93719	27.76129	27.83243	27.8812
27.89952	27.88332	27.98691	27.93745	27.76133	27.83257	27.88152
27.89955	27.88321	27.987	27.93683	27.76159	27.83282	27.88116
27.89974	27.88321	27.98701	27.93742	27.76189	27.83312	27.88153
27.89986	27.88334	27.98686	27.93712	27.76193	27.83339	27.88191
27.89966	27.88314	27.98721	27.93749	27.76217	27.83317	27.8819
27.89975	27.883	27.98707	27.9375	27.76216	27.83342	27.88217
27.89971	27.88329	27.98702	27.93761	27.76225	27.83342	27.88275
27.89968	27.88333	27.98714	27.93777	27.76231	27.834	27.88294
27.89975	27.88316	27.98703	27.9377	27.76245	27.83403	27.88312
27.8997	27.88312	27.98769	27.93789	27.76236	27.83417	27.88328
27.89977	27.8835	27.9871	27.93796	27.76274	27.83436	27.88387
27.89987	27.88354	27.98705	27.938	27.76273	27.83463	27.88424
27.89977	27.88317	27.98703	27.93815	27.76289	27.83471	27.8843
27.89975	27.88296	27.98726	27.93769	27.76272	27.83468	27.88358
27.89993	27.88308	27.98724	27.93793	27.76319	27.83505	27.88364
27.89974	27.88329	27.98732	27.93821	27.76307	27.8351	27.88419
27.89978	27.88334	27.98726	27.93817	27.76323	27.83503	27.88395
27.89953	27.88341	27.98725	27.93844	27.7633	27.83549	27.88486
27.89964	27.88345	27.98718	27.93861	27.76338	27.83553	27.88544
27.89977	27.88339	27.98734	27.93882	27.76305	27.83592	27.88604
27.89964	27.88323	27.98718	27.93877	27.76363	27.83599	27.88592
27.89954	27.88314	27.98708	27.93884	27.76351	27.8363	27.88606
27.89958	27.88302	27.98694	27.93896	27.76393	27.83611	27.88637
27.89963	27.88352	27.98719	27.93893	27.76413	27.83625	27.88657
27.89941	27.88334	27.98723	27.93919	27.76406	27.83669	27.88724
27.89957	27.88317	27.98752	27.93918	27.76453	27.83663	27.88698
27.89949	27.88324	27.98734	27.93889	27.76446	27.83679	27.8871
27.89965	27.88346	27.98726	27.93887	27.76455	27.83681	27.88744
27.8996	27.88346	27.98744	27.93935	27.76472	27.83699	27.8876
27.89955	27.88343	27.98757	27.93933	27.76438	27.83731	27.88801
27.89967	27.88355	27.98724	27.93938	27.76497	27.8373	27.88847
27.8996	27.88352	27.98749	27.93939	27.7648	27.83759	27.88802
27.89965	27.88337	27.98716	27.93944	27.76496	27.83776	27.88873
27.89974	27.88333	27.98754	27.93976	27.76525	27.83768	27.88891
27.89969	27.88321	27.98755	27.93956	27.76509	27.83769	27.88863
27.89973	27.88313	27.98749	27.93933	27.76526	27.83788	27.88919
27.89974	27.88339	27.98771	27.93975	27.76512	27.83817	27.88973
27.89956	27.88364	27.98757	27.93983	27.76536	27.83836	27.88975
27.89963	27.88362	27.98749	27.93973	27.76555	27.83845	27.89015
27.89958	27.88357	27.98763	27.93995	27.76558	27.83836	27.89021
27.89963	27.88346	27.98757	27.93999	27.76588	27.83853	27.8901
27.89958	27.8833	27.98785	27.94008	27.76575	27.83863	27.89076

27.89956	27.88338	27.98778	27.93997	27.76584	27.8388	27.89106
27.89953	27.88348	27.98792	27.94001	27.76599	27.839	27.89096
27.89954	27.88333	27.98748	27.94026	27.76606	27.83904	27.89097
27.89945	27.88329	27.98779	27.94018	27.7662	27.83933	27.89172
27.89953	27.88367	27.98774	27.94029	27.76634	27.83947	27.892
27.8996	27.88328	27.9879	27.94057	27.76652	27.83949	27.89139
27.89952	27.88315	27.98759	27.94034	27.7666	27.83955	27.89195
27.89965	27.8833	27.98786	27.94066	27.76668	27.83965	27.89197
27.8996	27.88353	27.98749	27.94063	27.76659	27.83985	27.89278
27.89957	27.8836	27.98738	27.94087	27.76664	27.83987	27.89271
27.8995	27.88112	27.98792	27.94089	27.76689	27.83967	27.89308
27.89934	27.88345	27.98808	27.94096	27.76692	27.83981	27.89311
27.89967	27.8835	27.98792	27.94086	27.76656	27.84028	27.89322
27.89978	27.88331	27.9878	27.94081	27.76717	27.84046	27.89359
27.8997	27.88353	27.98808	27.94084	27.76733	27.84056	27.89388
27.89965	27.88346	27.98806	27.9409	27.76736	27.84074	27.89422
27.89964	27.88349	27.98807	27.94094	27.76715	27.84065	27.89442
27.89956	27.88342	27.9875	27.94138	27.76719	27.84084	27.89459
27.89964	27.88351	27.98811	27.94103	27.76763	27.84097	27.89455
27.89935	27.88332	27.98794	27.94126	27.76743	27.8411	27.89501
27.89962	27.8833	27.98812	27.9409	27.76752	27.84107	27.89502
27.8993	27.88349	27.98791	27.94143	27.76788	27.84136	27.89491
27.89951	27.88344	27.98828	27.94119	27.76784	27.84161	27.89488
27.89938	27.88348	27.9881	27.94134	27.76798	27.84169	27.89525
27.89937	27.88336	27.98787	27.94153	27.768	27.84169	27.89584
27.8996	27.88313	27.98809	27.94113	27.7683	27.84164	27.89588
27.8995	27.88334	27.9883	27.94151	27.76802	27.84197	27.89636
27.89963	27.88351	27.98816	27.94175	27.76842	27.84154	27.89632
27.89966	27.88338	27.98823	27.94168	27.76838	27.8421	27.89664
27.8997	27.88341	27.98833	27.94172	27.76826	27.842	27.8972
27.89966	27.88349	27.9883	27.9418	27.76847	27.8424	27.89701
27.89961	27.88364	27.98825	27.94167	27.76868	27.84239	27.89714
27.89963	27.88351	27.98849	27.94184	27.76852	27.8426	27.89719
27.89946	27.88369	27.98834	27.94197	27.76892	27.84267	27.89773
27.89971	27.88361	27.98846	27.94187	27.7689	27.84245	27.89788
27.89946	27.88361	27.98809	27.9421	27.76904	27.84276	27.89781
27.89948	27.88348	27.98841	27.94217	27.76884	27.843	27.89856
27.89925	27.88358	27.98847	27.9422	27.76906	27.84302	27.89874
27.89935	27.88391	27.98824	27.94218	27.76903	27.84294	27.89882
27.8994	27.88363	27.98816	27.9422	27.76915	27.8431	27.8986
27.89935	27.88344	27.98838	27.94241	27.76915	27.84316	27.89872
27.89939	27.88349	27.98835	27.94242	27.76951	27.84357	27.89919
27.89926	27.88354	27.98834	27.9426	27.76941	27.84287	27.89887
27.89925	27.88359	27.98836	27.94269	27.76963	27.8435	27.89946
27.89966	27.88334	27.98871	27.94287	27.76958	27.84314	27.89921
27.89956	27.88353	27.9883	27.94262	27.76938	27.84368	27.89961

27.8994	27.88345	27.98814	27.94269	27.77006	27.84383	27.90006
27.89951	27.88342	27.98859	27.94268	27.7699	27.84389	27.90066
27.89951	27.88337	27.98851	27.94269	27.76977	27.84415	27.90069
27.89964	27.88354	27.98802	27.94256	27.77	27.84411	27.90086
27.89966	27.88362	27.98852	27.94277	27.77025	27.84419	27.90101
27.89961	27.88349	27.98869	27.94286	27.77048	27.84445	27.90096
27.89957	27.88356	27.98851	27.943	27.77031	27.84445	27.90063
27.89956	27.88353	27.98877	27.94299	27.77052	27.84463	27.90128
27.89963	27.88385	27.98874	27.94292	27.77057	27.84476	27.90174
27.8996	27.88316	27.98867	27.94312	27.7704	27.84495	27.90181
27.89954	27.88355	27.98848	27.94323	27.77065	27.84493	27.90156
27.89952	27.88334	27.98883	27.94329	27.77074	27.84497	27.90235
27.8995	27.88344	27.98833	27.94328	27.77095	27.84497	27.90271
27.89939	27.88345	27.98848	27.94367	27.7711	27.84518	27.90272
27.89967	27.88339	27.98868	27.94356	27.77094	27.84531	27.90331
27.8996	27.88328	27.98884	27.94356	27.77058	27.84515	27.90345
27.89948	27.88342	27.98879	27.94371	27.77113	27.8456	27.90379
27.89964	27.88331	27.98886	27.94384	27.77128	27.84556	27.90327
27.89959	27.88318	27.98901	27.94364	27.77124	27.84561	27.90388
27.89962	27.88331	27.98872	27.94383	27.77158	27.84574	27.90376
27.89945	27.88349	27.98883	27.94379	27.77142	27.84576	27.90422
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27.8995	27.88349	27.98869	27.94417	27.77159	27.84589	27.90419
27.89952	27.88327	27.98904	27.94426	27.77184	27.84592	27.90473
27.89941	27.88358	27.98884	27.94406	27.77181	27.84613	27.90513
27.89951	27.8833	27.98917	27.94443	27.77189	27.84628	27.90509
27.89936	27.88369	27.98899	27.94428	27.77204	27.84634	27.90499
27.89943	27.88353	27.98851	27.94407	27.77215	27.84586	27.90555
27.89948	27.88354	27.98905	27.94447	27.77227	27.84595	27.90569
27.89926	27.88366	27.9892	27.94458	27.77224	27.84654	27.90589
27.89925	27.8835	27.98911	27.94432	27.77227	27.84675	27.90624
27.89935	27.88384	27.98897	27.94459	27.77216	27.84672	27.90656
27.89928	27.88358	27.98856	27.94472	27.77236	27.84681	27.9064
27.89948	27.88359	27.9885	27.94459	27.77249	27.84689	27.90673
27.89957	27.88349	27.9891	27.94452	27.77257	27.84711	27.90633
27.89945	27.88357	27.98894	27.94489	27.77245	27.84721	27.90738
27.89958	27.88336	27.98889	27.94484	27.77265	27.84721	27.90761
27.89944	27.88398	27.98901	27.94491	27.77266	27.84743	27.90761
27.89945	27.88381	27.98927	27.94493	27.77291	27.84738	27.90748
27.89946	27.8839	27.9891	27.94538	27.77279	27.84737	27.90749
27.89927	27.88378	27.98932	27.94522	27.77276	27.84757	27.90812
27.8994	27.88373	27.98918	27.94517	27.77305	27.84788	27.90798
27.89923	27.88356	27.98905	27.94531	27.77298	27.84758	27.90827
27.89919	27.88374	27.98924	27.94511	27.77291	27.84791	27.9084
27.89918	27.88379	27.98899	27.94524	27.77324	27.84789	27.90905
27.89924	27.88367	27.98925	27.9457	27.77339	27.84803	27.90932

27.89946	27.88363	27.98939	27.94551	27.77363	27.84817	27.90912
27.89957	27.88348	27.9893	27.94565	27.77353	27.84837	27.90919
27.89958	27.8838	27.98938	27.9457	27.77356	27.84839	27.90999
27.89948	27.88372	27.98947	27.9458	27.77372	27.84833	27.90972
27.89957	27.88365	27.98901	27.94596	27.77384	27.84861	27.90941
27.89942	27.88352	27.98945	27.94591	27.7734	27.84854	27.91004
27.89945	27.88378	27.98899	27.94576	27.7737	27.84869	27.91032
27.89963	27.88359	27.98935	27.94578	27.7739	27.84875	27.91041
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27.89954	27.88358	27.98949	27.94583	27.77397	27.84907	27.91048
27.89946	27.88365	27.98957	27.94597	27.77402	27.84919	27.91104
27.89962	27.88344	27.98914	27.9462	27.77401	27.84911	27.9113
27.89942	27.88365	27.98965	27.94624	27.77414	27.8493	27.91121
27.89942	27.88376	27.9896	27.94652	27.77418	27.84947	27.9116
27.89955	27.8838	27.98949	27.9465	27.77427	27.84954	27.91153
27.89944	27.88386	27.98945	27.94633	27.77449	27.8495	27.91157
27.89945	27.88388	27.98968	27.94657	27.77438	27.84967	27.91187
27.89961	27.8839	27.98939	27.94674	27.77463	27.84984	27.91208
27.89938	27.88364	27.98955	27.94676	27.77446	27.84972	27.91234
27.89942	27.8837	27.98945	27.94686	27.77466	27.84981	27.91285
27.89928	27.88396	27.98963	27.94691	27.77463	27.84993	27.91266
27.8995	27.88382	27.98971	27.94704	27.77474	27.85004	27.91292
27.8993	27.88374	27.98964	27.94691	27.77449	27.84994	27.91305
27.89924	27.88364	27.98992	27.94716	27.77485	27.85024	27.91398
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27.89946	27.88376	27.98955	27.94695	27.77493	27.85048	27.91378
27.89964	27.88404	27.98985	27.947	27.77507	27.85072	27.91408
27.89966	27.8839	27.98997	27.94725	27.77484	27.85077	27.91396
27.89973	27.88388	27.98964	27.94741	27.7751	27.85096	27.91421
27.89969	27.88382	27.9898	27.9474	27.77534	27.85105	27.91433
27.8996	27.88387	27.99	27.94729	27.77542	27.85104	27.9143
27.89937	27.88394	27.98994	27.94781	27.77528	27.85109	27.91448
27.89945	27.8838	27.9901	27.94755	27.77515	27.85125	27.91547
27.89948	27.88386	27.99005	27.94756	27.77548	27.8513	27.91487
27.89954	27.88385	27.99001	27.94765	27.77574	27.85136	27.91526
27.89949	27.88362	27.99004	27.94771	27.77555	27.85143	27.91518
27.89952	27.88374	27.99001	27.948	27.77558	27.8516	27.91521
27.89943	27.88368	27.9898	27.94789	27.77552	27.8518	27.9152
27.89938	27.88374	27.98994	27.94808	27.77555	27.85167	27.91515
27.89941	27.88367	27.98984	27.94818	27.77581	27.85184	27.91612
27.89948	27.88377	27.99009	27.94809	27.77582	27.85185	27.91639
27.8996	27.88371	27.99	27.94807	27.77599	27.85212	27.91639
27.89961	27.88372	27.98996	27.94808	27.77592	27.85227	27.91664
27.89949	27.88381	27.98971	27.94824	27.77613	27.85248	27.91684
27.89943	27.8837	27.99019	27.94829	27.776	27.85244	27.9169
27.89927	27.8838	27.98962	27.94834	27.77617	27.8524	27.91686

27.89925	27.88387	27.98975	27.94819	27.77614	27.85268	27.91725
27.89937	27.88382	27.98977	27.94824	27.77637	27.85276	27.91767
27.89956	27.88364	27.98956	27.94818	27.77617	27.85277	27.91744
27.89945	27.88364	27.99008	27.9487	27.77649	27.85307	27.91792
27.89971	27.88385	27.99029	27.94868	27.77655	27.85303	27.91795
27.89936	27.88384	27.99009	27.9487	27.77657	27.85316	27.91846
27.89945	27.88374	27.99015	27.94882	27.77615	27.85275	27.9184
27.89924	27.88373	27.98989	27.94869	27.77646	27.85301	27.91884
27.89941	27.88379	27.98988	27.94877	27.7768	27.85312	27.91868
27.89941	27.88384	27.99035	27.94883	27.77664	27.85353	27.9193
27.89965	27.88392	27.98977	27.949	27.77662	27.85339	27.91862
27.8997	27.88392	27.99025	27.94902	27.77686	27.8536	27.91931
27.89947	27.88389	27.98994	27.94897	27.77673	27.85379	27.91921
27.89965	27.88377	27.99038	27.94883	27.77675	27.85357	27.91959
27.8992	27.8838	27.99044	27.94912	27.77695	27.85397	27.91945
27.89955	27.88363	27.99004	27.94921	27.77688	27.85419	27.92005
27.89951	27.88404	27.99037	27.94916	27.77709	27.8541	27.91995
27.89949	27.88384	27.9903	27.94935	27.77714	27.85362	27.92068
27.8994	27.88404	27.99045	27.94949	27.77732	27.85427	27.91992
27.89954	27.88393	27.99029	27.94927	27.77761	27.85478	27.92081
27.89962	27.88394	27.99043	27.94943	27.77714	27.85484	27.92061
27.89951	27.88399	27.99009	27.94947	27.7772	27.85506	27.92135
27.89948	27.88392	27.99063	27.94944	27.77722	27.85516	27.92152
27.89958	27.88399	27.99047	27.94957	27.77742	27.85517	27.92137
27.89979	27.8841	27.99066	27.94929	27.77764	27.85567	27.92157
27.89937	27.8842	27.99036	27.94968	27.77755	27.85542	27.92155
27.89952	27.884	27.99022	27.94973	27.77769	27.85474	27.92186
27.89966	27.88403	27.99048	27.9499	27.77711	27.85545	27.92174
27.89961	27.88393	27.99056	27.94991	27.77774	27.85564	27.92212
27.89938	27.88406	27.99036	27.94984	27.77772	27.8559	27.92232
27.89923	27.88379	27.99009	27.95008	27.77816	27.85553	27.92228
27.89998	27.88401	27.99016	27.95008	27.778	27.85554	27.92275
27.89985	27.88375	27.99052	27.95015	27.77787	27.85605	27.92279
27.89955	27.88392	27.99031	27.95012	27.77823	27.85635	27.92287
27.89957	27.88393	27.99042	27.95033	27.77815	27.85624	27.92297
27.89967	27.88387	27.99063	27.9504	27.77828	27.85662	27.92317
27.89983	27.88392	27.99063	27.95023	27.77815	27.85695	27.92349
27.89989	27.88412	27.9907	27.95019	27.7784	27.85721	27.92357
27.89964	27.88382	27.99069	27.95056	27.77812	27.85719	27.92369
27.89935	27.88414	27.99058	27.95051	27.77856	27.85726	27.9242
27.89953	27.88415	27.99039	27.95061	27.77809	27.85742	27.92425
27.89958	27.88435	27.99012	27.95063	27.77871	27.85749	27.92431
27.89954	27.88425	27.99062	27.95065	27.77862	27.8575	27.9245
27.89968	27.88432	27.99058	27.9506	27.7786	27.85738	27.92503
27.89944	27.88399	27.99024	27.95034	27.77848	27.85721	27.92498
27.89943	27.88424	27.99088	27.95073	27.77858	27.8579	27.92538

27.89958	27.88414	27.99085	27.95052	27.77868	27.85823	27.92507
27.8997	27.88418	27.99107	27.9508	27.77892	27.85833	27.92534
27.89968	27.88413	27.9899	27.95087	27.77875	27.85848	27.92443
27.89997	27.88398	27.99079	27.95096	27.7791	27.85871	27.92557
27.89995	27.88399	27.99024	27.95085	27.77888	27.8591	27.92562
27.89972	27.88432	27.99069	27.95115	27.77894	27.85931	27.92613
27.89966	27.88413	27.99026	27.95129	27.77916	27.85922	27.92593
27.8998	27.88404	27.99101	27.9512	27.77912	27.85958	27.92622
27.89973	27.88406	27.99071	27.95112	27.77943	27.85976	27.92619
27.89994	27.88416	27.99058	27.95135	27.77932	27.86002	27.92656
27.8998	27.88416	27.99078	27.95118	27.77922	27.86013	27.92656
27.89996	27.88411	27.99102	27.95104	27.77906	27.86029	27.92653
27.89968	27.88404	27.99115	27.9514	27.77963	27.8604	27.92657
27.89967	27.88413	27.99076	27.95134	27.77942	27.86055	27.92682
27.89975	27.8842	27.99081	27.95157	27.77933	27.86064	27.92752
27.89992	27.88381	27.99099	27.95148	27.77924	27.86064	27.92756
27.89984	27.88389	27.99072	27.95161	27.77914	27.86087	27.92763
27.89992	27.88399	27.99112	27.95178	27.77997	27.86095	27.92761
27.8999	27.88399	27.99124	27.95149	27.77974	27.86106	27.92763
27.89981	27.88419	27.99097	27.95153	27.77989	27.86124	27.92795
27.89982	27.88412	27.99117	27.9515	27.7798	27.86139	27.92812
27.89954	27.88373	27.99108	27.95191	27.77989	27.86124	27.9286
27.89969	27.88414	27.99104	27.95193	27.78029	27.8619	27.92878
27.89976	27.88409	27.99128	27.95196	27.77958	27.86211	27.92923
27.89983	27.8843	27.99123	27.95166	27.78006	27.86183	27.92924
27.89984	27.88424	27.99089	27.95216	27.7799	27.86216	27.92901
27.89993	27.8841	27.99154	27.95216	27.78004	27.8626	27.9293
27.89971	27.88434	27.99126	27.952	27.78018	27.86254	27.9294
27.89964	27.88424	27.99118	27.95221	27.78014	27.8623	27.92958
27.89972	27.88413	27.99123	27.95228	27.78006	27.86266	27.92986
27.8998	27.8843	27.9903	27.95242	27.78011	27.86291	27.92992
27.89984	27.88403	27.99112	27.95232	27.78013	27.86324	27.93001
27.8997	27.88414	27.9912	27.95236	27.78043	27.8635	27.93014
27.89963	27.8842	27.99103	27.95243	27.78044	27.86345	27.93035
27.89953	27.88428	27.99126	27.95251	27.7807	27.86387	27.93073
27.89974	27.88408	27.99116	27.95249	27.78082	27.86397	27.93072
27.89979	27.88393	27.9912	27.9526	27.78086	27.86428	27.93028
27.89999	27.88406	27.99119	27.9525	27.7809	27.86416	27.93132
27.90002	27.88402	27.99132	27.9525	27.78111	27.86434	27.93091
27.89978	27.88402	27.99152	27.95275	27.78102	27.86459	27.93117
27.8997	27.88424	27.99143	27.95282	27.78128	27.86432	27.93158
27.89747	27.88426	27.9915	27.95263	27.78121	27.86458	27.93159
27.89957	27.88405	27.99151	27.95287	27.78127	27.86472	27.93114
27.89969	27.8843	27.99134	27.95279	27.78119	27.86516	27.93175
27.89937	27.88438	27.99143	27.95281	27.78109	27.86557	27.93186
27.89978	27.88416	27.99152	27.95297	27.7811	27.86536	27.9322

27.89971	27.88398	27.99139	27.953	27.78157	27.86591	27.93162
27.89955	27.88419	27.99142	27.9529	27.78144	27.86576	27.93211
27.89956	27.88414	27.99142	27.95298	27.78169	27.86566	27.9323
27.89954	27.88447	27.99146	27.95331	27.78144	27.86589	27.93244
27.8998	27.88423	27.99154	27.95305	27.78138	27.86549	27.93249
27.89985	27.88412	27.99102	27.95304	27.78172	27.86652	27.9329
27.89964	27.88454	27.99136	27.95328	27.78134	27.86645	27.93306
27.89957	27.88408	27.9915	27.95339	27.78152	27.86627	27.93287
27.89976	27.88431	27.99153	27.95335	27.78172	27.86641	27.93298
27.89957	27.88405	27.99175	27.9535	27.78153	27.86649	27.93314
27.89957	27.88411	27.99165	27.95366	27.78158	27.86682	27.93378
27.8995	27.88458	27.99157	27.95358	27.78174	27.86688	27.93349
27.89965	27.88444	27.99174	27.95346	27.78212	27.86743	27.93351
27.89965	27.88396	27.99152	27.95336	27.7819	27.86783	27.93326
27.89946	27.88445	27.99167	27.95384	27.78202	27.86771	27.93394
27.89936	27.88429	27.99165	27.95377	27.7824	27.86776	27.93409
27.89941	27.88401	27.99176	27.95363	27.78222	27.86828	27.93445
27.89962	27.88412	27.99168	27.95381	27.7823	27.86857	27.93474
27.89959	27.88413	27.99155	27.95387	27.7824	27.86791	27.93404
27.89969	27.88419	27.9918	27.95401	27.78234	27.869	27.93436
27.89956	27.88426	27.99183	27.95392	27.78264	27.86898	27.93522
27.89953	27.88434	27.99194	27.95406	27.78268	27.86921	27.93531
27.89956	27.88433	27.99191	27.95396	27.78267	27.86922	27.93525
27.89953	27.88414	27.99191	27.95391	27.78254	27.86925	27.9353
27.89963	27.8842	27.99176	27.95433	27.78271	27.86966	27.93536
27.89965	27.88431	27.99177	27.9542	27.78257	27.87	27.93602
27.89976	27.88444	27.99205	27.95408	27.78289	27.86948	27.93566
27.89967	27.88435	27.99193	27.95422	27.78277	27.87011	27.9359
27.89968	27.88433	27.9919	27.95435	27.78305	27.87062	27.93643
27.89979	27.88425	27.99238	27.95425	27.78286	27.87072	27.93626
27.89953	27.88448	27.99219	27.95411	27.7825	27.87042	27.93656
27.89946	27.88437	27.99206	27.9542	27.78293	27.87081	27.93625
27.89961	27.88408	27.99215	27.95435	27.78312	27.87102	27.93692
27.89966	27.88439	27.9921	27.95449	27.78314	27.87135	27.93695
27.89981	27.88449	27.99187	27.95461	27.78335	27.87133	27.93698
27.89967	27.88428	27.99182	27.95456	27.78343	27.87163	27.93715
27.89969	27.88431	27.99204	27.95454	27.7834	27.87149	27.93712
27.89979	27.88442	27.99214	27.95499	27.78264	27.87161	27.9372
27.89968	27.88445	27.99221	27.95478	27.78321	27.87201	27.93702
27.89978	27.88441	27.99191	27.955	27.78369	27.87137	27.93756
27.89952	27.88419	27.99213	27.95509	27.78353	27.87234	27.93755
27.89977	27.88446	27.99217	27.95498	27.78387	27.87204	27.9379
27.8994	27.88425	27.99201	27.95499	27.78385	27.87189	27.93762
27.89967	27.88435	27.9917	27.95514	27.78372	27.87235	27.93807
27.89954	27.88432	27.99201	27.95534	27.78384	27.87256	27.93802
27.89973	27.88436	27.99232	27.95502	27.78398	27.87263	27.93794

27.89973	27.88444	27.99188	27.95528	27.78415	27.87285	27.9383
27.89983	27.8843	27.99208	27.95506	27.78379	27.87266	27.93877
27.89949	27.88425	27.99225	27.95554	27.78352	27.87316	27.93838
27.89953	27.88428	27.9923	27.95534	27.78374	27.87307	27.93886
27.89952	27.88446	27.99225	27.95517	27.78403	27.87341	27.93884
27.89958	27.88443	27.99209	27.95555	27.78392	27.87338	27.93917
27.89937	27.88432	27.99172	27.95521	27.78355	27.87341	27.9398
27.89967	27.88421	27.99228	27.95542	27.78424	27.87344	27.93963
27.89978	27.88434	27.99177	27.95548	27.78393	27.87367	27.93932
27.8998	27.8843	27.99243	27.95561	27.78393	27.87386	27.93955
27.89951	27.88412	27.99211	27.95588	27.78412	27.87388	27.93988
27.89954	27.88464	27.99191	27.95594	27.78415	27.87429	27.93966
27.89962	27.8847	27.99172	27.95563	27.78436	27.87462	27.93992
27.89982	27.88464	27.99198	27.95583	27.7843	27.87441	27.94004
27.89931	27.88451	27.99199	27.95579	27.78444	27.87456	27.94037
27.89969	27.88435	27.99188	27.95598	27.78469	27.87481	27.94038
27.89955	27.88446	27.99204	27.9561	27.78483	27.87498	27.94074
27.89982	27.88431	27.9921	27.95602	27.78475	27.87543	27.94048
27.89963	27.88449	27.99195	27.95611	27.78514	27.87527	27.94053
27.89972	27.88447	27.99225	27.95617	27.78503	27.87557	27.94036
27.89961	27.88412	27.99188	27.95613	27.78505	27.87559	27.94057
27.89954	27.88438	27.99257	27.95612	27.78524	27.87559	27.94107
27.89959	27.88427	27.99252	27.95626	27.78507	27.87523	27.94182
27.89938	27.88425	27.99243	27.95631	27.78527	27.87575	27.94157
27.89973	27.88444	27.99265	27.95643	27.78529	27.87571	27.94209
27.8996	27.88465	27.99248	27.95653	27.78533	27.87651	27.94214
27.89974	27.88451	27.99273	27.95623	27.78516	27.8759	27.94216
27.89967	27.88455	27.99236	27.9565	27.78538	27.87607	27.94229
27.89953	27.88449	27.99265	27.95672	27.78548	27.8761	27.94243
27.89966	27.88455	27.9927	27.95664	27.78538	27.87669	27.94274
27.89957	27.88451	27.99256	27.95647	27.78531	27.87695	27.94233
27.89958	27.88461	27.99248	27.95675	27.7856	27.87687	27.94257
27.89948	27.88445	27.99232	27.95668	27.78567	27.87695	27.94288
27.89942	27.88442	27.99258	27.95677	27.78496	27.87715	27.94207
27.89935	27.88461	27.99281	27.95691	27.7847	27.87755	27.94263
27.89944	27.88496	27.99268	27.95689	27.78584	27.87751	27.94305
27.89953	27.88446	27.99265	27.95685	27.78561	27.87741	27.94301
27.89962	27.8844	27.99278	27.95697	27.78555	27.87765	27.94343
27.89944	27.88433	27.99266	27.95698	27.78592	27.8772	27.94361
27.89955	27.88435	27.99301	27.95715	27.78556	27.87766	27.94333
27.89956	27.88441	27.99285	27.9572	27.78634	27.87774	27.94349
27.89951	27.88434	27.99276	27.95711	27.78594	27.87755	27.9441
27.89963	27.88434	27.99303	27.9573	27.78613	27.87821	27.94444
27.89962	27.88457	27.99298	27.95714	27.78631	27.87825	27.94402
27.89964	27.88416	27.9929	27.95721	27.78593	27.87838	27.94442
27.89958	27.88454	27.99275	27.95732	27.78591	27.87838	27.94484

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27.8993	27.88452	27.99242	27.95731	27.78592	27.87863	27.94467
27.89938	27.88446	27.99303	27.95766	27.78568	27.87892	27.94496
27.89947	27.88432	27.99302	27.95794	27.78593	27.87893	27.94491
27.89968	27.88452	27.99236	27.95757	27.78633	27.87931	27.94467
27.89943	27.88445	27.99267	27.95755	27.7865	27.87945	27.94516
27.89933	27.88457	27.9931	27.95747	27.78608	27.87938	27.94558
27.89928	27.88445	27.99308	27.95776	27.78632	27.87973	27.94566
27.8994	27.88458	27.99246	27.95758	27.78674	27.88013	27.94542
27.89953	27.8845	27.99291	27.95776	27.78645	27.87964	27.94517
27.89933	27.88458	27.99317	27.95771	27.78663	27.88026	27.94596
27.89953	27.88462	27.99305	27.95799	27.78725	27.88045	27.94573
27.8996	27.88439	27.9931	27.95786	27.78716	27.88066	27.94604
27.89962	27.88467	27.99289	27.95802	27.78718	27.88073	27.94643
27.89946	27.88456	27.99314	27.95819	27.78721	27.8801	27.9464
27.89958	27.88452	27.99282	27.95813	27.78685	27.88098	27.94646
27.89942	27.8846	27.99311	27.95825	27.78677	27.88049	27.94657
27.8996	27.88436	27.99311	27.95815	27.78686	27.88078	27.94675
27.89973	27.88464	27.993	27.95796	27.78703	27.8812	27.94621
27.89975	27.88427	27.99299	27.95804	27.78727	27.88105	27.94729
27.89969	27.88435	27.99307	27.95823	27.78691	27.88163	27.94695
27.89963	27.88434	27.99315	27.95808	27.7871	27.88135	27.94704
27.89945	27.88458	27.99305	27.95855	27.78734	27.88195	27.94742
27.89953	27.88463	27.9932	27.95826	27.78735	27.88164	27.9471
27.89948	27.88461	27.99324	27.95861	27.78739	27.88203	27.94738
27.89955	27.88469	27.99312	27.95837	27.78705	27.88223	27.94789
27.89974	27.88438	27.99338	27.95872	27.78756	27.88225	27.94765
27.89966	27.88457	27.99349	27.95842	27.78784	27.88248	27.94753
27.89949	27.88442	27.99306	27.95868	27.78764	27.88225	27.94792
27.89918	27.88457	27.99323	27.95866	27.78759	27.88288	27.94757
27.89962	27.88482	27.99324	27.95874	27.78765	27.88301	27.9473
27.89958	27.88454	27.99336	27.95891	27.78741	27.88307	27.94801
27.89959	27.8847	27.99343	27.95893	27.78802	27.88324	27.94823
27.89948	27.88461	27.99342	27.95862	27.78761	27.88313	27.94854
27.89952	27.88471	27.99354	27.95889	27.78707	27.88326	27.94869
27.89962	27.88475	27.99332	27.95901	27.78762	27.88358	27.94877
27.89961	27.88473	27.99373	27.95893	27.78787	27.88364	27.94809
27.89925	27.88477	27.99331	27.95889	27.78813	27.88381	27.94874
27.89949	27.88459	27.99274	27.95918	27.78809	27.88389	27.94877
27.89939	27.88454	27.99277	27.95912	27.78788	27.88415	27.94918
27.89962	27.88468	27.99362	27.95922	27.78807	27.88419	27.94965
27.89962	27.88488	27.99333	27.95923	27.7881	27.88353	27.94951
27.89969	27.88497	27.99358	27.95951	27.78873	27.88402	27.94877
27.89949	27.88472	27.99359	27.95929	27.78836	27.88456	27.94935
27.8996	27.88458	27.99372	27.95931	27.78865	27.88423	27.94978
27.89961	27.8846	27.99349	27.95941	27.78843	27.88461	27.9502

27.89951	27.88462	27.99353	27.95963	27.78857	27.88425	27.94978
27.89945	27.88479	27.9934	27.95937	27.78902	27.88473	27.95029
27.89936	27.88474	27.99357	27.95952	27.78904	27.88472	27.95031
27.89962	27.88457	27.99369	27.9594	27.78905	27.88539	27.94996
27.89954	27.88466	27.99379	27.95972	27.7888	27.88559	27.95033
27.89938	27.88477	27.99381	27.95942	27.78919	27.88557	27.95047
27.89957	27.88444	27.99364	27.95964	27.78931	27.88536	27.95037
27.89952	27.8843	27.99376	27.95966	27.78897	27.88577	27.95088
27.89979	27.88475	27.99354	27.95968	27.78941	27.88607	27.95118
27.89963	27.88485	27.99334	27.95989	27.78927	27.886	27.95067
27.89962	27.88466	27.99348	27.9596	27.78912	27.88605	27.95086
27.89955	27.88452	27.99382	27.95993	27.78883	27.88641	27.95126
27.89949	27.88451	27.99378	27.95997	27.78901	27.88618	27.95119
27.89969	27.88465	27.99335	27.95975	27.78953	27.88627	27.95177
27.89967	27.88486	27.9938	27.96003	27.78937	27.88666	27.95166
27.89944	27.88472	27.9934	27.9601	27.7897	27.88619	27.95192
27.89959	27.8847	27.99353	27.96041	27.78988	27.88663	27.95188
27.89958	27.88465	27.99347	27.96028	27.78969	27.88619	27.95178
27.89979	27.88475	27.99393	27.96033	27.78983	27.88682	27.952
27.89966	27.8848	27.99396	27.96033	27.78999	27.88727	27.95231
27.8995	27.88491	27.9937	27.96046	27.78958	27.88748	27.95222
27.8996	27.88462	27.99389	27.96034	27.78997	27.8874	27.95267
27.89977	27.88472	27.99392	27.9605	27.79032	27.88738	27.95274
27.89969	27.88497	27.99377	27.96021	27.79011	27.88737	27.95275
27.89958	27.8847	27.99412	27.96071	27.79027	27.88789	27.95279
27.89967	27.88491	27.99355	27.96059	27.79034	27.8881	27.95285
27.89967	27.88481	27.99384	27.96048	27.79044	27.88842	27.95297
27.89959	27.88444	27.99414	27.96041	27.79036	27.8884	27.95329
27.89971	27.88473	27.99404	27.96082	27.78969	27.88851	27.95375
27.89973	27.88492	27.99406	27.96049	27.79025	27.88851	27.95323
27.89947	27.88457	27.9938	27.9607	27.7908	27.88897	27.95331
27.89944	27.88477	27.99395	27.96043	27.79066	27.88858	27.95341
27.89952	27.88445	27.99436	27.96085	27.79068	27.88844	27.95343
27.89961	27.88482	27.99413	27.96087	27.79065	27.8889	27.95352
27.89947	27.88489	27.994	27.96095	27.79075	27.88878	27.95391
27.89933	27.88456	27.99412	27.96101	27.79078	27.88939	27.9542
27.89945	27.88483	27.99412	27.96115	27.79098	27.88873	27.9547
27.89964	27.88486	27.99404	27.96069	27.79097	27.88929	27.95453
27.89962	27.88495	27.99408	27.96099	27.79115	27.88873	27.95482
27.89963	27.88501	27.9937	27.96065	27.79093	27.88943	27.95489
27.89964	27.88504	27.99395	27.96119	27.79094	27.88957	27.95498
27.8997	27.88534	27.99412	27.96109	27.79116	27.88975	27.95512
27.89963	27.88472	27.99425	27.96086	27.79095	27.8904	27.95509
27.89973	27.88468	27.99377	27.96107	27.7913	27.88992	27.95523
27.89971	27.88467	27.99362	27.96129	27.7911	27.88952	27.95545
27.89976	27.88502	27.994	27.96141	27.79126	27.89049	27.95536

27.89975	27.88498	27.99426	27.96105	27.79126	27.89055	27.95595
27.89979	27.88445	27.99425	27.96139	27.79146	27.89115	27.95545
27.89954	27.88506	27.99362	27.96155	27.79083	27.89111	27.95569
27.89977	27.88501	27.99392	27.96144	27.79133	27.89132	27.95617
27.89961	27.8848	27.99439	27.96146	27.79151	27.89073	27.95645
27.89968	27.88495	27.99451	27.96166	27.7916	27.89147	27.95633
27.89957	27.88508	27.99406	27.96156	27.79163	27.89065	27.95647
27.89962	27.8848	27.99431	27.9616	27.79144	27.89157	27.95671
27.89988	27.88478	27.99446	27.96164	27.79133	27.89148	27.95624
27.89951	27.88479	27.99429	27.96189	27.79106	27.89151	27.95648
27.89963	27.8851	27.99439	27.96166	27.79154	27.89195	27.95717
27.89939	27.88505	27.99392	27.9617	27.79178	27.89192	27.95669
27.89928	27.88479	27.99424	27.96175	27.7921	27.89183	27.95732
27.89959	27.88488	27.99439	27.96207	27.79199	27.89178	27.957
27.89967	27.88487	27.99451	27.96189	27.79202	27.89236	27.95742
27.8998	27.88484	27.99439	27.96224	27.79183	27.89222	27.95717
27.89962	27.88471	27.99439	27.962	27.79197	27.89243	27.95738
27.89967	27.88504	27.99465	27.96213	27.79203	27.89253	27.95774
27.89966	27.88481	27.99447	27.96211	27.792	27.89244	27.95776
27.8996	27.88498	27.99449	27.962	27.79177	27.89267	27.95802
27.89949	27.88491	27.9947	27.96214	27.79222	27.89254	27.95788
27.89951	27.88483	27.9944	27.9622	27.79233	27.89278	27.95805
27.8996	27.8849	27.99406	27.96243	27.79201	27.89271	27.95845
27.89967	27.88482	27.99473	27.96263	27.79213	27.8933	27.95864
27.89954	27.8849	27.9944	27.96247	27.79222	27.89354	27.95836
27.89952	27.88505	27.99456	27.96252	27.79216	27.89351	27.95865
27.89977	27.8851	27.9946	27.96265	27.79251	27.89305	27.95881
27.89985	27.88517	27.99481	27.96231	27.79265	27.89363	27.95919
27.89979	27.88512	27.99405	27.96252	27.7928	27.8933	27.95901
27.89965	27.8849	27.99453	27.9619	27.79229	27.89364	27.95916
27.89942	27.88499	27.99433	27.96232	27.79272	27.89396	27.95877
27.8994	27.8851	27.99456	27.96286	27.79237	27.89432	27.95854
27.89955	27.88498	27.99469	27.96266	27.79232	27.89447	27.95901
27.89972	27.88485	27.9945	27.96302	27.79218	27.8938	27.95993
27.89969	27.8849	27.99472	27.9629	27.79235	27.89469	27.95952
27.89972	27.8851	27.99481	27.96293	27.79255	27.89442	27.96001
27.89958	27.88512	27.99465	27.96287	27.79279	27.89422	27.96008
27.89956	27.8851	27.99482	27.96302	27.79241	27.89474	27.96014
27.89948	27.88506	27.99495	27.96296	27.79273	27.89451	27.95997
27.89956	27.88498	27.99484	27.96302	27.79243	27.89472	27.96043
27.89964	27.88502	27.99506	27.96302	27.79292	27.8952	27.96029
27.89962	27.88495	27.99496	27.96319	27.79271	27.89553	27.96006
27.89967	27.88496	27.99477	27.96318	27.79298	27.89579	27.95897
27.89973	27.88522	27.99486	27.96317	27.79317	27.89593	27.9614
27.89939	27.88492	27.9947	27.96266	27.7929	27.89569	27.9617
27.89944	27.88499	27.9948	27.96288	27.79316	27.89591	27.95715

27.89968	27.88497	27.99498	27.96337	27.79346	27.89602	53.7909
27.89954	27.88493	27.99497	27.96306	27.7935	27.89648	30.44515
27.89965	27.88465	27.99504	27.96344	27.79344	27.89659	30.07089
27.89975	27.88489	27.99519	27.96346	27.79334	27.89685	24.68525
27.89966	27.8851	27.99496	27.96384	27.79322	27.89689	24.69082
27.89969	27.88502	27.99521	27.96299	27.79334	27.89687	24.69411
27.89944	27.88491	27.99511	27.96362	27.79364	27.89699	24.69608
27.89967	27.88515	27.99522	27.96374	27.79392	27.89729	
27.8995	27.88481	27.99512	27.96381	27.79386	27.89683	
27.89962	27.88493	27.99492	27.96383	27.79395	27.89707	
27.89953	27.88499	27.99506	27.96378	27.79405	27.89739	
27.89985	27.88498	27.99517	27.96394	27.79394	27.89777	
27.89972	27.88502	27.99534	27.96386	27.79361	27.89786	
27.89955	27.88509	27.99538	27.96413	27.79374	27.89743	
27.89944	27.88511	27.99546	27.9639	27.79361	27.89842	
27.89965	27.88489	27.99463	27.96406	27.79393	27.89838	
27.89985	27.88529	27.99504	27.96406	27.79419	27.89856	
27.89966	27.88525	27.99481	27.96389	27.79358	27.89829	
27.89968	27.8853	27.99538	27.96417	27.79317	27.89865	
27.89983	27.88493	27.99535	27.96416	27.79391	27.89894	
27.89999	27.88512	27.99552	27.9642	27.79401	27.89931	
27.89983	27.88519	27.99508	27.96396	27.79403	27.89894	
27.89977	27.8852	27.99506	27.96425	27.79419	27.89891	
27.89983	27.88516	27.99502	27.96435	27.79386	27.89917	
27.89984	27.88499	27.99534	27.96439	27.79413	27.89923	
27.89983	27.88541	27.99487	27.96428	27.79423	27.89926	
27.8999	27.88521	27.99541	27.96425	27.79372	27.89977	
27.89971	27.88504	27.99553	27.96442	27.79446	27.89949	
27.89969	27.88519	27.99534	27.96421	27.79437	27.89975	
27.89992	27.88542	27.99544	27.96436	27.79443	27.8996	
27.8999	27.88498	27.99556	27.96433	27.79429	27.9002	
27.89996	27.88519	27.99522	27.96469	27.7941	27.90014	
27.89975	27.88517	27.99554	27.96459	27.79463	27.90026	
27.9	27.88526	27.99533	27.96472	27.7949	27.90062	
27.89986	27.88502	27.99552	27.96468	27.79501	27.90067	
27.89983	27.88525	27.99563	27.96471	27.79486	27.90107	
27.89987	27.8854	27.99547	27.96494	27.79534	27.9006	
27.89998	27.88561	27.99555	27.96488	27.79523	27.90144	
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27.8996	27.88536	27.99505	27.96507	27.79527	27.90079	
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27.89981	27.88512	27.99546	27.96505	27.7952	27.90152	
27.89989	27.8854	27.99569	27.96523	27.79502	27.90208	
27.89994	27.88541	27.99583	27.96492	27.7949	27.90205	
27.89994	27.88509	27.99516	27.96494	27.79532	27.90214	
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27.90007	27.88529	27.99557	27.96509	27.79572	27.90249
27.89984	27.88526	27.99561	27.96522	27.79562	27.90299
27.89981	27.88509	27.99546	27.96517	27.79576	27.90278
27.90013	27.88529	27.99534	27.96563	27.79555	27.90314
27.90004	27.88526	27.995	27.9653	27.7954	27.90303
27.90016	27.88534	27.99536	27.96549	27.7955	27.90316
27.8997	27.88524	27.99561	27.96543	27.79544	27.90339
27.89976	27.88533	27.99567	27.96527	27.79571	27.90383
27.89985	27.88518	27.99583	27.9653	27.79571	27.90371
27.89974	27.88523	27.99582	27.96578	27.79564	27.90333
27.89982	27.88539	27.9957	27.96567	27.79536	27.904
27.89974	27.88497	27.99573	27.96559	27.7957	27.90393
27.89987	27.88509	27.99591	27.96567	27.79523	27.9045
27.90004	27.88534	27.99595	27.9657	27.79607	27.90453
27.89996	27.88531	27.99591	27.96535	27.79572	27.90447
27.89998	27.88543	27.99547	27.96586	27.79561	27.905
27.90004	27.88498	27.99594	27.96571	27.79603	27.90475
27.89971	27.88524	27.99609	27.96582	27.79592	27.90458
27.89997	27.88521	27.99576	27.96569	27.79614	27.90484
27.90013	27.88526	27.99624	27.96567	27.79624	27.9054
27.89986	27.88537	27.99613	27.96565	27.79651	27.90531
27.90008	27.88546	27.99602	27.96586	27.79638	27.90524
27.8999	27.88517	27.99553	27.96569	27.79618	27.90566
27.89995	27.88524	27.99573	27.96588	27.79585	27.90593
27.89984	27.88529	27.99571	27.96611	27.79653	27.90578
27.9	27.88541	27.99592	27.96613	27.79643	27.90593
27.89991	27.88522	27.99606	27.96596	27.79603	27.90622
27.8998	27.88531	27.99563	27.96605	27.79645	27.90677
27.89997	27.88525	27.99595	27.96598	27.79617	27.90656
27.90014	27.88557	27.99599	27.96611	27.79631	27.90632
27.8999	27.88554	27.99589	27.96625	27.79692	27.90699
27.89997	27.88558	27.99601	27.96615	27.7968	27.90744
27.90008	27.88557	27.99597	27.9661	27.79729	27.90766
27.89994	27.88553	27.99599	27.96636	27.79709	27.90749
27.89966	27.88552	27.99618	27.96631	27.79717	27.90755
27.90002	27.88552	27.99637	27.9666	27.79636	27.90532
27.89981	27.88544	27.99609	27.9664	27.79676	27.90761
27.90009	27.88544	27.99591	27.96635	27.79701	27.90753
27.89991	27.88557	27.99615	27.96642	27.7975	27.90814
27.90006	27.88571	27.99565	27.96646	27.79671	27.90797
27.90006	27.88555	27.99549	27.96648	27.79695	27.91536
27.90009	27.88554	27.99615	27.96655	27.79734	39.30494
27.90017	27.88555	27.99605	27.96668	27.79663	31.48487
27.90002	27.88542	27.99589	27.96674	27.79711	24.69239
27.89991	27.88554	27.99607	27.9667	27.79756	39.86155

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27.89999	27.88544	27.99619	27.96675	27.79806	24.62868
27.89994	27.88533	27.99619	27.96654	27.79367	24.63467
27.89989	27.88547	27.99632	27.96546	27.7976	24.64281
27.90014	27.88541	27.99628	27.96562	27.79787	24.64579
27.89993	27.88541	27.99615	27.96685	27.79795	24.64774
27.90002	27.88546	27.9963	27.96601	27.79759	24.64831
27.9001	27.88556	27.99652	27.96678	27.79756	24.64881
27.89999	27.88544	27.99633	27.96672	27.79738	24.64907
27.90003	27.88553	27.99637	27.96703	27.79784	24.64892
27.89994	27.8855	27.99666	27.96664	19.2112	24.64958
27.8997	27.8855	27.99651	27.96563	14.12173	24.64877
27.90023	27.88564	27.99666	7.44536	12.64032	24.64963
27.90008	27.88546	27.99627	39.30891	24.18159	24.6497
27.90013	27.88558	27.99661	12.70751	24.5252	24.64974
27.90026	27.88564	27.99651	24.70825	24.53284	24.64986
27.90004	27.88552	27.99671	24.70165	24.53565	24.65035
27.90003	27.88558	27.99633	24.7051	24.53674	24.65051
27.89988	27.88553	27.99532	24.70602	24.5377	24.6504
27.89997	27.88551	27.99476	24.70742	24.5382	24.65004
27.89993	27.88539	27.99625	24.70777	24.53874	24.65017
27.89988	27.88555	27.99572	24.70795	24.53927	24.65054
27.89999	27.8854	27.99615	24.70813	24.5393	24.6506
27.90007	27.88531	27.99617	24.70821	24.53967	24.65053
27.89992	27.88543	27.9965	24.70886	24.53983	24.65025
27.9001	27.88569	27.99603	24.70893	24.53965	24.65037
27.90009	27.88552	5.703	24.70847	24.53949	24.6504
27.90003	27.88555	5.67133	24.70908	24.54004	24.65037
27.90005	27.88568	12.77588	24.70909	24.54027	24.64968
27.90015	27.88552	24.73272	24.70919	24.5405	24.65069
27.89988	27.88561	24.73644	24.70918	24.5401	24.65086
27.89991	27.88559	24.73679	24.70876	24.54027	24.65038
27.90001	27.88579	24.73707	24.70907	24.54037	24.65041
27.90013	27.88555	24.73706	24.70922	24.5402	24.65065
27.90019	27.8854	24.73752	24.70918	24.54037	24.65047
27.90011	27.88557	24.73829	24.70881	24.54008	24.65047
27.89989	27.88576	24.73823	24.70794	24.54028	24.65096
27.90023	27.88548	24.73846	24.7077	24.54005	24.65072
27.90019	27.88567	24.73829	24.70891		24.65071
27.9	27.88555	24.73782	24.70916		24.65088
27.90021	27.8855	24.73845	24.70891		24.65133
27.90024	27.88555	24.73838	24.70869		24.6515
27.90026	27.88558	24.73778	24.7092		24.65146
27.90032	27.8856	24.73809	24.709		24.6511
27.9005	27.88552	24.73861	24.7091		24.65145
27.90034	27.88544	24.73861	24.70901		24.65136

27.89987	27.88561	24.73791	24.70923		24.65101
27.90003	27.88577	24.73804	24.70905		24.65101
27.9001	27.88556	24.73832	24.70843		24.65135
27.89994	27.88571	24.73808	24.7094		24.65133
27.90018	27.88582	24.7386	24.70921		24.65131
27.90015	27.8857	24.73828	24.70922		24.65142
27.89982	27.88558	24.73791	24.70924		24.65122
27.90013	27.88554	24.738	24.70909		24.65143
27.90008	27.88595	24.73817	24.70882		24.65146
27.9002	27.88561	24.73827	24.70898		24.65139
27.90019	27.88581	24.7381	24.70857		24.65121
27.89958	27.88581	24.73791	24.70863		24.65164
27.89989	27.88563	24.7381	24.70821		24.65136
27.89955	27.88584		24.70895		24.65134
27.89962	27.88552		24.70876		24.65153
27.89997	27.88572		24.70902		24.65169
27.90009	27.88584		24.70844		24.65166
27.90005	27.88577		24.70854		24.65172
27.89976	27.88571		24.70945		24.65163
27.8999	27.88586		24.70852		24.65162
27.90001	27.88564		24.70861		24.65129
27.90009	27.88562		24.70903		24.65158
27.90008	27.88565		24.70857		24.65164
27.90024	27.88561		24.70922		24.65189
27.90009	27.88568		24.70837		24.65155
27.90001	27.88563		24.70916		24.65185
27.89999	27.88555		24.70913		24.65166
27.90011	27.88595		24.70929		24.65143
27.9003	27.88583		24.70862		24.65105
27.90016	27.88554		24.70853		24.65169
27.90011	27.88574		24.70887		24.65152
27.90005	27.88562		24.70865		24.65147
27.90003	27.88586		24.70883		24.65154
27.90002	27.88575		24.70937		24.65165
	27.88575		24.70907		24.65173
	27.88577		24.70843		24.65155
	27.88562		24.70892		24.65157
	27.88568		24.7088		24.65132
	27.88588		24.70928		24.65172
	27.88593		24.70902		24.65119
	27.88596		24.7092		24.65149
	27.88606		24.70948		24.65144
	27.88599		24.70838		24.65171
	27.8859		24.70948		24.6514
	27.88614		24.7092		24.65139
	27.88594		24.7091		24.65172

27.88586	24.70933	24.65163
27.88609	24.7093	24.65163
27.88593	24.70906	24.65166
27.88554	24.70945	24.65163
27.88607	24.70881	24.65188
27.88613	24.70927	24.65077
27.88613	24.70867	24.65123
27.88558	24.70892	24.65216
28.32017	24.709	24.65165
5.72058	24.7089	24.65172
5.6809	24.70916	24.65197
5.68286	24.70893	24.65207
21.34282	24.70879	24.65202
24.62478	24.70883	24.65174
24.62641	24.70868	24.65152
24.62593	24.70839	24.65172
24.62398	24.70943	24.65142
24.62414	24.70879	24.65143
24.62336	24.70874	24.65142
24.62449	24.70887	24.65217
24.62376	24.70936	24.65193
24.62252	24.70924	24.65128
	24.70917	24.65088
	24.70916	24.65157
	24.70924	24.65165
	24.7091	24.65147
	24.70826	24.65167
	24.70912	24.65196
	24.70889	24.65219
	24.70942	24.65194
	24.70945	24.65151
	24.70984	24.65191
	24.70946	24.65187
	24.70895	24.6521
	24.71	24.65206
	24.70949	24.65187
	24.70971	24.65189
	24.7098	24.65231
	24.70925	24.65153
	24.70869	24.65195
	24.70956	24.65152
	24.70886	24.65202
	24.70937	24.65208
	24.70943	24.65188
	24.70969	24.65227
	24.71018	24.65128

24.70941	24.65166
24.70963	24.65172
24.7098	24.65176
24.70937	24.65214
24.70923	24.65226
24.70946	24.65221
24.7096	24.65199
24.70934	24.65167
24.70903	24.65246
24.70949	24.65167
24.70967	24.65244
24.7095	24.65233
24.70941	24.65229
24.70953	24.65178
24.70932	24.65211
24.71037	24.65216
24.70985	24.65192
24.70946	24.65218
24.70936	24.65233
24.70968	24.65177
24.70963	24.65209
24.70919	24.65225
24.70937	24.6519
24.70949	24.65179
24.70961	24.65234
24.70991	24.65236
24.70942	24.65227
24.70944	24.65196
24.70947	24.65234
24.70948	24.6523
24.70932	24.65278
24.7095	24.6523
24.70978	24.6522
24.70972	24.65187
24.70936	24.65237
24.70919	24.65238
24.70958	24.65213
24.70863	24.65173
24.70859	24.65239
24.70658	24.65214
24.70696	24.65207
24.70892	24.65177
24.70639	24.65212
24.54964	24.6526
25.0351	24.65212
24.00038	24.65267

24.65199
24.65229
24.65273
24.65242
24.65259
24.65218
24.6527
24.65077
24.65275
24.6526
24.64842
24.64412
24.64543
24.64629
24.64336
24.64237
24.63868
24.63756
24.0785
22.301
-4.75008
5.67509
5.67247
5.67223
5.68017

Raw data values from the TGA experiment with Helium, Argon and water vapour are shown below:

400 water	**500 water**	**600 water**	**700 water**	**750 water**	**800 water**	**900 water**	**400 water redone**
3.25973	9.4896	3.26026	3.26027	3.26016	3.26021	3.25952	3.2599
3.25978	9.48966	3.26043	3.26018	3.26006	3.25981	3.25967	3.25991
3.25973	9.4897	3.26033	3.26023	3.26001	3.26	3.25967	3.2599
3.25972	9.4896	3.26042	3.26018	3.26003	3.25995	3.25973	3.25986
3.25979	9.48977	3.26035	3.26021	3.26011	3.25986	3.25978	3.25994
3.25978	9.48976	3.2603	3.26016	3.26001	3.25988	3.25975	3.25986
3.25976	9.48974	3.26034	3.26017	3.25999	3.25985	3.25975	3.25993
3.2598	9.4898	3.2603	3.26024	3.26005	3.25985	3.25975	3.25988
3.25967	9.48973	3.26024	3.26019	3.26003	3.25986	3.25962	3.25993
3.25975	9.48966	3.26029	3.2602	3.26003	3.25995	3.25961	3.25994
3.25959	9.48965	3.2603	3.26031	3.26008	3.25993	3.25954	3.25984
3.25982	9.48967	3.26021	3.26021	3.25999	3.25993	24.65751	3.25989
3.25982	9.48959	3.26027	3.26021	3.26001	3.26003	24.65677	3.25988
3.25974	9.4896	3.26027	3.26028	3.25995	3.25998	24.65614	3.25989
3.25983	9.48961	3.26024	3.26041	3.26002	3.2599	24.65865	3.25981
3.25972	9.48952	3.26026	3.26023	3.26002	3.25987	24.65764	3.25981
3.25973	9.48965	9.53137	3.26027	3.25991	3.25998	24.65661	3.25979
3.25975	9.48975	9.53139	3.26022	3.26	3.25993	24.65574	3.25982
3.25974	9.48965	9.53151	3.26022	-0.00006	3.2599	24.65629	3.2598
9.59554	9.48957	9.5316	3.26016	9.63052	3.25998	24.65626	3.25971
9.59556	9.48956	9.53161	3.26013	9.63047	3.25992	24.65577	3.25978
9.5954	9.48958	9.53151	3.26021	9.63064	3.25996	24.65602	3.25971
9.59548	9.48965	9.53161	3.26033	9.63041	3.2599	24.65631	3.25979
9.59556	9.48955	9.5315	3.26018	9.63043	3.25993	24.65639	3.25988
9.59553	9.48963	9.53155	3.26023	9.63048	3.25991	24.65652	3.2597
9.59551	9.48971	9.53154	3.2602	9.63043	3.25997	24.65692	3.25972
9.59549	9.48966	9.53159	3.2603	8.83868	3.25993	24.65709	3.25976
9.59558	9.48971	9.53153	3.26021	5.68259	3.25984	24.65728	3.25988
9.59559	9.48964	9.53148	3.26031	5.68277	3.25996	24.65695	-0.00007
9.59562	9.48952	9.53154	3.26038	5.68274	3.25995	12.52777	0
9.59563	9.48971	9.53152	3.2602	5.68277	3.25993	5.67913	0
9.5956	9.48959	9.53164	3.26031	17.513	3.25984	5.67992	0
9.59559	9.48954	9.5313	3.26021	28.1189	3.25984	5.6933	0
9.59549	9.48953	9.53149	3.26029	28.11894	3.25982	37.21368	0
9.59563	9.48959	9.53162	3.2602	28.11905	3.2599	10.66384	0
9.59548	5.68352	9.53151	3.26026	28.11909	3.25981	6.31422	0
9.59539	5.6836	9.53145	3.26029	28.11913	3.25983	6.31487	0
9.59545	5.68368	9.53152	3.26029	28.11915	3.25982	6.31381	0
5.68255	5.68362	9.53134	3.26022	28.11911	3.25978	6.31333	0
5.68273	5.68407	9.5314	3.26019	28.11899	3.25981	6.31279	0
5.68263	27.56571	9.53146	3.2602	28.119	3.25988	6.31219	0
5.68267	27.56563	9.53148	3.26028	28.11895	3.25994	6.3123	0
5.68243	27.56572	9.53144	3.26028	28.11894	3.25533	6.3128	0

5.68249	27.56564	9.53146	3.26026	28.11899	0	6.31314	0
28.41538	27.56561	9.53151	3.26031	28.11887	0.00005	6.31333	0
28.03904	27.56563	9.53156	3.26032	13.49391	-0.00002	6.31277	0
28.03918	27.56565	9.53138	3.26023	5.68269	0	6.31295	0
28.03924	27.56554	9.5314	3.26026	5.68263	0	6.31288	0
28.03932	27.56538	9.53143	3.26018	5.68265	0	5.67939	0
28.03938	27.56551	9.53154	3.26026	5.68306	0	5.67914	0
28.03925	27.56552	9.5315	3.26033	21.0902	0	5.68013	0
28.03939	27.56563	9.53146	3.26026	24.85903	0	5.68037	0
28.0392	27.56549	9.53145	3.26029	24.85903	0	21.04783	0
28.03922	27.56555	9.53147	3.26029	24.85909	0	24.65693	0
28.03926	27.56558	9.53145	3.26023	24.85907	0	24.6558	0
28.03929	27.56566	9.5315	3.26017	24.85901	0	24.65612	0
28.03937	27.56565	9.53138	3.26033	24.85912	0	24.6564	-2.11102
28.03935	27.56568	9.53146	3.26037	24.85907	0	24.65618	5.72751
28.03942	27.56554	9.53135	3.26032	24.85905	0	24.65784	9.70302
28.0394	27.56563	9.53135	3.26029	24.85907	0	24.65853	9.70296
28.03937	27.56553	9.53137	3.26022	24.85911	0	24.65866	9.70293
28.03937	27.56547	9.53136	3.26021	24.85903	0	24.65885	9.70291
28.03939	27.56556	9.53144	3.26025	24.85917	8.37949	24.65897	9.70282
25.15421	27.56554	9.53144	3.26031	24.8592	9.59612	24.65876	9.70261
5.68252	27.56557	9.53138	3.26029	24.85913	9.59613	24.65898	9.70278
5.68252	27.56561	9.53126	3.26027	24.85915	9.59622	24.65862	9.70281
5.68595	27.56562	8.35358	3.26022	24.85917	9.59615	24.65876	9.70285
10.39406	27.56562	5.683	3.26033	24.85916	9.59631	24.65869	9.70286
24.77975	27.56561	5.6833	3.26022	24.85909	9.59635	24.65878	9.70289
24.77967	27.56563	5.6832	3.26018	24.85917	9.59634	24.65873	9.7029
24.77965	27.56564	5.68317	3.26025	24.85903	9.59609	24.65893	9.70297
24.77965	27.56562	5.6831	9.54277	24.85906	9.59607	24.65872	9.70271
24.77977	27.56555	5.6831	9.54284	24.8591	9.59606	24.65894	9.70273
24.7797	27.56566	5.69743	9.54291	24.85882	9.59623	24.65872	9.70275
24.77959	27.56536	5.67291	9.54297	24.85897	9.59603	24.65885	9.70283
24.77975	27.56561	24.74717	9.54287	24.85915	5.68268	24.65903	9.7027
24.77977	27.56558	24.74703	9.54284	24.85911	5.68271	24.65907	8.16428
24.77975	27.56555	24.74719	9.54304	24.85911	5.68274	24.6589	5.68208
24.77973	27.56548	24.74701	9.54294	24.85907	5.68271	24.65898	5.68193
24.77972	27.5656	24.74715	9.54298	24.85905	5.68268	24.65878	5.682
24.77957	27.57833	24.74722	9.543	24.859	5.68295	24.65896	5.68207
24.77955	5.68312	24.7471	9.54311	24.85898	5.68278	24.65915	5.68223
24.7796	5.68352	24.74722	9.54286	24.85902	5.6857	24.65901	5.68225
24.7798	5.68357	24.74725	9.54289	24.85915	18.83981	24.65895	5.68209
24.77977	5.68356	24.7472	9.54293	24.85905	27.76139	24.65886	12.49952
24.77959	5.68356	24.74713	9.54297	24.8591	27.76146	24.65888	28.20016
24.77962	5.6827	24.74711	8.3558	24.85917	27.76147	24.65903	28.20021
24.77959	18.24422	24.74722	3.25992	24.85913	27.76149	24.65899	28.20013
24.77963	24.30502	24.74722	0.00018	24.85914	27.76162	24.65884	28.20012

24.77962	24.30478	24.74724	-0.0001	24.85921	27.76159	24.65903	28.20014
24.77963	24.30514	24.74721	0.00003	24.85912	27.76164	24.65891	28.20005
24.77966	24.30519	24.74727	0	24.85908	27.76171	24.6589	28.20017
24.77973	24.30518	24.74737	4.56124	24.85909	27.76167	24.65903	28.20022
24.77963	24.30549	24.74719	5.68342	24.85907	27.76166	24.65912	28.20016
24.77964	24.30527	24.74711	5.68323	24.85908	27.76144	24.65898	28.20018
24.77945	24.30527	24.74706	14.48422	24.85915	27.76144	24.65921	28.20013
24.77957	24.30522	24.74707	27.96283	24.85906	27.76137	24.65914	16.24122
24.77962	24.30527	24.74723	27.96279	24.85912	27.76141	24.65912	5.35802
24.77955	24.30531	24.74702	27.9629	24.85913	27.76147	24.65889	5.68756
24.77962	24.30513	24.74713	27.96296	24.85908	27.7614	24.65919	24.94002
24.77956	24.3052	24.74721	27.96287	24.85908	27.76152	24.65914	24.94049
24.77968	24.30522	24.74727	27.96292	24.85915	16.32304	24.65914	24.94022
24.77969	24.3051	24.74716	27.96292	24.85905	5.68274	24.65892	24.96322
24.77966	24.30515	24.74734	27.96284	24.85912	5.68271	24.65894	24.94029
24.77956	24.30528	24.74721	27.96292	24.8592	5.67255	24.65909	24.94012
24.77952	24.30535	24.74727	27.96294	24.85914	24.50366	24.65903	24.94031
24.77965	24.30539	24.74736	27.9629	24.85913	24.50313	24.6589	24.94021
24.77958	24.30504	24.74716	27.96291	24.8592	24.50009	24.65894	24.94022
24.77971	24.30513	24.74709	27.96296	24.85916	24.50164	24.65906	24.94022
24.77961	24.30529	24.74689	27.96287	24.85915	24.50168	24.65859	13.73554
24.77948	24.30528	24.74735	27.96295	24.85911	24.50161	24.65877	24.94148
24.77957	24.30515	24.74743	27.963	24.85912	24.50172	24.65895	24.94022
24.77966	24.30503	24.74729	27.96287	24.8592	24.50172	24.65858	24.94026
24.77965	24.30517	24.74736	27.96289	24.85916	24.50176	24.65896	24.94031
24.77954	24.30516	24.74745	5.68324	24.85921	24.50169	24.6589	24.94018
24.77962	24.30532	24.7473	5.6834	24.85915	24.50151	24.65897	24.94021
24.77971	24.3053	24.74727	5.68335	24.85918	24.50155	24.65902	24.94029
24.77973	24.30526	24.74731	5.68375	24.85918	24.50173	24.65897	24.9404
24.77967	24.30523	24.74732	24.70286	24.85919	24.50199	24.65909	24.94032
24.77975	24.30521	24.74737	24.70277	24.85915	24.5018	24.65892	24.9403
24.77977	24.30508	24.7475	24.70271	24.85915	24.50193	24.65903	24.94033
24.77942	24.30499	24.74752	24.7026	24.85915	24.50197	24.65897	24.94077
24.77915	24.30522	24.7475	24.70276	24.8591	24.50206	24.6591	24.9407
24.77971	24.30515	24.74739	24.70269	24.85917	24.50201	24.65878	24.9408
24.77984	24.30531	24.74742	24.70267	24.8591	24.502	24.65926	24.94074
24.77976	24.30537	24.7474	24.70274	24.85913	24.50196	24.65903	24.94067
24.77951	24.30524	24.74742	24.7027	24.85913	24.50187	24.65904	24.94068
24.77983	24.30523	24.74741	24.7029	24.85916	24.50189	24.65876	24.94077
24.7797	24.30521	24.74745	24.70279	24.85922	24.50188	24.65903	24.94075
24.77972	24.30525	24.74751	24.70297	24.85911	24.50209	24.65898	24.94076
24.77971	24.30527	24.74757	24.70286	24.85912	24.50197	24.65909	24.9406
24.77971	24.30518	24.74748	24.70288	24.85913	24.50183	24.65879	24.9408
24.77963	24.30531	24.74746	24.70292	24.85913	24.50185	24.65911	24.9408
24.77977	24.30531	24.74748	24.70295	24.85922	24.50187	24.65882	24.94067
24.77981	24.30525	24.74732	24.70283	24.85911	24.50185	24.6588	24.94072

24.7798	24.30521	24.74753	24.70294	24.85922	24.50183	24.65897	24.94079
24.77974	24.30516	24.74741	24.70277	24.85912	24.50189	24.65885	24.94076
24.77983	24.30517	24.74744	24.70283	24.85906	24.50189	24.65902	24.9407
24.7798	24.30512	24.74752	24.70292	24.85908	24.50185	24.65909	24.94071
24.77977	24.30517	24.7474	24.7028	24.85909	24.50191	24.65891	24.94069
24.77983	24.30532	24.74755	24.70286	24.85907	24.50191	24.65891	24.9407
24.77972	24.3053	24.74754	24.70289	24.8591	24.50187	24.65905	24.94075
24.77979	24.30528	24.74757	24.70295	24.85908	24.5019	24.65853	24.94073
24.77969	24.30516	24.74759	24.70298	24.85909	24.50196	24.65867	24.94072
24.77975	24.30527	24.74747	24.70288	24.85917	24.5019	24.659	24.94065
24.77977	24.30525	24.74746	24.70288	24.859	24.50187	24.65866	24.94068
24.77974	24.3053	24.74748	24.70293	24.85887	24.50196	24.6587	24.94066
24.77973	24.30517	24.74746	24.70285	24.85904	24.50183	24.65895	24.94072
24.77988	24.30519	24.74739	24.70282	24.85899	24.50188	24.65902	24.94065
24.77972	24.30521	24.74747	24.70287	24.85911	24.50189	24.65882	24.94058
24.77963	24.30516	24.74743	24.70277	24.85914	24.50193	24.65873	24.94055
24.77957	24.30521	24.7475	24.70288	24.85901	24.50191	24.65864	24.94062
24.77969	24.30513	24.74742	24.70289	24.85906	24.50193	24.65892	24.94065
24.77976	24.30533	24.74748	24.70289	24.85902	24.50202	24.65869	24.94063
24.77968	24.30537	24.74749	24.70279	24.85902	24.50192	24.65895	24.94063
24.77967	24.30538	24.74728	24.70287	24.85905	24.50189	24.65846	24.94082
24.77952	24.30521	24.74741	24.70287	24.859	24.50197	24.65865	24.94066
24.77966	24.3053	24.74745	24.70282	24.85916	24.50177	24.65866	24.94062
24.77969	24.30527	24.74729	24.70275	24.85898	24.50197	24.65828	24.94072
24.7798	24.3052	24.74742	24.7028	24.85896	24.50194	24.65833	24.94068
24.77974	24.30524	24.74734	24.70287	24.85902	24.50212	24.65859	24.9407
24.7797	24.30524	24.74706	24.7029	24.85899	24.50214	24.65874	24.94065
24.77963	24.3053	24.74732	24.70288	24.85902	24.50203	24.65881	24.94063
24.77963	24.30523	24.7474	24.70287	24.85903	24.50199	24.65896	24.94061
24.77976	24.30517	24.74736	24.70276	24.85902	24.50202	24.65863	24.94065
24.77966	24.30521	24.74736	24.70285	24.85899	24.50197	24.65879	24.94068
24.77982	24.30526	24.74696	24.70292	24.85906	24.50205	24.65875	24.94075
24.77962	24.3053	24.74722	24.70297	24.85892	24.50198	24.65844	24.94069
24.77967	24.3053	24.74746	24.70296	24.85894	24.502	24.65885	24.94071
24.77974	24.30527	24.74741	24.70298	24.85888	24.50201	24.6588	24.94068
24.77967	24.30532	24.74736	24.70289	24.85904	24.50199	24.65854	24.94065
24.77965	24.30532	24.74719	24.70287	24.85914	24.502	24.65861	24.94071
24.77963	24.30529	24.74745	24.70285	24.85926	24.50202	24.65822	24.94071
24.7795	24.30523	24.74742	24.70292	24.85909	24.50194	24.65828	24.94066
24.77949	24.30528	24.74735	24.70299	24.859	24.50197	24.65791	24.94074
24.77951	24.30537	24.74739	24.70295	24.85903	24.50201	24.65857	24.94046
24.77963	24.3053	24.74745	24.70298	24.85906	24.50193	24.65826	24.94048
24.77948	24.30539	24.74738	24.70293	24.85904	24.50198	24.65838	24.9406
24.77952	24.30524	24.74716	24.70289	24.85888	24.502	24.65837	24.94057
24.77955	24.30523	24.74751	24.70287	24.85895	24.50205	24.65875	24.94043
24.77947	24.30534	24.74743	24.70283	24.85886	24.50203	24.65856	24.94055

24.77955	24.30532	24.74736	24.70293	24.85899	24.50202	24.65867	24.94057
24.77942	24.30531	24.74722	24.70293	24.85893	24.50201	24.65838	24.94042
24.77952	24.30533	24.74626	24.70292	24.85895	24.50211	24.65796	24.94074
24.77954	24.30531	24.74584	24.70298	24.85896	24.50212	24.65861	24.94069
24.77966	24.30539	24.74666	24.70286	24.85896	24.50207	24.65861	24.9406
24.77949	24.3054	24.74647	24.703	24.85886	24.50209	24.65858	24.94057
24.77955	24.30539	24.74632	24.70294	24.85887	24.50193	24.65869	24.94066
24.77952	24.30545	24.74673	24.70296	24.85908	24.50215	24.65846	24.94064
24.77939	24.30536	24.74713	24.70298	24.859	24.5021	24.65838	24.94068
24.77963	24.30549	24.7471	24.70293	24.85892	24.50204	24.65845	24.9406
24.77951	24.30531	24.747	24.70289	24.85879	24.50205	24.6584	24.94055
24.77954	24.30528	24.74731	24.70296	24.85886	24.50206	24.65866	24.94067
24.77955	24.30541	24.74714	24.70293	24.85889	24.50204	24.65846	24.94054
24.77942	24.30542	24.7465	24.70296	24.85894	24.50214	24.65835	24.9407
24.7794	24.30529	24.74661	24.70296	24.85887	24.50205	24.65837	24.94058
24.77943	24.30533	24.74657	24.70295	24.85874	24.50203	24.65836	24.94067
24.77928	24.30529	24.74731	24.70296	24.8588	24.50211	24.65833	24.94066
24.77942	24.30532	24.74736	24.70304	24.85867	24.50206	24.65832	24.94067
24.77943	24.30538	24.74695	24.70293	24.85887	24.50202	24.65862	24.94055
24.77929	24.30531	24.74691	24.70303	24.85879	24.50215	24.65865	24.94061
24.77946	24.30528	24.74572	24.70294	24.85871	24.50209	24.65861	24.94062
24.77941	24.30529	24.74619	24.70309	24.85864	24.50192	24.65846	24.94061
24.77926	24.30541	24.74591	24.70292	24.85876	24.50216	24.65839	24.94061
24.7795	24.30531	24.7462	24.70294	24.85874	24.5022	24.65863	24.94067
24.77937	24.30529	24.74548	24.70288	24.85874	24.50208	24.65872	24.94044
24.77937	24.30537	24.74631	24.70294	24.85878	24.50197	24.65833	24.94055
24.77912	24.30532	24.74664	24.70306	24.85858	24.50193	24.65845	24.94059
24.77921	24.30535	24.74654	24.70305	24.85859	24.50213	24.65839	24.94056
24.77919	24.30537	24.74616	24.70304	24.85856	24.50207	24.65851	24.94051
24.77924	24.30521	24.74623	24.70299	24.8585	24.50209	24.65807	24.94049
24.77921	24.30536	24.74639	24.70293	24.85855	24.50197	24.6583	24.94053
24.77919	24.30541	24.74677	24.70306	24.8586	24.50197	24.65833	24.94044
24.77936	24.30538	24.74628	24.70305	24.85836	24.50184	24.65791	24.94059
24.77952	24.30533	24.74657	24.70307	24.8587	24.50198	24.65792	24.94072
24.77942	24.30536	24.7459	24.70289	24.85859	24.50208	24.65842	24.94068
24.77949	24.30531	24.74559	24.70296	24.85861	24.5018	24.65819	24.94043
24.77942	24.30545	24.74525	24.70304	24.85848	24.50199	24.65803	24.94063
24.77928	24.30543	24.74538	24.70304	24.85859	24.50193	24.65848	24.94064
24.77928	24.30529	24.74478	24.70296	24.85873	24.50195	24.65833	24.94054
24.77922	24.30525	24.74498	24.70296	24.85872	24.50196	24.65833	24.94063
24.7792	24.30499	24.74428	24.70305	24.85862	24.50178	24.65788	24.94068
24.77914	24.30533	24.7436	24.70302	24.8587	24.50192	24.65776	24.94043
24.77925	24.30533	24.74332	24.70296	24.8587	24.50176	24.65787	24.94079
24.77922	24.30541	24.74386	24.70307	24.85847	24.50168	24.65833	24.94035
24.77928	24.30533	24.74426	24.70299	24.85859	24.50162	24.65836	24.94052
24.77926	24.3054	24.74433	24.70292	24.85864	24.50188	24.65825	24.94058

24.77921	24.30539	24.74457	24.70298	24.85849	24.50184	24.65786	24.94041
24.77942	24.30527	24.74507	24.70294	24.85865	24.50195	24.65811	24.94044
24.77944	24.30537	24.74535	24.70301	24.85836	24.50191	24.65803	24.94064
24.77937	24.30535	24.74468	24.70291	24.85844	24.50191	24.65775	24.94053
24.77939	24.30533	24.74436	24.70277	24.85832	24.50179	24.65786	24.94049
24.77923	24.30539	24.7438	24.70261	24.85838	24.50175	24.65781	24.94042
24.77925	24.30547	24.7446	24.70284	24.85847	24.50187	24.65851	24.94063
24.77928	24.30547	24.7444	24.70276	24.85852	24.50195	24.65829	24.94053
24.77923	24.30532	24.74496	24.7028	24.85837	24.5017	24.65843	24.94046
24.77908	24.30528	24.74425	24.70299	24.85839	24.50167	24.65815	24.9406
24.77923	24.30527	24.743	24.70283	24.85841	24.50173	24.65808	24.94055
24.77919	24.30533	24.74387	24.70296	24.85845	24.50151	24.6578	24.94029
24.77899	24.30527	24.74366	24.70291	24.85837	24.50173	24.65803	24.94046
24.77907	24.30546	24.7441	24.70297	24.85839	24.50163	24.65804	24.94044
24.77923	24.30528	24.74414	24.70282	24.85825	24.50179	24.65725	24.94035
24.7792	24.3052	24.74434	24.70292	24.85842	24.50183	24.65775	24.94028
24.77894	24.30528	24.74441	24.70294	24.85842	24.50193	24.65763	24.94039
24.77904	24.30531	24.74378	24.70289	24.8583	24.50174	24.6579	24.94031
24.77905	24.30534	24.74412	24.70301	24.85835	24.50143	24.65733	24.94028
24.77904	24.30536	24.74365	24.70306	24.8585	24.50171	24.65797	24.94045
24.77898	24.30528	24.74312	24.70301	24.85825	24.5017	24.65787	24.94059
24.77905	24.30522	24.74333	24.70299	24.85828	24.50147	24.65806	24.94026
24.77899	24.30535	24.74293	24.70302	24.8582	24.50194	24.65757	24.94048
24.77895	24.3052	24.74347	24.70304	24.8583	24.50208	24.65744	24.94024
24.779	24.30527	24.7439	24.70302	24.85845	24.50196	24.65785	24.94022
24.77899	24.30536	24.74336	24.70282	24.85837	24.50185	24.6575	24.94058
24.77889	24.30525	24.74345	24.70284	24.8583	24.5019	24.65749	24.94056
24.77882	24.30527	24.7437	24.70291	24.85829	24.50181	24.65827	24.94056
24.77894	24.30519	24.74256	24.703	24.85822	24.5019	24.65756	24.94066
24.77913	24.30525	24.74219	24.70306	24.85825	24.50192	24.65742	24.94074
24.77909	24.30519	24.74283	24.70303	24.85835	24.50189	24.65754	24.94045
24.77901	24.30529	24.74225	24.70305	24.85822	24.50192	24.65777	24.94054
24.77902	24.3054	24.74238	24.70303	24.85814	24.50174	24.65761	24.94041
24.77901	24.30529	24.74201	24.70304	24.85831	24.50185	24.65786	24.9406
24.77909	24.30538	24.7422	24.70296	24.85831	24.50169	24.65769	24.94045
24.77896	24.3053	24.74305	24.70301	24.8583	24.5018	24.65743	24.94041
24.77894	24.30533	24.74318	24.70294	24.85832	24.5017	24.65792	24.94035
24.77888	24.30535	24.74441	24.70293	24.8583	24.50169	24.65745	24.94048
24.77906	24.30529	24.74374	24.70303	24.85823	24.50163	24.65759	24.94045
24.77898	24.30535	24.74292	24.70297	24.85828	24.50171	24.65746	24.94051
24.77902	24.30526	24.74206	24.70311	24.85822	24.50176	24.65731	24.94046
24.77892	24.30527	24.74226	24.70323	24.85835	24.50169	24.6572	24.94036
24.77907	24.30524	24.74137	24.70334	24.85825	24.50161	24.65736	24.94056
24.77886	24.30522	24.74175	24.70317	24.85828	24.50173	24.65747	24.94033
24.77895	24.30518	24.74184	24.70308	24.85806	24.50165	24.6576	24.94052
24.77901	24.30526	24.7423	24.70311	24.85812	24.50173	24.65764	24.94072

24.77882	24.3053	24.74275	24.70319	24.85824	24.50163	24.6577	24.94049
24.77888	24.30521	24.74225	24.70319	24.85828	24.50162	24.65715	24.94048
24.77889	24.3053	24.74177	24.70292	24.85821	24.50183	24.65754	24.9405
24.77905	24.3053	24.74181	24.70284	24.85813	24.50168	24.65745	24.94046
24.77895	24.30522	24.74135	24.70297	24.85805	24.5018	24.65721	24.94053
24.77882	24.30524	24.74134	24.70321	24.85806	24.50182	24.65728	24.94054
24.77887	24.30529	24.74062	24.70327	24.85799	24.5018	24.6576	24.94033
24.77895	24.30533	24.74002	24.70311	24.85812	24.50174	24.65729	24.94058
24.77883	24.30519	24.74216	24.70311	24.85816	24.50177	24.65693	24.94056
24.77888	24.30528	24.7397	24.70302	24.85797	24.50189	24.65735	24.94055
24.77888	24.30524	24.74052	24.70306	24.85808	24.5019	24.65695	24.9404
24.7789	24.3051	24.74103	24.70331	24.85809	24.50184	24.65779	24.9406
24.77885	24.30523	24.7421	24.70318	24.85818	24.50173	24.65727	24.94042
24.7789	24.30522	24.74216	24.70313	24.85806	24.50157	24.6573	24.94043
24.7787	24.30524	24.74143	24.70317	24.8581	24.50187	24.65738	24.94038
24.77867	24.30537	24.74092	24.70312	24.85798	24.50185	24.65745	24.94034
24.77885	24.30532	24.74207	24.70308	24.85816	24.5017	24.65746	24.94058
24.77875	24.30537	24.74186	24.70307	24.8581	24.50179	24.65332	24.94036
24.77888	24.3053	24.74161	24.70314	24.85807	24.50191	33.44051	24.94041
24.77883	24.30513	24.74119	24.7033	24.85838	24.50149	16.61343	24.94055
24.77877	24.30518	24.74113	24.70296	24.8581	24.5015	32.00111	24.94045
24.77868	24.3052	24.74215	24.70283	24.85793	24.50164	27.90964	24.9404
24.77888	24.30525	24.74219	24.70297	24.85804	24.5017	27.91397	24.94062
24.77877	24.30523	24.74151	24.70298	24.85795	24.50127	27.91522	24.94048
24.7789	24.30533	24.74111	24.70313	24.85791	24.50156	27.91613	24.94037
24.7787	24.30526	24.74036	24.7031	24.8578	24.50174	27.91726	24.94057
24.77865	24.30524	24.74054	24.70311	24.85789	24.50167	27.91816	24.9404
24.77881	24.30528	24.74005	24.70324	27.4301	24.50156	27.9198	24.94041
24.77872	24.3053	24.73996	24.70319	48.3297	24.50155	27.92178	24.9405
24.77866	24.30528	24.74042	24.70308	36.15313	24.50166	27.9229	24.94056
24.77873	24.30525	24.74103	24.7032	32.76559	24.50164	27.92453	24.94055
24.77875	24.30523	24.74107	24.70326	28.11804	24.50155	27.92574	24.94038
24.77862	24.30546	24.7406	24.70319	28.11811	24.50149	27.92677	24.94027
24.77864	24.30543	24.74041	24.70321	28.11827	24.50155	27.92783	24.94042
24.77864	24.30537	24.74013	24.70322	28.11818	24.50165	27.92874	24.94031
24.77864	24.30529	24.73977	24.70329	28.11822	24.50152	27.92922	24.94031
24.77863	24.30521	24.74064	24.70306	28.11826	24.50156	27.93016	24.94019
24.77877	24.30522	24.74175	24.70311	28.11844	24.50144	27.93103	24.94034
24.77862	24.30534	24.74042	24.70319	28.11823	24.50152	27.93179	24.94045
24.77858	24.30535	24.73957	24.70315	28.11837	24.50148	27.93289	24.94031
24.77877	24.30533	24.73991	24.70311	28.11889	24.50134	27.93283	24.94028
42.14504	24.30538	24.74063	24.70321	28.11912	24.50152	27.93297	24.94035
9.17134	24.30535	24.74097	24.70321	28.11968	24.50145	27.93378	24.94059
28.01777	24.30549	24.74063	24.70322	28.11985	24.50123	27.93469	24.94024
28.03905	24.30541	24.74011	24.70321	28.12024	24.50151	27.93597	24.94034
28.03865	24.30541	24.7415	24.7032	28.12071	24.50154	27.93639	24.94031

28.03865	24.30545	24.74042	24.70308	28.12122	24.50151	27.93718	24.94032
28.03884	24.30531	24.73961	24.7031	28.12156	24.50156	27.93758	24.94052
28.03894	24.3052	24.74	24.70314	28.12187	24.50155	27.93775	24.94034
28.03887	24.30522	24.74175	24.70329	28.12235	24.50154	27.93746	24.94031
28.03871	24.30534	24.74244	24.7033	28.12269	24.50144	27.93782	24.94045
28.03901	24.30528	24.74357	24.70329	28.12312	24.50156	27.93878	24.94046
28.03863	24.30535	24.74277	24.70331	28.12341	24.50157	27.93914	24.94034
28.0387	24.30532	24.74271	24.70318	28.12375	24.5015	27.93976	24.94027
28.03853	24.30527	24.74194	24.70323	28.1242	24.5014	27.94033	24.94049
28.03855	24.30529	24.74288	24.70329	28.1245	24.50159	27.94073	24.94035
28.03851	24.30516	24.74203	24.70304	28.12464	24.50141	27.94083	24.94046
28.03851	24.30517	24.74107	24.70311	28.12512	24.50139	27.94133	24.94038
28.03867	24.30524	24.74104	24.70303	28.12551	24.50136	27.9417	24.94053
28.03859	24.30538	24.73967	24.70312	28.12571	24.50134	27.94204	24.94036
28.03863	24.30534	24.73927	24.70315	28.12612	24.50142	27.9422	24.9405
28.03839	24.30526	33.70392	24.70309	28.12646	24.50154	27.94281	24.94043
28.0384	24.30531	34.833	24.70313	28.12653	24.50156	27.94292	24.94053
28.03833	24.30514	39.88089	24.70304	28.12677	24.5016	27.94347	24.94062
28.03851	24.30527	27.99939	24.70304	28.12721	24.50147	27.94372	24.94052
28.03856	24.30529	28.00417	24.70315	28.12735	24.50152	27.94442	24.94036
28.03857	24.30519	28.00463	24.7031	28.12757	24.50149	27.94467	24.94041
28.03816	24.30522	28.00525	24.70297	28.12778	24.50138	27.94496	24.94037
28.0384	24.30528	28.00539	24.70308	28.12796	24.50151	27.94523	24.9405
28.03834	24.3051	28.00591	24.70304	28.12821	24.50145	27.94533	24.94032
28.03843	24.30517	28.00584	24.70301	28.1285	24.50138	27.94544	24.94045
28.03831	24.30526	28.00577	24.70296	28.12883	24.5014	27.9459	24.94049
28.03832	24.30516	28.00578	24.70303	28.12902	24.50121	27.94634	24.94059
28.03818	24.30522	28.00585	24.70302	28.12946	24.50153	27.94648	24.9406
28.03836	29.37891	28.00614	24.70324	28.12976	24.50128	27.94675	24.94056
28.03842	43.5839	28.00599	24.70304	28.12973	24.50138	27.94704	24.94034
28.03823	37.9166	28.00602	24.70319	28.12985	24.50157	27.94732	24.94035
28.03826	26.90529	28.00582	24.7033	28.12987	24.50153	27.94766	24.94047
28.03827	27.56647	28.00591	24.70287	28.13024	24.50153	27.9477	24.94058
28.03805	27.56602	28.00595	24.70154	28.13033	24.5015	27.94816	24.9406
28.03814	27.566	28.0061	10.55568	28.13048	24.5014	27.94813	24.9406
28.03799	27.56605	28.00609	5.68246	28.1307	24.50152	27.94901	24.94049
28.03817	27.56606	28.00572	20.36495	28.13065	24.50151	27.9488	24.94054
28.0382	27.56595	28.00618	27.95272	28.131	24.50141	27.94885	24.94047
28.03819	27.56592	28.00626	27.96359	28.13133	24.50146	27.94919	24.94054
28.03808	27.56606	28.00634	27.96342	28.13149	24.5015	27.94968	24.94055
28.03806	27.56601	28.00635	27.9634	28.13169	24.5013	27.95034	24.9406
28.03809	27.56614	28.00631	27.96324	28.13192	24.50153	27.95073	24.94072
28.03809	27.56606	28.00631	27.96364	28.13194	24.50149	27.95028	24.94046
28.03806	27.56607	28.00638	27.96356	28.13202	24.5014	27.95015	24.94065
28.03814	27.56608	28.00667	27.96355	28.13213	24.50129	27.95062	24.94062
28.03822	27.56609	28.0065	27.96355	28.13248	24.50135	27.95154	24.94037

28.03845	27.56606	28.00664	27.96367	28.13253	24.50146	27.95168	24.94043
28.03803	27.56592	28.00659	27.96368	28.13266	24.50122	27.95162	24.94055
28.0381	27.56604	28.00659	27.96388	28.13285	24.50136	27.95193	24.94071
28.03805	27.56596	28.00654	27.96396	28.13317	24.50136	27.95252	24.94049
28.03812	27.56611	28.00658	27.96411	28.13331	24.50058	27.95215	24.94066
28.03801	27.56602	28.00676	27.96435	28.13325	63.4664	27.95297	24.94041
28.03803	27.566	28.00669	27.96459	28.13352	31.5342	27.95306	24.9406
28.03818	27.56618	28.00683	27.96466	28.13342	27.73399	27.95339	24.94056
28.03799	27.5662	28.0068	27.9652	28.1336	27.76053	27.95311	24.94046
28.03793	27.56598	28.00677	27.96514	28.13409	27.76042	27.95403	24.9405
28.03782	27.56599	28.00682	27.96536	28.13397	27.76046	27.9532	24.94041
28.03802	27.56589	28.00689	27.96543	28.13435	27.76102	27.95326	24.94062
28.03804	27.56607	28.00684	27.9658	28.1344	27.76135	27.95363	24.94068
28.03815	27.56605	28.00701	27.96577	28.13448	27.76091	27.95383	24.94046
28.03805	27.56605	28.00717	27.96622	28.13478	27.76117	27.95362	24.94059
28.03798	27.56595	28.00721	27.96635	28.13455	27.76179	27.95428	24.94053
28.03797	27.56603	28.00719	27.96656	28.13474	27.76242	27.95457	24.94067
28.03807	27.56592	28.00704	27.96673	28.13486	27.76318	27.9551	24.94068
28.03797	27.56595	28.00707	27.9668	28.13513	27.76339	27.95526	24.94083
28.03796	27.56597	28.00704	27.96717	28.13515	27.76469	27.95495	24.9408
28.03777	27.56588	28.00697	27.96734	28.13522	27.76531	27.95532	24.94056
28.03797	27.56602	28.00699	27.96751	28.13543	27.76625	27.95528	24.94052
28.03784	27.56582	28.00708	27.96781	28.13565	27.76712	27.95568	24.94049
28.03804	27.56595	28.00723	27.96791	28.13591	27.76743	27.9557	24.94062
28.03801	27.56614	28.00734	27.96773	28.13601	27.7674	27.9559	24.94052
28.03792	27.56588	28.00726	27.96808	28.13591	27.7689	27.95631	24.9405
28.03771	27.56585	28.00738	27.96814	28.13597	27.76912	27.95636	25.60227
28.03758	27.5658	28.00729	27.96833	28.13558	27.76955	27.95642	31.58359
28.03793	27.56593	28.00716	27.9685	28.13615	27.77005	27.95664	5.68469
28.03791	27.56585	28.00722	27.96858	28.13653	27.77023	27.9567	12.52667
28.03797	27.56587	28.00726	27.96882	28.1365	27.77072	27.95692	28.20142
28.03785	27.5659	28.00732	27.969	28.13616	27.77106	27.95689	28.20145
28.03791	27.56589	28.00729	27.96893	28.1367	27.77173	27.95726	28.20159
28.03762	27.56576	28.00735	27.96935	28.1366	27.77203	27.95738	28.20119
28.03787	27.56587	28.00738	27.96928	28.13695	27.77219	27.95792	28.2012
28.03797	27.56591	28.0074	27.96947	28.13701	27.77277	27.9578	28.20141
28.03782	27.56567	28.0075	27.96958	28.13712	27.77335	27.95782	28.20122
28.03772	27.56596	28.00752	27.96994	28.13738	27.77361	27.95801	28.2013
28.03761	27.56593	28.00748	27.9699	28.13743	27.77374	27.95779	28.20115
28.03779	27.56579	28.00755	27.97006	28.13744	27.77425	27.95842	28.20142
28.03801	27.56586	28.00759	27.97008	28.13747	27.77417	27.95886	28.20138
28.03766	27.56569	28.00748	27.97031	28.13739	27.77477	27.95848	28.20125
28.0379	27.56566	28.00756	27.97042	28.13759	27.77554	27.9588	28.20124
28.03778	27.56567	28.00748	27.97061	28.1376	27.77532	27.95888	28.20126
28.03783	27.56578	28.00775	27.97079	28.13778	27.77584	27.95882	28.20116
28.03783	27.56591	28.00759	27.97078	28.13784	27.77631	27.95897	28.2013

28.03787	27.56585	28.00789	27.97092	28.13806	27.77622	27.9594	28.20114
28.03772	27.56592	28.00772	27.97119	28.13796	27.77615	27.95899	28.20126
28.03788	27.56595	28.00767	27.97126	28.13819	27.77613	27.9597	28.2011
28.03793	27.56574	28.00778	27.97137	28.13834	27.77676	27.95985	28.2013
28.03777	27.5659	28.00786	27.97143	28.1386	27.77737	27.95988	28.2013
28.03784	27.56579	28.00766	27.97151	28.13852	27.77742	27.96017	28.20144
28.03781	27.56587	28.00769	27.97165	28.13853	27.77786	27.95998	28.20122
28.03776	27.56602	28.00799	27.97189	28.13887	27.77754	27.96001	28.20131
28.0378	27.56574	28.00773	27.97202	28.1389	27.77837	27.96029	28.20117
28.0377	27.56571	28.00793	27.97205	28.1388	27.77838	27.96024	28.2012
28.03764	27.5656	28.00787	27.97218	28.13899	27.77851	27.96023	28.20127
28.03762	27.56573	28.00788	27.97227	28.13901	27.77868	27.96067	28.20116
28.0377	27.56578	28.008	27.97249	28.13919	27.7796	27.96062	28.20124
28.03769	27.56582	28.0078	27.97266	28.13949	27.77925	27.96067	28.2012
28.03734	27.56584	28.00799	27.97284	28.13935	27.77958	27.96101	28.20119
28.03767	27.56599	28.008	27.97292	28.13922	27.7796	27.96103	28.20108
28.03769	27.56577	28.00801	27.97298	28.1395	27.7799	27.96112	28.20125
28.03732	27.56569	28.00807	27.97317	28.13966	27.78037	27.96111	28.2011
28.03758	27.56584	28.00792	27.97338	28.13964	27.78061	27.96128	28.20109
28.03741	27.56582	28.00812	27.97343	28.13977	27.78064	27.96141	28.20103
28.03755	27.56597	28.00814	27.97342	28.13977	27.78076	27.96144	28.20111
28.03721	27.56576	28.00805	27.97359	28.13991	27.7805	27.96201	28.20112
28.03724	27.56592	28.0081	27.97366	28.14008	27.78069	27.96193	28.20111
28.03753	27.56583	28.00813	27.97394	28.13995	27.78091	27.96182	28.20104
28.03778	27.56594	28.00825	27.97385	28.14004	27.78124	27.96268	28.20116
28.0376	27.56584	28.00829	27.97384	28.14012	27.78124	27.96248	28.20108
28.03763	27.56586	28.00815	27.9741	28.14033	27.78155	27.96229	28.20119
28.03739	27.566	28.00812	27.97411	28.14025	27.78182	27.96244	28.2009
28.03727	27.56595	28.00831	27.97415	28.14043	27.78189	27.9627	28.20118
28.03749	27.56605	28.00819	27.9745	28.14053	27.78194	27.96257	28.20117
28.03734	27.56603	28.00813	27.97454	28.14057	27.78227	27.96285	28.20104
28.03752	27.56617	28.00828	27.9746	28.14074	27.78248	27.9629	28.20095
28.03741	27.56593	28.00834	27.97468	28.14071	27.78282	27.9627	28.20105
28.03759	27.56612	28.00839	27.97466	28.14066	27.78288	27.96313	28.20103
28.03757	27.5661	28.00831	27.97508	28.1407	27.78321	27.96301	28.20116
28.03758	27.56569	28.00811	27.97506	28.14093	27.78306	27.96317	28.20122
28.03772	27.56576	28.0082	27.97497	28.14097	27.7834	27.9635	28.20117
28.03751	27.56603	28.00834	27.97514	28.14117	27.78343	27.96318	28.20118
28.03738	27.56603	28.00825	27.97531	28.14142	27.7838	27.96335	28.20109
28.03756	27.56597	28.00838	27.97532	28.14111	27.78388	27.96364	28.20125
28.03737	27.56627	28.00837	27.97554	28.14131	27.784	27.96373	28.20121
28.0377	27.56615	28.00863	27.97548	28.14145	27.78407	27.96365	28.20104
28.03748	27.56584	28.00839	27.97558	28.14151	27.78421	27.96356	28.20091
28.03743	27.56602	28.00845	27.97562	28.14148	27.78409	27.96432	28.20116
28.03744	27.56597	28.00844	27.976	28.14165	27.78461	27.96425	28.20103
28.03744	27.56595	28.00835	27.97603	28.1417	27.78496	27.9649	28.20112

28.03734	27.56582	28.00844	27.97607	28.14179	27.78519	27.9648	28.20121
28.03744	27.56603	28.00843	27.97626	28.1418	27.78496	27.96465	28.20125
28.0374	27.56609	28.00866	27.97634	28.14201	27.78502	27.96475	28.20113
28.03731	27.56575	28.00859	27.97646	28.1417	27.78525	27.96495	28.20092
28.03736	27.56586	28.0086	27.97626	28.14197	27.78528	27.96495	28.20094
28.0374	27.56572	28.00856	27.97625	28.14199	27.78532	27.96508	28.20099
28.03721	27.56587	28.00876	27.97626	28.14203	27.78555	27.96422	28.20123
28.03721	27.56584	28.00862	27.97646	28.14223	27.78591	27.96502	28.201
28.03735	27.56599	28.00867	27.97668	28.14217	27.7859	27.96558	28.20115
28.03736	27.56582	28.00867	27.97668	28.14229	27.78605	27.96549	28.20112
28.03732	27.56583	28.00869	27.97672	28.14247	27.78625	27.9661	28.2012
28.03732	27.56579	28.00846	27.97691	28.14253	27.78612	27.96597	28.20115
28.03727	27.56584	28.00851	27.97712	28.14267	27.78659	27.96638	28.20092
28.03731	27.56614	28.0087	27.97691	28.14248	27.78634	27.9661	28.20112
28.03724	27.56596	28.00865	27.97714	28.14281	27.78648	27.96596	28.201
28.03724	27.5659	28.0087	27.97713	28.14271	27.78671	27.96527	28.20118
28.03728	27.56569	28.00884	27.97743	28.14288	27.78694	27.96597	28.20107
28.03746	27.56573	28.00868	27.97746	28.14282	27.78683	27.9654	28.20104
28.03735	27.56591	28.00858	27.97713	28.14318	27.7876	27.96588	28.2011
28.03736	27.56587	28.00877	27.97748	28.14288	27.78748	27.96595	28.20117
28.03727	27.56581	28.00891	27.97765	28.14309	27.78734	27.96629	28.20113
28.03718	27.56605	28.00886	27.97765	28.14314	27.78787	27.96647	28.20096
28.03702	27.56574	28.0086	27.9779	28.14295	27.78791	27.96665	28.20104
28.03755	27.56563	28.00873	27.97818	28.14322	27.7886	27.96642	28.2008
28.03712	27.56584	28.00881	27.978	28.14324	27.78816	27.96644	28.201
28.03728	27.56597	28.00886	27.97815	28.14319	27.78822	27.96693	28.20112
28.03719	27.566	28.00898	27.97815	28.14349	27.78798	27.96735	28.20089
28.03716	27.56587	28.00881	27.97814	28.1433	27.78824	27.96676	28.20098
28.03727	27.56589	28.00894	27.97832	28.14331	27.78832	27.96747	28.20097
28.0374	27.5659	28.00894	27.97828	28.14348	27.78833	27.96679	28.20123
28.03726	27.566	28.00914	27.97854	28.14352	27.78884	27.9673	28.20111
28.03717	27.56539	28.00879	27.97837	28.14381	27.78866	27.96729	28.20105
28.03727	27.5652	28.00914	27.97839	28.14363	27.78853	27.96745	28.20103
28.03712	27.56596	28.00898	27.9786	28.14362	27.78882	27.96764	28.20106
28.03725	27.56597	28.00918	27.9787	28.14388	27.78907	27.96786	28.2011
28.03719	27.56589	28.00914	27.97887	28.14412	27.78894	27.9677	28.20124
28.03709	27.56595	28.00927	27.97888	28.14431	27.78924	27.9674	28.20127
28.03694	27.56599	28.00909	27.97895	28.144	27.78923	27.96822	28.20118
28.03714	27.56605	28.00928	27.97909	28.14415	27.7892	27.96805	28.20097
28.03703	27.56616	28.00895	27.97896	28.14416	27.78966	27.96815	28.20108
28.03708	27.56572	28.00878	27.97905	28.14406	27.78941	27.96823	28.20111
28.0373	27.56626	28.00919	27.97905	28.14418	27.78948	27.96793	28.20102
28.03718	27.56608	28.00904	27.97928	28.1442	27.78991	27.9684	28.20106
28.03709	27.56613	28.00889	27.97935	28.14378	27.79008	27.96843	28.20093
28.03693	27.56596	28.00915	27.97942	28.14453	27.78982	27.96816	28.20111
28.03699	27.56596	28.00914	27.97926	28.14458	27.79002	27.96835	28.20109

28.03718	27.56589	28.00889	27.97957	28.14464	27.79037	27.96886	28.20109
28.03724	27.56597	28.00917	27.97962	28.14465	27.79027	27.96912	28.20122
28.03718	27.56588	28.0093	27.97953	28.14459	27.79037	27.96856	28.20118
28.03718	27.56594	28.00917	27.97977	28.14473	27.79075	27.96878	28.20112
28.03714	27.56574	28.00924	27.97997	28.14485	27.79037	27.96932	28.2014
28.03703	27.56592	28.00927	27.97955	28.14478	27.79077	27.96923	28.20112
28.03715	27.56583	28.00922	27.97967	28.1448	27.79062	27.96943	28.20117
28.0373	27.56601	28.00927	27.97983	28.14483	27.79085	27.96896	28.20131
28.03697	27.56599	28.00941	27.98002	28.1449	27.7911	27.96952	28.20092
28.03687	27.56598	28.00924	27.98006	28.14508	27.79124	27.96947	28.20119
28.03688	27.56578	28.00918	27.98013	28.14513	27.79126	27.96971	28.20109
28.03726	27.56603	28.0092	27.98012	28.14507	27.79172	27.96962	28.20133
28.03703	27.56586	28.00933	27.98014	28.14529	27.79106	27.96985	28.20092
28.03684	27.56589	28.00931	27.98016	28.14528	27.79116	27.9699	28.20123
28.0368	27.56607	28.00931	27.98028	28.1453	27.79149	27.96991	28.20116
28.03696	27.56595	28.00926	27.98044	28.14538	27.79175	27.96975	28.20126
28.037	27.56599	28.00936	27.98033	28.14551	27.79189	27.97034	28.20121
28.03673	27.56566	28.00944	27.98045	28.14547	27.79226	27.97009	28.20118
28.03679	27.56599	28.00952	27.98047	28.14543	27.79248	27.97019	28.20109
28.037	27.5659	28.00959	27.98072	28.14574	27.79231	27.97054	28.20135
28.03705	27.5658	28.00946	27.98079	28.14563	27.79179	27.97006	28.20101
28.03686	27.56598	28.00935	27.98071	28.14539	27.79231	27.97059	28.2012
28.03693	27.56587	28.00947	27.98077	28.14593	27.79204	27.97045	28.2012
28.03693	27.56593	28.00956	27.98082	28.14569	27.79211	27.97064	28.20114
28.03688	27.56597	28.00941	27.98098	28.14596	27.7921	27.97081	28.20118
28.03716	27.56603	28.00935	27.98104	28.14595	27.79203	27.97073	28.2012
28.03673	27.56603	28.00932	27.98115	28.14627	27.79212	27.97076	28.20125
28.03702	27.566	28.00932	27.98115	28.14616	27.79253	27.97105	28.2013
28.03714	27.56617	28.00959	27.98113	28.14616	27.79223	27.97106	28.20105
28.03704	27.56598	28.00961	27.98121	28.14635	27.79226	27.97086	28.20113
28.03701	27.56608	28.00955	27.98125	28.1464	27.79211	27.97112	28.20124
28.03683	27.56601	28.00982	27.98137	28.14629	27.79207	27.97095	28.20116
28.03731	27.56607	28.00984	27.98142	28.14608	27.79281	27.97144	28.20112
28.03693	27.56599	28.0095	27.98135	28.14653	27.79259	27.97156	28.20109
28.03707	27.56608	28.0097	27.98149	28.14648	27.79289	27.97148	28.20123
28.03741	27.56584	28.00964	27.9816	28.1464	27.79293	27.97164	28.2014
28.0371	27.56602	28.00954	27.9817	28.14647	27.79293	27.97192	28.20117
28.03713	27.56599	28.00954	27.98171	28.14654	27.79293	27.97154	28.20114
28.037	27.56605	28.00959	27.9819	28.14645	27.79331	27.97204	28.20098
28.03697	27.56605	28.00979	27.98167	28.14677	27.79333	27.97202	28.20113
28.0368	27.56621	28.00978	27.98174	28.1468	27.7934	27.97235	28.20128
28.03693	27.56619	28.00956	27.98193	28.1466	27.79301	27.97219	28.20119
28.03681	27.56603	28.00964	27.98191	28.14684	27.79346	27.97223	28.20121
28.03705	27.56598	28.00977	27.9821	28.14638	27.79352	27.97246	28.20134
28.03719	27.56628	28.00978	27.98214	28.147	27.79359	27.9722	28.20115
28.03716	27.56619	28.00982	27.98222	28.14701	27.79308	27.97238	28.20127

28.03683	27.56605	28.00982	27.98201	28.14711	27.79403	27.97265	28.20125
28.03698	27.56612	28.00962	27.98212	28.14707	27.79348	27.97264	28.20129
28.03687	27.56592	28.00983	27.9823	28.14716	27.7936	27.97226	28.20114
28.03673	27.56603	28.0098	27.98235	28.14725	27.79387	27.97285	28.20117
28.03686	27.56606	28.00973	27.98233	28.147	27.79366	27.97293	28.20093
28.03669	27.56599	28.0099	27.98244	28.14705	27.7943	27.97259	28.20148
28.03679	27.56615	28.00974	27.98234	28.14724	27.79418	27.97249	28.20125
28.03674	27.56624	28.00982	27.98258	28.1471	27.79435	27.97274	28.20124
28.03689	27.56592	28.00989	27.98256	28.14758	27.79429	27.973	28.20114
28.03678	27.56602	28.01003	27.98259	28.14736	27.79428	27.9728	28.2012
28.03653	27.56621	28.00987	27.98278	28.1475	27.79476	27.97322	28.20131
28.03684	27.56616	28.00989	27.98279	28.1474	27.79465	27.97285	28.20114
28.03673	27.56611	28.00961	27.98262	28.14755	27.79448	27.97243	28.20122
28.03709	27.56606	28.00972	27.9828	28.14767	27.79475	27.97322	28.20117
28.03702	27.56621	28.00987	27.98285	28.14756	27.79503	27.97328	28.20134
28.03682	27.56609	28.0099	27.98303	28.14778	27.79484	27.97327	28.20139
28.03704	27.56599	28.01001	27.98304	28.14775	27.79545	27.9733	28.20099
28.03667	27.56595	28.00981	27.98294	28.14779	27.79469	27.9733	28.20122
28.03689	27.56589	28.01001	27.98319	28.14793	27.79465	27.97329	28.20125
28.03694	27.56605	28.01022	27.9832	28.14788	27.79451	27.9738	28.2011
28.03645	27.56624	28.01009	27.98309	28.14805	27.79496	27.97408	28.20123
28.03675	27.56626	28.00984	27.9834	28.14803	27.79478	27.97441	28.20119
28.03665	27.56611	28.01014	27.98329	28.14801	27.79489	27.97466	28.20115
28.03674	27.56588	28.0101	27.98303	28.14803	27.79458	27.97419	28.2013
28.03686	27.56596	28.00998	27.98339	28.14814	27.79491	27.97448	28.20119
28.03679	27.56604	28.00995	27.98362	28.14811	27.79521	27.97441	28.20115
28.03661	27.56614	28.00992	27.98334	28.14833	27.79523	27.97421	28.20135
28.03666	27.56605	28.01009	27.98346	28.14827	27.79517	27.97477	28.20116
28.03674	27.56626	28.01015	27.98369	28.14826	27.79566	27.9744	28.20128
28.03654	27.56606	28.0101	27.98358	28.14851	27.79577	27.97471	28.20126
28.03656	27.56612	28.00992	27.98354	28.14835	27.79554	27.97448	28.20127
28.03686	27.56609	28.01021	27.98364	28.1485	27.7957	27.97487	28.20126
28.03676	27.5662	28.01025	27.98369	28.1484	27.79572	27.97463	28.20142
28.0365	27.56612	28.0102	27.98384	28.14858	27.79597	27.97469	28.20117
28.03658	27.56599	28.01008	27.98389	28.1484	27.79618	27.97463	28.2014
28.03675	27.56609	28.01009	27.98392	28.14863	27.79603	27.97496	28.20126
28.03684	27.56613	28.01029	27.98411	28.14885	27.79635	27.97524	28.20126
28.03662	27.566	28.01015	27.98388	28.14866	27.79606	27.97517	28.20141
28.03679	27.56602	28.01026	27.98403	28.1488	27.79627	27.97546	28.20142
28.03692	27.56588	28.01031	27.98406	28.14884	27.7963	27.97543	28.20128
28.03685	27.56609	28.0104	27.98416	28.14895	27.79656	27.97602	28.20129
28.03667	27.56601	28.01034	27.98412	28.14896	27.79624	27.97583	28.2014
28.03684	27.56607	28.01026	27.98373	28.149	27.79629	27.97571	28.20127
28.03657	27.5663	28.01011	27.98408	28.14921	27.79647	27.97587	28.20124
28.03637	27.56608	28.01038	27.98419	28.14903	27.79657	27.97603	28.20114
28.03661	27.5663	28.01038	27.98438	28.14909	27.79674	27.97559	28.20137

28.03665	27.56609	28.0104	27.98455	28.14922	27.79678	27.97529	28.20118
28.03629	27.56616	28.01052	27.98447	28.14926	27.79625	27.9758	28.20151
28.03662	27.56607	28.01044	27.9844	28.14948	27.79703	27.97623	28.20132
28.0365	27.56609	28.01048	27.98454	28.14941	27.79696	27.97598	28.20138
28.03644	27.56623	28.01031	27.98472	28.14942	27.79684	27.97591	28.20129
28.03657	27.56629	28.01035	27.98457	28.14945	27.79725	27.976	28.20135
28.03661	27.56625	28.01039	27.98466	28.14976	27.79722	27.97599	28.20139
28.03665	27.566	28.01041	27.98472	28.14976	27.7974	27.97666	28.20151
28.03613	27.56596	28.01036	27.98476	28.14965	27.79722	27.97648	28.20135
28.03634	27.56606	28.01041	27.98464	28.14971	27.79737	27.9769	28.20132
28.03629	27.566	28.01041	27.98453	28.1498	27.79789	27.97692	28.20145
28.03663	27.56618	28.01051	27.98499	28.14978	27.79739	27.97637	28.20135
28.03669	27.56621	28.01039	27.98449	28.14977	27.79705	27.97662	28.20125
28.0367	27.56605	28.01021	27.98507	28.14968	27.79778	27.97655	28.2013
28.03662	27.56609	28.01038	27.98507	28.14975	27.79788	27.97691	28.20165
28.03651	27.56605	28.01035	27.98523	28.14976	27.79709	27.9772	28.20133
28.03653	27.56599	28.01054	27.98512	28.14998	27.79814	27.97712	28.20124
28.03697	27.56608	28.01061	27.98535	28.14993	27.7979	27.97732	28.20137
28.03656	27.56591	28.01049	27.98529	28.15009	27.79812	27.97741	28.20139
28.03661	27.56607	28.01062	27.98506	28.15019	27.798	27.97689	28.20148
28.03661	27.56603	28.01053	27.98515	28.15	27.79755	27.97733	28.20131
28.03667	27.566	28.01048	27.98534	28.14993	27.798	27.97691	28.20136
28.03643	27.56622	28.01057	27.9853	28.15022	27.79819	27.9776	28.20144
28.03662	27.56616	28.01062	27.9854	28.15045	27.79819	27.97795	28.20127
28.03622	27.56599	28.01052	27.98539	28.15036	27.79829	27.97781	28.20137
28.03646	27.56615	28.01036	27.98553	28.15039	27.79802	27.97717	28.20133
28.03641	27.56624	28.01048	27.98545	28.15039	27.79809	27.97808	28.20109
28.03652	27.56628	28.01063	27.98557	28.15043	27.7982	27.97816	28.20152
28.03642	27.56618	28.01061	27.98545	28.15056	27.79841	27.97809	28.20126
28.03637	27.56611	28.01059	27.98555	28.15063	27.79764	27.97826	28.20127
28.0363	27.56615	28.0107	27.98567	28.15064	27.79719	27.97849	28.20128
28.03651	27.56615	28.01079	27.98575	28.15082	27.79769	27.97863	28.20147
28.03635	27.56647	28.01041	27.98578	28.15067	27.79781	27.97863	28.20129
28.03638	27.5664	28.01069	27.98593	28.15079	27.79826	27.97872	28.20128
28.03642	27.56602	28.01079	27.9859	28.1509	27.7984	27.97842	28.2012
28.03624	27.56623	28.01074	27.986	28.15101	27.79863	27.97862	28.20148
28.03609	27.56657	28.01089	27.98581	28.15104	27.79923	27.97868	28.20145
28.03657	27.56635	28.01077	27.98598	28.15095	27.79866	27.97837	28.20138
28.0364	27.5663	28.0105	27.98611	28.15107	27.79931	27.97874	28.20139
28.03642	27.56626	28.01074	27.98612	28.15107	27.79939	27.97905	28.20136
28.03635	27.56621	28.01072	27.9862	28.15118	27.7995	27.979	28.20156
28.03658	27.56627	28.01087	27.98607	28.15122	27.79909	27.97928	28.20134
28.03654	27.56606	28.0107	27.986	28.15125	27.79934	27.97919	28.2015
28.03653	27.56624	28.011	27.98625	28.15143	27.7993	27.97935	28.20151
28.03669	27.56566	28.0108	27.98629	28.15131	27.79946	27.97942	28.20153
28.03608	27.5658	28.01092	27.98643	28.15127	27.79924	27.97946	28.20128

28.03629	27.566	28.01092	27.9864	28.15153	27.79958	27.97971	28.20132
28.0362	27.56612	28.01082	27.98636	28.15138	27.79961	27.97863	28.20146
28.03618	27.56638	28.01069	27.98643	28.15144	27.79956	27.97946	28.20143
28.03631	27.56621	28.01073	27.98665	28.15119	27.79943	27.97937	28.20168
28.03611	27.56604	28.01081	27.98655	28.15159	27.79986	27.97899	28.2013
28.03607	27.56625	28.01097	27.98656	28.1516	27.79873	27.97999	28.20144
28.03611	27.56617	28.01088	27.98656	28.15159	27.79987	27.97994	28.20128
28.03627	27.56608	28.01047	27.98674	28.15173	27.79949	27.98025	28.20118
28.03616	27.56638	28.01052	27.98665	28.15178	27.79961	27.98028	28.20128
28.03603	27.56616	28.01097	27.98679	28.15177	27.79924	27.98029	28.20144
28.03626	27.56638	28.01103	27.98663	28.15184	27.7998	27.98034	28.20127
28.03615	27.56657	28.0109	27.98683	28.15208	27.80027	27.98066	28.20127
28.03613	27.5666	28.01064	27.98681	28.15177	27.79967	27.98122	28.20119
28.03623	27.5665	28.0108	27.98696	28.15165	27.79917	27.98131	28.20132
28.03619	27.56652	28.01071	27.98695	28.15179	27.79972	27.98092	28.20145
28.03596	27.5665	28.01096	27.98696	28.15196	27.79991	27.98087	28.2014
28.0362	27.56639	28.01094	27.98703	28.15219	27.80011	27.98072	28.20131
28.03631	27.5664	28.01103	27.98708	28.15201	27.79984	27.98072	28.20128
28.03569	27.56633	28.01095	27.98707	28.1523	27.79934	27.98107	28.20137
28.03621	27.56627	28.01086	27.98719	28.1522	27.80028	27.98049	28.20139
28.03608	27.56629	28.01101	27.98733	28.15253	27.80029	27.98133	28.20148
28.03615	27.56637	28.01081	27.98715	28.15212	27.80013	27.98096	28.20144
28.03605	27.56641	28.01085	27.98712	28.15254	27.80027	27.98145	28.20153
28.03624	27.56652	28.01112	27.98726	28.15245	27.80023	27.98153	28.20124
28.03618	27.56611	28.01109	27.98724	28.15249	27.80038	27.98182	28.2014
28.03607	27.56625	28.01089	27.98735	28.15262	27.80081	27.9822	28.20163
28.03613	27.56639	28.01086	27.98736	28.15257	27.80053	27.98146	28.20151
28.03595	27.56653	28.01107	27.98756	28.15265	27.80052	27.98187	28.20149
28.03624	27.56584	28.01105	27.98754	28.15264	27.80113	27.98196	28.20144
28.0361	27.56628	28.011	27.98766	28.15258	27.80113	27.98191	28.2015
28.03634	27.56639	28.0112	27.98743	28.15287	27.80114	27.98239	28.20142
28.03632	27.56609	28.01123	27.98775	28.15282	27.80123	27.98241	28.20145
28.03611	27.56626	28.0111	27.98778	28.15289	27.80089	27.98209	28.20156
28.03617	27.56634	28.01102	27.98776	28.15318	27.8006	27.98202	28.20145
28.03611	27.5662	28.01122	27.98762	28.15288	27.80106	27.98241	28.20156
28.03611	27.56639	28.01109	27.98753	28.15251	27.80144	27.98162	28.20142
28.03605	27.56631	28.01115	27.98783	28.15302	27.80147	27.98279	28.20139
28.03607	27.56619	28.0111	27.98787	28.1531	27.8014	27.98269	28.20163
28.03604	27.5661	28.01111	27.98749	28.15313	27.80141	27.98303	28.20141
28.03615	27.5662	28.01109	27.98768	28.15313	27.80165	27.98245	28.20157
28.03599	27.5661	28.01112	27.98809	28.15337	27.80201	27.98276	28.20139
28.03621	27.56619	28.01115	27.98803	28.15309	27.80185	27.98233	28.20148
28.0362	27.5662	28.01118	27.98809	28.1529	27.80155	27.98329	28.20161
28.0361	27.56624	28.01103	27.98809	28.15329	27.80177	27.9831	28.20166
28.03601	27.56631	28.01107	27.98814	28.15296	27.80191	27.98342	28.20142
28.03572	27.56627	28.0112	27.98828	28.15318	27.80216	27.98266	28.20141

28.03603	27.56617	28.01143	27.98823	28.15326	27.80237	27.9834	28.20144
28.03585	27.56624	28.01123	27.98829	28.15335	27.80171	27.98285	28.2015
28.03612	27.56646	28.01122	27.98836	28.15354	27.8022	27.98354	28.20153
28.03602	27.56642	28.01124	27.98849	28.15368	27.80238	27.98326	28.20144
28.03631	27.56652	28.0112	27.98839	28.15378	27.80197	27.9831	28.20157
28.03616	27.56606	28.01115	27.9883	28.15393	27.80259	27.98338	28.20157
28.03609	27.56607	28.01119	27.98843	28.1538	27.80199	27.98318	28.20146
28.03607	27.56632	28.01123	27.98861	28.15396	27.8022	27.98379	28.20166
28.03589	27.56633	28.0113	27.98837	28.1535	27.80179	27.98372	28.2015
28.03578	27.56636	28.01132	27.98866	28.15388	27.80263	27.98379	28.20156
28.03548	27.56638	28.01117	27.9882	28.15395	27.80278	27.98352	28.2016
28.03589	27.56628	28.01121	27.98818	28.15391	27.80238	27.98375	28.20156
28.03555	27.56647	28.01137	27.98854	28.1539	27.80288	27.98385	28.20159
28.03554	27.56631	28.01144	27.98871	28.15409	27.80266	27.98403	28.20186
28.03622	27.5663	28.01121	27.98873	28.15411	27.80283	27.98468	28.2018
28.03575	27.5662	28.01143	27.98887	28.15416	27.80289	27.98413	28.20147
28.03589	27.56619	28.01141	27.98883	28.15432	27.8025	27.98424	28.20163
28.03592	27.56632	28.01139	27.98908	28.15405	27.80202	27.98394	28.20165
28.03616	27.5664	28.01134	27.98899	28.15413	27.80261	27.98487	28.20176
28.03586	27.56639	28.01139	27.989	28.15431	27.80281	27.98481	28.20158
28.03607	27.56622	28.01141	27.98901	28.15461	27.8026	27.98396	28.20161
28.03593	27.56618	28.01147	27.98888	28.15473	27.80286	27.98522	28.2015
28.03597	27.56605	28.01159	27.98921	28.15454	27.80283	27.98466	28.20166
28.03616	27.56615	28.01155	27.98919	28.15453	27.80328	27.9849	28.2015
28.0359	27.56606	28.01146	27.98909	28.15473	27.80317	27.98526	28.20161
28.0357	27.56608	28.01142	27.9889	28.15462	27.8035	27.98536	28.20152
28.03599	27.56619	28.01149	27.98899	28.15464	27.80375	27.98545	28.20158
28.03521	27.56625	28.0117	27.9892	28.15457	27.80406	27.9851	28.20147
28.03566	27.56652	28.01163	27.98923	28.15486	27.80384	27.98592	28.20154
28.03633	27.56626	28.01153	27.98905	28.15431	27.80357	27.98539	28.20143
28.03595	27.5665	28.01125	27.98902	28.15484	27.80435	27.98582	28.20153
28.03593	27.56612	28.01143	27.98933	28.15465	27.80444	27.98453	28.20149
28.03587	27.56576	28.01154	27.98936	28.15487	27.80295	27.98614	28.20159
28.03579	27.56634	28.01167	27.98939	28.15482	27.80407	27.9861	28.20156
28.0356	27.56637	28.01144	27.98944	28.1552	27.80429	27.98584	28.20159
28.03576	27.56641	28.01156	27.9896	28.15493	27.80392	27.98678	28.20152
28.0357	27.56641	28.01147	27.98943	28.15523	27.80389	27.98632	28.20174
28.03571	27.56632	28.01146	27.98965	28.15518	27.80385	27.9864	28.20159
28.03566	27.5662	28.01168	27.9897	28.15482	27.80324	27.98576	28.20156
28.03548	27.56627	28.01162	27.98933	28.15515	27.80325	27.98646	28.20172
28.03587	27.56609	28.01162	27.98939	28.15534	27.80348	27.98621	28.20153
28.03564	27.56613	28.01178	27.98987	28.15502	27.80309	27.98572	28.20155
28.03571	27.56625	28.01171	27.98973	28.15542	27.80299	27.98652	28.20142
28.03577	27.56627	28.01154	27.9896	28.15535	27.80353	27.98697	28.20161
28.03554	27.56633	28.01151	27.98993	28.15542	27.80364	27.98699	28.20161
28.03583	27.56627	28.01165	27.9899	28.15547	27.804	27.98657	28.20134

28.03574	27.56621	28.01164	27.98988	28.15552	27.80455	27.98686	28.20171
28.03561	27.56621	28.01168	27.98988	28.15557	27.80441	27.9864	28.20157
28.03578	27.56616	28.01168	27.98993	28.15539	27.80438	27.98706	28.20152
28.03601	27.56631	28.01169	27.99012	28.15551	27.80431	27.98723	28.20155
28.03577	27.56638	28.01161	27.99001	28.15583	27.80366	27.98737	28.20136
28.03582	27.56626	28.01169	27.99016	28.1557	27.80468	27.98732	28.20138
28.0358	27.56629	28.01162	27.99017	28.15585	27.80413	27.98744	28.20164
28.03591	27.56639	28.01165	27.99021	28.15577	27.80448	27.98748	28.20164
28.03586	27.56649	28.01168	27.99037	28.15571	27.80463	27.98742	28.20169
28.03584	27.5664	28.01173	27.99032	28.15573	27.80492	27.98714	28.20165
28.03572	27.56624	28.01182	27.99041	28.15593	27.80498	27.98705	28.20176
28.03547	27.56639	28.01176	27.99036	28.15608	27.8056	27.98704	28.20163
28.03566	27.5664	28.01178	27.99051	28.15614	27.80475	27.98713	28.2016
28.03545	27.5665	28.01189	27.99049	28.15614	27.80477	27.98767	28.20171
28.03564	27.56639	28.01176	27.99045	28.15626	27.80573	27.98783	28.2016
28.03532	27.56645	28.01177	27.99026	28.15621	27.80548	27.98822	28.20166
28.03569	27.56645	28.01183	27.99057	28.1564	27.80543	27.9876	28.20161
28.03556	27.56637	28.01186	27.9907	28.15636	27.80472	27.98804	28.20178
28.03579	27.56638	28.01191	27.9907	28.15649	27.8062	27.98838	28.20161
28.03562	27.56617	28.01184	27.99072	28.15625	27.80561	27.98838	28.20166
28.0356	27.5663	28.01177	27.99058	28.15632	27.80519	27.98848	28.20154
28.03551	27.56627	28.0118	27.99087	28.1565	27.80486	27.98864	28.20155
28.03584	27.56617	28.0118	27.99076	28.15648	27.80465	27.98862	28.20163
28.03558	27.56628	28.0119	27.99095	28.15667	27.80537	27.98845	28.20144
28.0355	27.56634	28.0118	27.99095	28.15679	27.80527	27.98842	28.20137
28.03576	27.5663	28.01201	27.99086	28.15663	27.80496	27.98873	28.20163
28.03554	27.56618	28.01202	27.99042	28.15673	27.80477	27.98881	28.20172
28.0356	27.56633	28.01194	27.99029	28.15652	27.80566	27.98862	28.20159
28.03531	27.56628	28.01177	27.99078	28.15663	27.80569	27.98902	28.20144
28.03581	27.56626	28.01192	27.99059	28.15688	27.80558	27.98837	28.20172
28.03561	27.5664	28.01185	27.99072	28.15664	27.80564	27.98931	28.20165
28.0357	27.56634	28.0118	27.99105	28.15664	27.80606	27.98861	28.20165
28.03552	27.56632	28.01195	27.99137	28.15666	27.80635	27.98952	28.20161
28.03551	27.56629	28.01206	27.99098	28.15716	27.80572	27.98981	28.20168
28.03578	27.56635	28.01154	27.99089	28.15686	27.80602	27.9898	28.20175
28.03575	27.56632	28.01223	27.99111	28.15705	27.80615	27.98941	28.2018
28.03538	27.5663	28.01199	27.9913	28.15713	27.80609	27.98957	28.20161
28.03576	27.56639	28.01193	27.99143	28.15725	27.80539	27.9894	28.20171
28.03535	27.56631	28.01211	27.99146	28.15723	27.80597	27.98935	28.20183
28.03536	27.56632	28.01165	27.99143	28.157	27.80598	27.9897	28.20165
28.03537	27.56641	28.01214	27.9913	28.15716	27.80572	27.98976	28.2016
28.03582	27.56627	28.01209	27.99156	28.1574	27.8054	27.98958	28.20169
28.0354	27.56645	28.01161	27.99146	28.15741	27.80598	27.98967	28.20169
28.03545	27.56654	28.01194	27.99154	28.15747	27.80602	27.99026	28.20167
28.0355	27.56644	28.0118	27.99149	28.15738	27.80531	27.98978	28.20194
28.03534	27.56644	28.01191	27.99145	28.15745	27.80536	27.98988	28.20143

28.03534	27.56637	28.01205	27.99144	28.15747	27.80609	27.99024	28.20179
28.03538	27.56655	28.01224	27.99158	28.15741	27.80608	27.99047	28.20179
28.03579	27.56649	28.01216	27.99188	28.15767	27.80561	27.99023	28.20182
28.03571	27.56637	28.01224	27.99175	28.15751	27.806	27.99086	28.2018
28.03497	27.56645	28.01226	27.99172	28.1575	27.80577	27.99061	28.20225
28.03531	27.56639	28.01209	27.99188	28.15715	27.80653	27.99075	28.20191
28.0351	27.5664	28.01221	27.99188	28.15758	27.80654	27.9902	28.20159
28.03541	27.56664	28.01222	27.99185	28.15766	27.80709	27.99112	28.20158
28.03543	27.5665	28.01223	27.99133	28.15797	27.80693	27.99059	28.20181
28.03573	27.56622	28.01221	27.99192	28.15821	27.80716	27.99124	28.20187
28.03527	27.56631	28.01205	27.99192	28.15817	27.8071	27.99072	28.20151
28.03551	27.56664	28.01233	27.99155	28.15807	27.80699	27.99104	28.20156
28.03528	27.5665	28.01228	27.99154	28.15756	27.80703	27.99159	28.2017
28.0353	27.5663	28.01215	27.9919	28.15812	27.80673	27.9913	28.20203
28.03509	27.56635	28.01231	27.99121	28.15796	27.80717	27.99058	28.20175
28.03528	27.56646	28.01207	27.99181	28.15798	27.80658	27.99056	28.20179
28.03524	27.5663	28.01237	27.9921	28.15813	27.80663	27.99164	28.2017
28.03497	27.56635	28.01212	27.99202	28.15819	27.8066	27.9911	28.20176
28.03556	27.56631	28.01215	27.99184	28.15813	27.80668	27.99167	28.20184
28.03559	27.56627	28.01225	27.9922	28.15843	27.80683	27.99194	28.20187
28.03563	27.56663	28.01218	27.99227	28.15842	27.80677	27.9919	28.2019
28.03522	27.56653	28.01202	27.99219	28.15833	27.8079	27.99255	28.20157
28.03552	27.5667	28.01221	27.99181	28.15825	27.80749	27.99254	28.20173
28.03541	27.56661	28.01231	27.99233	28.15833	27.80775	27.99179	28.20164
28.03523	27.56651	28.01219	27.99228	28.15835	27.80726	27.99248	28.20171
28.03538	27.56639	28.01247	27.99227	28.15869	27.80732	27.99256	28.20171
28.03497	27.56666	28.01233	27.99246	28.15854	27.80893	27.99234	28.20178
28.0353	27.56637	28.01228	27.99241	28.15844	27.80856	27.99246	28.20198
28.03547	27.56636	28.01207	27.99258	28.15858	27.80716	27.99286	28.20168
28.03541	27.56637	28.01228	27.99231	28.15857	27.80773	27.99231	28.20182
28.03535	27.56632	28.01229	27.99246	28.15857	27.808	27.99256	28.2018
28.03564	27.56665	28.01206	27.99253	28.15878	27.80816	27.99264	28.20192
28.03535	27.5664	28.01228	27.99263	28.15821	27.8084	27.9927	28.20154
28.03483	27.56654	28.01237	27.9926	28.15866	27.80818	27.9928	28.2018
28.03553	27.56653	28.01242	27.99189	28.159	27.80831	27.99263	28.20195
28.03527	27.56627	28.0121	27.99234	28.15885	27.80813	27.99313	28.20163
28.03531	27.56657	28.01239	27.99276	28.15876	27.80842	27.99325	28.2019
28.03516	27.56638	28.01243	27.99275	28.15877	27.8087	27.99291	28.20175
28.03541	27.56643	28.01241	27.99287	28.1588	27.80858	27.99255	28.2017
28.03546	27.56657	28.01234	27.99276	28.15895	27.80883	27.99274	28.20227
28.03513	27.56654	28.01236	27.99301	28.15893	27.80872	27.99345	28.2019
28.03557	27.56651	28.01259	27.99296	28.15878	27.80885	27.99303	28.20179
28.03557	27.56641	28.01256	27.99304	28.1591	27.80927	27.99356	28.20196
28.03546	27.56624	28.01247	27.99298	28.15891	27.80916	27.99272	28.20177
28.03556	27.56654	28.01247	27.99309	28.15921	27.80917	27.99381	28.2021
28.0354	27.56643	28.01247	27.99306	28.15937	27.80901	27.99352	28.20199

28.03527	27.56658	28.01252	27.99316	28.15949	27.80911	27.99351	28.2016
28.0354	27.56642	28.01252	27.99301	28.15934	27.80943	27.99387	28.2019
28.03538	27.56646	28.01258	27.99321	28.15937	27.8096	27.99378	28.20179
28.03546	27.56676	28.01258	27.99337	28.15932	27.80953	27.99383	28.20185
28.03547	27.56641	28.01271	27.99319	28.1596	27.80943	27.99424	28.20194
28.03545	27.56659	28.01252	27.99318	28.15911	27.80892	27.99431	28.20194
28.03551	27.56632	28.01258	27.99346	28.15933	27.80849	27.9945	28.20179
28.03538	27.56638	28.01254	27.99319	28.15956	27.80873	27.99441	28.20182
28.03526	27.5665	28.01239	27.99311	28.15961	27.80811	27.99431	28.20186
28.03527	27.56658	28.01259	27.99343	28.15935	27.80895	27.99423	28.20201
28.03521	27.56656	28.01272	27.99331	28.1595	27.80841	27.99453	28.20185
28.03535	27.56659	28.01274	27.993	28.15976	27.80944	27.9945	28.20179
28.03527	27.56658	28.01266	27.99345	28.15972	27.8093	27.99464	28.20185
28.03568	27.56652	28.01258	27.99356	28.15958	27.80913	27.99434	28.20168
28.03537	27.56679	28.01268	27.99354	28.15972	27.80904	27.99432	28.20185
28.03556	27.5666	28.01251	27.99371	28.1598	27.80935	27.99449	28.20189
28.03509	27.56645	28.01269	27.99369	28.1598	27.80946	27.99446	28.20186
28.03523	27.56651	28.01267	27.99385	28.16	27.80994	27.99468	28.20191
28.03513	27.56652	28.01268	27.99379	28.15998	27.81024	27.99502	28.20187
28.03524	27.56647	28.01276	27.99373	28.16004	27.80993	27.99487	28.20219
28.03553	27.56668	28.01261	27.99386	28.15992	27.81004	27.99474	28.20186
28.03501	27.56653	28.0125	27.99395	28.16023	27.8103	27.99466	28.20195
28.03516	27.56654	28.0127	27.99393	28.16028	27.81028	27.99538	28.20205
28.03524	27.56661	28.0127	27.99339	28.16041	27.81029	27.99483	28.20191
28.03491	27.56657	28.01237	27.99371	28.16025	27.81035	27.99546	28.20202
28.03529	27.5665	28.01283	27.9933	28.16039	27.81076	27.99549	28.20194
28.0351	27.56657	28.0127	27.99368	28.1602	27.8102	27.99516	28.20188
28.03535	27.56664	28.01266	27.99416	28.16024	27.8103	27.99549	28.20204
28.03514	27.56663	28.01247	27.99396	28.16043	27.81179	27.99575	28.20201
28.035	27.5665	28.01288	27.99402	28.16043	27.81042	27.99567	28.20213
28.03521	27.56651	28.01269	27.99384	28.16045	27.8105	27.9949	28.20215
28.03493	27.56655	28.01262	27.99388	28.16053	27.8112	27.99552	28.20186
28.0344	27.56657	28.01268	27.99415	28.16056	27.81139	27.99615	28.20206
28.03501	27.56637	28.01273	27.99435	28.16051	27.81201	27.99558	28.20181
28.03542	27.56679	28.01266	27.99431	28.16061	27.81088	27.99552	28.20193
28.03536	27.56657	28.01273	27.99411	28.16062	27.81058	27.99592	28.20197
28.03508	27.5666	28.01252	27.99368	28.16066	27.81044	27.99585	28.20212
28.03491	27.56659	28.01274	27.99407	28.16075	27.81018	27.9963	28.20188
28.03534	27.56661	28.01288	27.99385	28.16085	27.80973	27.99629	28.20212
28.03512	27.56666	28.01301	27.99356	28.1608	27.81049	27.99636	28.20216
28.03487	27.56658	28.01284	27.99398	28.16089	27.81056	27.99673	28.20187
28.03486	27.56648	28.01285	27.99417	28.16017	27.81058	27.99693	28.20176
28.03518	27.56659	28.01295	27.99422	28.16098	27.81143	27.9968	28.20216
28.03473	27.5666	28.01289	27.99458	28.16105	27.81114	27.99675	28.20187
28.03504	27.56649	28.01304	27.99475	28.161	27.81103	27.9968	28.20218
28.03502	27.56662	28.01312	27.99463	28.16117	27.8103	27.99738	28.20196

28.03485	27.56655	28.01283	27.99456	28.16071	27.8102	27.9969	28.20202
28.0351	27.56653	28.01302	27.99458	28.16116	27.81051	27.99688	28.20204
28.03531	27.56668	28.01306	27.99472	28.16092	27.81102	27.99642	28.2022
28.03513	27.56675	28.01333	27.99463	28.16107	27.81035	27.99668	28.20194
28.0349	27.56649	28.01298	27.99486	28.16126	27.81132	27.99694	28.20189
28.0351	27.5668	28.01304	27.99431	28.16118	27.81155	27.99694	28.20215
28.03525	27.56681	28.01307	27.99422	28.16109	27.8115	27.99714	28.20221
28.03478	27.56651	28.01272	27.99479	28.16069	27.81102	27.99728	28.20207
28.03468	27.56659	28.01311	27.99497	28.16145	27.81042	27.99707	28.20203
28.03499	27.56656	28.01306	27.99492	28.16152	27.81134	27.99721	28.20207
28.03513	27.56648	28.01312	27.99509	28.16162	27.81182	27.99787	28.20221
28.03486	27.56663	28.01309	27.9951	28.16159	27.81122	27.99769	28.20186
28.03443	27.56673	28.01312	27.99511	28.16157	27.81136	27.9977	28.20206
28.03465	27.56659	28.0128	27.99484	28.1616	27.81121	27.99761	28.20201
28.03491	27.5665	28.01309	27.99524	28.16156	27.8115	27.99819	28.20195
28.03481	27.56666	28.01293	27.99472	28.16148	27.81168	27.99777	28.20198
28.03471	27.5667	28.01314	27.99476	28.16152	27.81145	27.99795	28.20197
28.03516	27.56653	28.01306	27.99482	28.16142	27.81132	27.99758	28.20197
28.03493	27.5667	28.013	27.99481	28.16149	27.81172	27.99741	28.2021
28.03518	27.56668	28.01278	27.99467	28.16151	27.81177	27.9975	28.20209
28.0355	27.56668	28.01254	27.9949	28.16186	27.81081	27.99788	28.20214
28.03497	27.56671	28.01315	27.99522	28.16186	27.81049	27.99834	28.20207
28.03533	27.56673	28.01333	27.99534	28.16187	27.81097	27.99867	28.20205
28.03498	27.5668	28.01293	27.99542	28.16215	27.81167	27.9984	28.20203
28.0352	27.56671	28.01301	27.99526	28.16195	27.81173	27.99823	28.20216
28.03514	27.56676	28.01314	27.99519	28.16183	27.8121	27.99821	28.2023
28.03502	27.56681	28.01323	27.99527	28.16201	27.81294	27.99873	28.2018
28.03534	27.56691	28.01322	27.99523	28.16188	27.81189	27.99891	28.20209
28.03464	27.56675	28.01314	27.9955	28.16168	27.81223	27.99893	28.20221
28.03489	27.5667	28.01338	27.99568	28.16203	27.81295	27.99906	28.2022
28.03507	27.56672	28.01312	27.99561	28.16225	27.81236	27.9986	28.2022
28.03494	27.56669	28.01328	27.99561	28.16206	27.81223	27.99923	28.20195
28.03484	27.56702	28.01333	27.9957	28.16247	27.81142	27.99943	28.20208
28.03506	27.56661	28.01326	27.99577	28.16228	27.81166	27.99905	28.2021
28.03481	27.56667	28.01325	27.99583	28.16188	27.81266	27.99903	28.20213
28.03493	27.56643	28.01322	27.99587	28.16226	27.81325	27.999	28.2023
28.03494	27.56666	28.01304	27.99592	28.16232	27.81278	27.99917	28.20209
28.03497	27.56661	28.01293	27.99591	28.16164	27.813	27.99876	28.20199
28.03476	27.56679	28.01306	27.99555	28.16254	27.81353	27.99961	28.20222
28.03502	27.56671	28.0132	27.99543	28.16204	27.81311	27.99876	28.20215
28.03495	27.56682	28.01314	27.99591	28.16254	27.81411	28.00004	28.20196
28.03497	27.56667	28.01352	27.99572	28.16264	27.8141	27.99916	28.20208
28.03494	27.56653	28.01341	27.99582	28.16252	27.8142	27.99926	28.20223
28.03513	27.56654	28.01359	27.9957	28.16258	27.81419	27.99996	28.20231
28.03467	27.56682	28.01351	27.99591	28.16236	27.81265	27.99992	28.2021
28.03495	27.5667	28.01331	27.99553	28.16273	27.81288	27.99963	28.20219

28.03509	27.56689	28.01346	27.99534	28.16288	27.81381	27.99983	28.20231
28.03489	27.56696	28.01336	27.99565	28.16266	27.81315	27.99996	28.2022
28.03491	27.56669	28.01341	27.99622	28.16285	27.81242	28.00039	28.20217
28.03469	27.56653	28.01339	27.99627	28.16287	27.81223	28.00024	28.20225
28.03482	27.56675	28.0134	27.99619	28.16295	27.81262	27.99996	28.20224
28.03515	27.567	28.0134	27.99604	28.16287	27.8137	28.00015	28.20214
28.03517	27.56692	28.01349	27.99644	28.16243	27.81404	27.99968	28.20238
28.03485	27.56689	28.01343	27.99624	28.1631	27.81356	28.00062	28.20235
28.03495	27.56687	28.01342	27.99649	28.1626	27.81361	28.00056	28.20239
28.03477	27.56675	28.01319	27.99654	28.16263	27.81435	28.00071	28.20217
28.03476	27.56678	28.01342	27.99636	28.16298	27.81456	28.00104	28.2022
28.0349	27.56679	28.01338	27.99652	28.16311	27.81419	28.00087	28.202
28.035	27.56666	28.01341	27.99666	28.16314	27.81373	28.00082	28.20192
28.0347	27.56683	28.01343	27.9966	28.16299	27.81436	28.0005	28.20252
28.03493	27.56695	28.01337	27.99622	28.16321	27.8138	28.00098	28.20213
28.03496	27.56696	28.01344	27.99665	28.16321	27.81443	28.00069	28.20213
28.03533	27.56688	28.01355	27.99671	28.16324	27.81435	28.00108	28.20226
28.03473	27.56679	28.01344	27.99674	28.16324	27.81444	28.00112	28.20197
28.03496	27.56693	28.01344	27.99671	28.16315	27.81421	28.00107	28.20217
28.03496	27.56688	28.01344	27.99689	28.16342	27.81442	28.00155	28.20229
28.03479	27.5668	28.01344	27.99681	28.16341	27.81496	28.002	28.20243
28.03509	27.56664	28.0135	27.99697	28.16343	27.81475	28.00075	28.20223
28.03505	27.56666	28.01329	27.99642	28.16343	27.81543	28.00108	28.20222
28.0353	27.56702	28.01344	27.99628	28.16354	27.81519	28.00136	28.20223
28.03475	27.56691	28.01351	27.99659	28.16357	27.81461	28.00206	28.20223
28.035	27.56688	28.01339	27.99692	28.16379	27.81449	28.00133	28.20203
28.03494	27.5669	28.01344	27.99717	28.16313	27.81447	28.00153	28.20217
28.03497	27.56689	28.01351	27.99696	28.16337	27.81561	28.00158	28.20205
28.03474	27.56692	28.01362	27.99664	28.1636	27.81543	28.00178	28.20244
28.03482	27.56661	28.01362	27.99695	28.16348	27.8154	28.00207	28.20242
28.03487	27.56665	28.01341	27.99644	28.16378	27.81655	28.0015	28.20227
28.03483	27.56665	28.01357	27.99715	28.164	27.816	28.00239	28.20234
28.03466	27.56677	28.01352	27.99701	28.16365	27.81602	28.00203	28.20211
28.03476	27.5667	28.01362	27.9967	28.16337	27.81604	28.00282	28.2023
28.03473	27.56682	28.01369	27.99672	28.16356	27.81543	28.00263	28.20237
28.03452	27.56684	28.0133	27.99646	28.16353	27.81496	28.00315	28.20221
28.03459	27.5668	28.01336	27.99675	28.16361	27.81559	28.00218	28.20248
28.03428	27.56693	28.01358	27.99747	28.16388	27.81626	28.00263	28.20239
28.03433	27.56685	28.01398	27.99711	28.16374	27.8165	28.00297	28.20245
28.03454	27.56689	28.01383	27.99727	28.16395	27.81588	28.00288	28.20238
28.03474	27.5669	28.01378	27.99743	28.16373	27.81666	28.00304	28.20227
28.03477	27.56692	28.01363	27.99758	28.16403	27.81701	28.00266	28.20232
28.03476	27.56686	28.01391	27.99745	28.16362	27.81718	28.00313	28.20233
28.03493	27.56681	28.01387	27.99734	28.16425	27.81645	28.00328	28.20252
28.03479	27.5669	28.01384	27.9977	28.16436	27.81597	28.00262	28.20228
28.03465	27.56695	28.01396	27.99694	28.16435	27.81673	28.00307	28.20236

28.03469	27.56689	28.01384	27.99755	28.16417	27.81734	28.00285	28.20241
28.03481	27.56674	28.01378	27.99775	28.16427	27.81699	28.0034	28.20267
28.03452	27.56715	28.0138	27.99786	28.16438	27.81719	28.00308	28.20228
28.03467	27.56697	28.01387	27.99773	28.16447	27.81741	28.00335	28.20207
28.03472	27.56695	28.0137	27.99805	28.16417	27.81746	28.00344	28.20237
28.03449	27.56694	28.0139	27.99784	28.16448	27.81675	28.00294	28.20219
28.0346	27.56692	28.01371	27.99797	28.16418	27.81687	28.0039	28.20228
28.03483	27.56715	28.01369	27.99746	28.16418	27.81713	28.00318	28.20248
28.0348	27.56711	28.01371	27.99787	28.1645	27.81744	28.00344	28.20201
28.03462	27.56701	28.01363	27.99801	28.16474	27.81762	28.00366	28.20245
28.03479	27.56691	28.01355	27.99794	28.16476	27.81602	28.00394	28.20221
28.03474	27.56676	28.01394	27.99803	28.16495	27.81685	28.00373	28.20234
28.03449	27.56695	28.01389	27.99787	28.16475	27.81583	28.00382	28.20245
28.03477	27.56698	28.01394	27.99761	28.16487	27.81566	28.00387	28.20247
28.03474	27.56692	28.01398	27.99791	28.16481	27.81665	28.00422	28.2025
28.03471	27.56701	28.01405	27.99776	28.16499	27.81661	28.00434	28.20239
28.03471	27.56694	28.01381	27.99809	28.16501	27.8167	28.0033	28.20226
28.03464	27.56696	28.01389	27.99816	28.16491	27.81684	28.00391	28.20248
28.03436	27.56692	28.01405	27.99803	28.16498	27.81731	28.00358	28.20241
28.03449	27.56686	28.01396	27.99809	28.16514	27.81671	28.00385	28.20243
28.03496	27.56683	28.01379	27.99842	28.16506	27.81792	28.00412	28.2024
28.03471	27.56699	28.01408	27.9984	28.1652	27.81766	28.00507	28.20214
28.03451	27.56695	28.01399	27.99831	28.16525	27.81797	28.00474	28.20227
28.03446	27.56703	28.01395	27.99846	28.16508	27.81838	28.00471	28.20236
28.03453	27.56692	28.01409	27.99839	28.16513	27.81878	28.00458	28.20233
28.0347	27.56703	28.01369	27.99855	28.16505	27.81897	28.00521	28.20245
28.03433	27.56705	28.01413	27.99861	28.16509	27.81824	28.00507	28.20209
28.03451	27.56676	28.01393	27.99882	28.16503	27.8178	28.00526	28.20211
28.0348	27.56706	28.01412	27.9987	28.1653	27.81766	29.61596	28.20239
28.03483	27.56695	28.01407	27.99883	28.16533	27.81778	10.35568	28.20241
28.03465	27.56706	28.01408	27.99872	28.16548	27.81735	92.2939	28.2023
28.03439	27.56708	28.014	27.99873	28.16561	27.8188	24.52386	28.2025
28.0344	27.56704	28.01406	27.99891	28.16544	27.81848	31.37113	28.20255
28.03434	27.56674	28.01385	27.99887	28.16516	27.81754	24.73174	28.20235
28.0347	27.56705	28.014	27.99895	28.16515	27.81853	24.74096	28.20241
28.03515	27.5671	28.0138	27.99889	28.16571	27.81835	24.74543	28.20255
28.03491	27.56702	28.01401	27.99888	5.74584	27.81874	24.74364	28.20253
28.03453	27.56689	28.01412	27.99913	5.67751	27.81922	24.74515	28.20233
28.03475	27.56687	28.01398	27.99901	46.9226	27.81993	24.7433	28.20235
28.03477	27.56718	28.01418	27.9989	26.77843	27.81995	24.7442	28.20232
28.03428	27.56706	28.01377	27.99894	24.90007	27.81924	24.74374	28.20254
28.03449	27.56688	28.01357	27.99882	24.89656	27.82001	24.74463	28.20255
28.03432	27.56701	28.01411	27.99838	24.9005	27.81985	24.74173	28.20257
28.0345	27.56687	28.01427	27.99902	24.90207	27.81932	24.74537	28.20248
28.03454	27.56725	28.01407	27.99933	24.90301	27.81975	24.74177	28.20261
28.03429	27.56711	28.01419	27.99868	24.90338	27.81964	24.74246	28.20241

28.03409	27.56696	28.0144	27.999	24.9035	27.81917	24.74475		28.20229
28.20547	27.56711	28.01442	27.99856	24.90414	27.81963	24.74512		28.20251
33.5727	27.56691	28.01404	27.99887	24.90445	27.81911	24.73966		28.20231
13.96396	27.56704	28.01416	27.99946	24.90368	27.81885			28.20262
38.08334	27.56722	28.014	27.99903	24.90389	27.81897			28.20246
24.77214	27.56713	28.01407	27.99922	24.90462	27.81891			28.20262
24.77301	27.56728	28.01396	27.99954	24.90425	27.81916			28.20238
24.77319	27.56705	28.01421	27.99902	24.90466	27.81963			28.20266
24.77361	27.567	28.01426	27.99958	24.90455	27.81953			28.20251
24.77363	27.56693	28.01419	27.99932	24.90453	27.82022			28.20283
24.77403	27.56716	28.01423	27.9993	24.90431	27.8203			28.20259
24.77421	27.56728	28.01435	27.99955	24.90429	27.81982			28.20248
24.77402	27.56705	28.01429	27.99957	24.90399	27.8205			28.20263
24.77396	27.56706	28.01423	27.99958	24.9037	27.82048			28.2023
24.77348	27.56727	28.01409	27.9993	24.90431	27.81992			28.20263
24.77323	27.56709	28.01417	27.99925	24.90463	27.81892			28.20271
24.77339	27.56705	28.01418	27.99956	24.90523	27.81971			28.2025
24.77378	27.56713	28.01439	27.99972	24.905	27.81979			28.20245
24.77401	27.56725	28.01442	27.99925	24.90446	27.8203			28.20259
24.77406	27.56722	28.01435	27.99935	24.90447	27.82081			28.20258
24.7738	27.56708	28.01436	27.99989	24.90513	27.82097			28.20251
24.77362	27.56716	28.01441	27.99949	24.90431	27.82124			28.20264
24.77366	27.56728	28.01426	27.99928	24.90409	27.82083			28.20252
24.77381	27.56726	28.01387	27.99973	24.90501	27.82093			28.2024
24.77416	27.56727	28.01444	27.99962	24.90416	27.821			28.20253
24.77418	27.56714	20.20768	27.99934	24.90496	27.8207			28.20264
24.77396	27.56709	20.7427	27.99995	24.9043	27.82086			28.2026
24.77429	27.56709	24.75183	28.00018	24.90482	27.81979			28.20259
24.77413	27.56704		28.00009	24.90468	27.82027			28.20258
24.77395	27.56687		27.99951	24.90509	27.82049			28.20249
24.77417	27.56723		27.9996	24.90514	27.82025			28.20254
24.77423	27.5671		27.99965	24.90516	27.82014			28.20239
24.77431	27.5672		27.99983	24.90451	27.82033			28.20242
24.77383	27.56723		28.00021	24.90475	27.82092			28.20275
24.771	27.56709		27.99997	24.90543	27.82068			28.2026
24.77155	27.56722		28.00013	24.90492	27.82061			28.20253
24.77054	27.56722		28.00038	24.90505	27.82035			28.20266
24.76942	27.56718		28.00008	24.90452	27.82113			28.2027
	27.56716		28.00045	24.90435	27.82076			28.20263
	27.56727		28.00054	24.90482	27.82195			28.20275
	27.56745		28.0004	24.90418	27.82071			28.20268
	27.56705		28.00004	24.90397	27.82058			28.20275
	27.56729		28.00007	24.90467	27.82172			28.20289
	27.56733		28.0003	24.90427	27.82239			28.20249
	27.56731		28.00064	24.90438	27.82239			28.20273
	25.08349		28.00063	24.90473	27.82206			28.20298

5.66193	28.00072	24.90559	27.82221	28.2028
28.87005	28.00063	24.90537	27.82195	28.20265
24.34813	28.00094	24.90518	27.82211	28.20267
24.303	28.00047	24.90495	27.82276	28.2026
24.30436	28.00017	24.90519	27.8227	28.20265
24.30495	28.0008	24.90505	27.82261	28.20269
24.30531	28.00085	24.90491	27.82252	28.20246
24.30566	28.00067	24.90485	27.82296	28.20261
24.30579	28.00082	24.90572	27.82273	28.20264
24.30609	28.00092	24.90503	27.82281	28.20244
24.30539	28.00099	24.90501	27.82296	28.20261
24.30575	28.00091	24.90482	27.82339	28.2026
24.30595	28.00107	24.90549	31.89629	28.20239
24.30594	28.00093	24.90449	43.1608	28.20263
24.30629	28.001	24.90439	36.19036	28.2025
24.30631	28.00111	24.90469	24.54915	28.20264
24.30627	28.00111	24.90452	24.55511	28.20272
24.3056	28.001	24.9047		28.20268
24.30612	28.00131	24.9022		28.20266
24.30628	28.00147	24.90502		28.20261
24.3062	28.00143	24.9046		28.20274
24.30611	28.00147	24.90504		28.20289
24.30601	28.00125	24.90535		28.20267
24.30563	28.00069	24.9058		28.20289
	28.00094	24.90536		28.20291
	28.00129	24.90564		28.20282
	28.00064	24.90548		28.20269
	28.00122	24.90571		28.20251
	28.00116	24.90568		28.20267
	28.00077	24.90481		28.20262
	28.00145	24.90503		28.20268
	28.00181	24.90476		28.20279
	28.00187	24.90514		28.20264
	28.00185			28.20269
	28.00181			28.20278
	28.00187			28.2026
	28.00201			28.20269
	28.00161			28.20266
	28.00183			28.20254
	28.00213			28.20273
	28.00207			28.2027
	28.00211			28.20256
	28.0021			28.20278
	28.00198			28.20266
	28.00234			28.20248
	28.00219			8.9232

28.00152	5.68007
28.00219	-0.32685
28.00174	0.00003
27.99935	
41.72992	
5.68217	
5.68228	
29.05068	
24.73532	
24.73882	
24.73987	
24.74055	
24.74022	
24.74018	
24.74109	
24.7406	
24.74085	
24.74112	
24.74109	
24.74119	
24.74096	
24.74111	
24.74138	
24.74157	
24.74156	
24.74137	
24.74177	
24.74192	
24.74148	
24.74132	
24.74078	
24.74112	
24.7411	
24.74134	
24.74125	
24.74173	
24.74159	
24.7416	
24.74171	
24.74162	
24.74116	
24.7413	
24.74138	
24.74195	
24.74166	
24.74158	

24.74166
24.74115
24.74175
24.74187
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24.74185
24.74166
24.7412
24.742
24.74171
24.74144
24.74183
24.74201
24.7411
24.74184
24.74198
24.74216
24.7417
24.73582

Raw data values from the TGA experiment with pure Helium are shown below:

600 O2 plansee	500 He only	600 He only	500 He only redone
3.25997	3.25756	3.25998	3.25972
3.26006	3.25763	3.26006	3.25974
3.26002	3.25762	3.26002	3.25985
3.26007	3.25756	3.25997	3.2598
3.26014	3.25753	3.25997	3.25985
3.25987	3.25758	3.25999	3.25983
3.25998	3.25761	3.25996	3.25977
3.26005	3.25756	3.25996	3.25981
3.26004	3.25751	3.25992	3.25984
3.26001	3.25753	3.2599	3.25975
3.26	3.25744	3.25998	3.25979
3.26003	3.25756	3.25993	3.25979
3.25997	3.2575	3.25994	3.2599
3.25993	3.25763	3.26001	3.25975
3.25991	3.25769	3.25996	3.25978
3.25996	3.25767	3.25994	3.25979
3.25999	3.25753	3.25997	3.25984
3.25995	3.25757	3.25986	3.25983
3.26	3.25749	3.25991	3.25985
3.26003	3.25744	3.25998	3.25976
3.26004	3.25745	3.25995	3.25974
3.26	3.25751	3.25992	3.2598
3.25996	3.25751	3.25986	3.25981
3.25994	3.25755	3.25989	3.25978
3.26002	3.25757	3.25995	3.25979
0.10619	3.25747	3.25997	3.25982
-0.00001	3.25756	3.25994	3.25979
0	3.25762	3.25995	3.25976
0	3.25762	3.26002	3.25977
0	3.25758	3.25994	3.25978
0	3.25759	3.25985	3.25979
5.68258	3.25752	3.25977	3.2598
5.68265	3.25755	3.25989	3.2598
8.30055	3.2576	3.25993	3.25973
9.60611	3.25759	3.25991	3.25982
9.60617	3.25763	3.25979	3.25978
9.60642	3.25758	3.25979	3.25975
9.60633	3.25748	3.25985	3.25977
9.60635	3.25757	3.25985	3.25972
9.60627	3.25756	3.25982	3.25978
9.60623	3.25751	3.25977	3.25978
9.60619	3.25754	3.25979	3.25973
9.60628	3.25752	3.25991	3.25961

9.60621	3.25753	3.25988	3.25973
9.60623	3.25752	3.25992	3.25978
9.60626	3.25756	3.25991	3.25969
9.60625	3.25758	3.25989	3.25975
9.60611	3.25761	3.25979	3.25972
9.60629	3.25758	3.25988	3.25977
9.60618	3.25764	3.25986	3.25978
5.68241	3.25749	3.25987	3.25979
5.68259	3.25756	3.25985	3.2598
5.68239	3.25758	3.25988	3.25976
5.68264	3.2575	3.25982	3.25969
5.68255	3.25752	3.25987	3.25969
5.86745	3.25743	3.25991	3.25976
28.16605	3.25743	3.26005	3.25974
28.16619	3.25742	3.25991	3.25972
28.16616	3.25754	3.25984	3.25977
28.16619	3.25746	3.25983	3.25979
28.16613	3.25749	3.25989	3.25972
28.166	3.25748	3.25989	3.2597
28.16611	3.25746	3.25992	3.25968
28.16607	3.2575	3.25998	3.25972
28.16619	3.25755	3.25989	3.25967
28.16596	3.25735	3.25991	3.25969
28.16604	3.25694	3.25996	3.2597
28.16603	3.25747	3.25995	3.25972
28.16608	3.25748	3.25988	3.25972
28.16613	3.25744	3.25996	3.25977
28.16604	3.25736	3.25993	-0.00023
28.16601	3.25747	3.25992	-0.00025
28.16599	3.25743	3.25985	-0.00024
28.16598	3.25747	3.25984	-0.0002
28.16604	3.25746	3.25979	0.00005
28.1661	3.25741	3.25982	0
28.16613	3.25749	3.2599	0
28.16619	3.25756	3.25982	0
28.16603	3.25745	3.25977	5.68727
28.16604	3.2575	3.25987	5.68217
5.68214	3.25748	3.2598	5.68221
5.68258	3.25752	3.25978	5.68231
5.68249	3.25752	3.25987	5.68234
5.6824	3.25743	3.25988	5.68222
5.68251	3.00477	3.25998	9.68266
6.15507	1.98055	3.25992	9.68248
26.34197	5.6841	3.25991	9.68265
24.90606	5.68386	3.25988	9.68266
24.90598	5.68391	3.25988	9.68265

24.90582	5.68386	3.25989	9.68263
24.90593	9.4379	3.25984	9.68264
24.90603	9.43833	3.25986	9.68262
24.90621	9.43834	3.25984	9.68258
24.90619	9.43843	3.25992	9.68265
24.90606	9.43852	3.25977	9.68255
24.90624	9.43844	0.00019	9.68261
24.90617	9.43825	0.00022	9.68256
24.90625	9.43838	0.00011	9.68248
24.90629	9.43851	0.00011	9.68233
24.9064	9.43842	0.00019	9.68256
24.90638	9.43838	0.00012	9.68247
24.90606	9.43857	0.00014	9.68254
24.90617	5.68401	0.00021	5.68225
24.90627	5.68353	0.00017	5.68226
24.90617	5.68391	0.00019	5.68222
24.90632	5.68381	0.00015	5.68208
24.90614	5.68383	0.00019	5.68208
24.90628	5.68383	0.00019	5.68215
24.9063	5.68387	0.00019	5.68221
24.90621	5.6838	0.00019	5.68217
24.90629	5.68376	0.00011	5.68224
24.90642	5.68384	0.00001	6.12834
24.9063	5.68382	0	28.2355
24.90643	5.68393	0	28.23559
24.90645	5.68377	0	28.2356
24.90617	5.68374	0	28.23566
24.90621	5.68514	0	28.23558
24.90624	27.78261	0	28.2353
24.90634	27.79682	0	28.23557
24.90626	27.7967	1.76569	28.23563
24.90642	27.79685	5.68235	28.23568
24.90635	27.79699	5.68307	28.23576
24.90641	27.79696	7.77448	28.23554
24.90621	27.79688	9.58852	28.23566
24.90639	27.7968	9.58864	28.23547
24.90635	27.79692	9.58877	28.2357
24.90637	27.79685	9.58881	28.23565
24.90649	27.79688	9.58877	28.23561
24.90645	27.79678	9.58874	28.2356
24.9065	27.79668	9.58875	28.23557
24.90629	27.79678	9.5888	28.23563
24.90628	27.79674	9.58885	28.23563
24.9065	27.79675	9.58883	28.23563
24.90636	27.79682	9.58875	28.23554
24.90648	27.79685	9.58879	28.23559

24.90645	5.67585	9.58887	28.23564
24.90629	31.22835	9.58874	28.23562
24.90628	10.61988	9.58875	28.23564
24.90637	5.68232	9.58877	28.23556
24.90646	24.5389	9.58874	28.23537
24.90644	24.54034	9.58865	28.2355
24.90642	24.54021	9.58857	28.2356
24.90651	24.53913	5.68254	28.23564
24.90663	24.53894	5.68255	28.23552
24.90645	24.53917	5.68259	28.23523
24.90638	24.53918	5.68253	28.23571
24.90663	24.5725	5.68251	28.2355
24.9066	24.53938	5.68251	28.23543
24.90668	24.53925	5.68249	28.23569
24.90651	24.53925	5.68244	28.23544
24.90661	24.53913	5.68245	28.23541
24.90657	24.53947	5.6825	28.23565
24.90669	24.53935	5.68247	28.23562
24.90652	24.53929	5.68251	28.23557
24.90661	24.53938	5.68238	28.23557
24.90661	24.53939	8.01751	28.23549
24.90648	24.5394	28.07216	28.23552
24.90651	24.53939	28.07229	28.23583
24.90638	24.5393	28.07217	28.23573
24.90639	24.53946	28.07213	28.23574
24.90648	24.53942	28.07215	5.68229
24.9065	24.5394	28.07215	5.68214
24.90655	24.53944	28.07221	5.68219
24.90644	24.53945	28.07213	17.72005
24.90636	24.53945	28.07219	24.97582
24.90644	24.53947	28.07217	24.97584
24.90644	24.53941	28.07214	24.97583
24.90641	24.53949	28.07214	24.97573
24.90647	24.53945	28.07216	24.9756
24.90633	24.53947	28.07224	24.97573
24.9064	24.53945	28.0723	24.97568
24.9065	24.53952	28.07214	24.97547
24.90648	24.53948	28.0721	24.97569
24.90634	24.53952	28.07222	24.9759
24.90645	24.53948	28.07211	24.97582
24.90648	24.53939	28.07223	24.97575
24.90645	24.53947	28.07225	24.97596
24.90645	24.53947	28.07223	24.97585
24.90642	24.53948	17.90104	24.9757
24.90656	24.53949	5.68231	24.97608
24.90656	24.53949	5.68224	24.97585

24.9064	24.53929	8.68324	24.97601
24.90661	24.53947	24.81227	24.97622
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24.90637	24.53951	24.81227	24.97588
24.90636	24.53953	24.81227	24.97602
24.90626	24.53935	24.81232	24.97602
24.90629	24.53947	24.81213	24.97608
24.90631	24.5395	24.81236	24.9761
24.90627	24.53941	24.81235	24.97607
24.90645	24.53954	24.81211	24.97606
24.90666	24.53947	24.8122	24.97605
24.9064	24.53945	24.81254	24.97612
24.90642	24.53946	24.81251	24.97614
24.90634	24.53943	24.8125	24.97609
24.90655	24.53963	24.81255	24.97619
24.90643	24.53937	24.81225	24.97611
24.90637	24.53951	24.81235	24.97614
24.90644	24.53943	24.81235	24.97612
24.90647	24.53945	24.8123	24.97606
24.90648	24.53928	24.81227	24.97613
24.90649	24.53928	24.81235	24.9761
24.9062	24.53949	24.81226	24.97604
24.90641	24.53946	24.81232	24.97615
24.90636	24.53946	24.81233	24.9762
24.90629	24.53942	24.81247	24.97617
24.90638	24.53939	24.8124	24.97604
24.90645	24.53953	24.81241	24.97611
24.90647	24.53942	24.81237	24.97611
24.90627	24.53952	24.81238	24.9761
24.90649	24.53943	24.8123	24.97609
24.90647	24.53951	24.8123	24.97608
24.90641	24.53936	24.81222	24.97617
24.90631	24.53943	24.81243	24.97611
24.90626	24.53956	24.81241	24.9762
24.9062	24.53941	24.81239	24.97629
24.90625	24.53945	24.81237	24.97617
24.90628	24.53951	24.81233	24.97608
24.90632	24.53951	24.81239	24.97626
24.90626	24.53936	24.81227	24.9762
24.90631	24.53938	24.81225	24.97631
24.90618	24.53948	24.81236	24.97644
24.90622	24.53942	24.8124	24.9764
24.9062	24.53942	24.81237	24.97641
24.90608	24.53935	24.81238	24.9762
24.9061	24.53944	24.81244	24.97637
24.90624	24.53926	24.81235	24.97623

24.90638	24.5395	24.81236	24.97638
24.90627	24.53941	24.81245	24.97635
24.90604	24.53942	24.81241	24.9762
24.906	24.53936	24.81236	24.97618
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24.90614	24.53949	24.81248	24.97658
24.90623	24.5394	24.81238	24.97657
24.90612	24.53941	24.81239	24.97642
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24.90611	24.53933	24.81246	24.97633
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24.90599	24.53943	24.81249	24.97647
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24.90587	24.53926	24.81251	24.9764
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24.90599	24.53931	24.81243	24.97635
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24.90602	24.53928	24.81237	24.97642
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24.90608	24.53932	24.81255	24.97628
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24.90595	24.53921	24.8124	24.97626
24.90593	24.53934	24.81256	24.97633
24.9059	24.5393	24.81245	24.9763
24.90575	24.53938	24.81241	24.9763
24.90587	24.5394	24.81233	24.97633
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24.90593	24.5392	24.81238	24.97623
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24.90594	24.53925	24.81238	24.97619
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24.90607	24.53932	24.81239	24.97629
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24.90571	24.53902	24.81221	24.97617
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24.9057	24.53921	24.81202	24.97618
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28.16273	24.53906	24.81214	24.97617
28.16256	24.53921	24.81208	24.97613
28.16241	24.5392	24.8122	24.97597
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28.16416	24.53906	24.81192	24.97617
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28.1645	27.79699	24.81183	24.9762
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28.16338	27.79672	24.81184	24.9762
28.16368	27.79686	24.81201	24.97628
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28.16456	27.79684	24.8119	24.97631
28.16482	27.79677	24.8119	24.97609
28.16408	27.79671	24.81195	24.97609
28.16456	27.79667	24.81193	24.97628
28.16439	27.79677	24.81195	24.97631
28.16438	27.79682	24.81173	24.97597
28.16484	27.79696	24.81185	24.97619
28.16425	27.7968	24.8118	24.97607
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28.16522	27.79689	24.81178	24.97606
28.16483	27.79679	24.81189	24.97597
28.16474	27.79692	24.81177	24.97605
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28.16458	27.79656	24.81185	28.23158
28.16406	27.7963	24.81183	28.23622
28.16445	27.79649	24.81183	28.23608
28.16422	27.79675	24.81183	28.23637
28.16426	27.79651	24.81177	28.23662
28.16376	27.79671	24.81178	28.23633
28.16421	27.7967	24.81165	28.2364
28.16411	27.79679	24.81173	28.23661
28.16438	27.79688	24.81189	28.2365
28.16364	27.79693	24.81181	28.23646
28.16495	27.79672	24.81185	28.23657
28.16433	27.7965	24.81174	28.23624
28.16366	27.79673	24.81189	28.23643
28.16437	27.7966	24.8118	28.23637
28.16426	27.79667	24.81165	28.23635
28.16449	27.79676	24.81174	28.23627
28.16443	27.7967	24.80961	28.23642
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28.16404	27.79696	28.07161	28.23637
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28.16382	27.79656	28.07198	28.23629

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28.16433	27.79686	28.07198	28.23632
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28.16352	27.79667	28.07241	28.23626
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28.16284	27.79656	28.07236	28.23629
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28.16258	27.79681	28.07271	28.23635
28.16327	27.79663	28.07262	28.23634
28.16339	27.79667	28.07254	28.23659
28.16288	27.79674	28.07271	28.23644
28.16309	27.79684	28.07262	28.23622
28.1629	27.79664	28.07263	28.23612
28.16266	27.79664	28.07239	28.23637
28.16219	27.79675	28.07249	28.2363
28.16253	27.79687	28.07261	28.23633
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28.16249	27.79668	28.07263	28.2362

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28.16042	27.79674	28.0727	28.2362
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28.1611	27.79657	28.07347	28.23626
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28.1622	27.79667	28.0735	28.23629
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28.16088	27.79657	28.0744	28.23656
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28.1607	27.79645	28.07427	28.23644
28.16072	27.79645	28.07435	28.2366
28.16002	27.79662	28.07438	28.23644
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28.16052	27.79646	28.07458	28.23623
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28.16155	27.79649	28.0746	28.23628
28.16167	27.7965	28.07462	28.23645
28.16112	27.7965	28.07484	28.23632
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28.15983	27.79641	28.07482	28.23654
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28.1622	27.79632	28.075	28.2362
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28.16092	27.79638	28.07523	28.23617
28.16138	27.7965	28.07519	28.23603
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28.16221	27.79656	28.07517	28.23631
28.16237	27.79668	28.07523	28.23636
28.16247	27.79649	28.07543	28.23661
28.16201	27.79656	28.07524	28.23644
28.16169	27.7963	28.07538	28.23635
28.16198	27.79659	28.07527	28.23621
28.16263	27.79652	28.07534	28.23654
28.16151	27.79639	28.0753	28.23658
28.16256	27.79629	28.07538	28.23652
28.16223	27.79642	28.07545	28.23662
28.16274	27.79642	28.07529	28.23627
28.16328	27.79636	28.07551	28.23642
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28.16285	27.79634	28.07557	28.23641
28.16226	27.79635	28.07549	28.23666
28.16169	27.79636	28.07564	28.23624
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28.16195	27.79656	28.0754	28.23639
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28.1616	27.79651	28.07548	28.23653
28.16171	27.79626	28.0754	28.23659
28.16181	27.79625	28.0754	28.23659
28.1618	27.79658	28.07537	28.23656
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28.16146	27.79651	28.07577	28.23643
28.16257	27.79639	28.07566	28.23632
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28.16241	27.79621	28.07559	28.23644
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28.16222	27.7966	28.07556	28.23654

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28.16057	27.79641	28.07618	28.23662
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28.16126	27.7965	28.07617	28.23656
28.16109	27.79622	28.07594	28.23661
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28.16057	27.79624	28.07608	28.23667
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28.16133	27.79629	28.07615	28.23662
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28.17174	27.7963	28.07657	28.23678
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28.17155	27.79618	28.07685	28.23675
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28.17295	27.79625	28.07677	28.2369

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28.17409	27.79646	28.07748	28.23653
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28.17389	27.79606	28.07745	28.23649
28.17408	27.79606	28.07778	28.23647
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28.17382	27.79612	28.07754	28.23642
28.17402	27.79619	28.07759	28.23654

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28.17407	27.79627	28.07757	28.23674
28.17401	27.79628	28.07771	28.23679
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28.17436	27.79622	28.07768	28.2369
28.17442	27.79637	28.0777	28.23692
28.17428	27.79618	28.07749	28.23674
28.17432	27.79606	28.07752	28.23679
28.17444	27.79619	28.0775	28.23645
28.17434	27.79612	28.07752	28.23666
28.17426	27.7961	28.07768	28.23659
28.17459	27.79616	28.07784	28.23671
28.17446	27.79615	28.07786	28.23663
28.17442	27.79611	28.07766	28.23669
28.17444	27.79604	28.07767	28.23669
28.17451	27.79599	28.07761	28.23669
28.1744	27.79612	28.07764	28.23632
28.17441	27.79614	28.07795	28.2364
28.17456	27.79619	28.07786	28.23658
28.1743	27.79626	28.07783	28.23689
28.17447	27.79608	28.07763	28.23666
28.17432	27.79616	28.07791	28.23666
28.17417	27.79618	28.07779	28.23682
28.17439	27.79613	28.07778	28.23696
28.1747	27.79617	28.07791	28.23704
28.17469	27.7962	28.07786	28.23696
28.17475	27.7962	28.07783	28.2365
28.17466	27.79613	28.07793	28.23688
28.17455	27.79612	28.07781	28.23694
28.17456	27.79621	28.07791	28.23662
28.17463	27.79617	28.07791	28.23666
28.17467	27.79604	28.07814	28.23701
28.17459	27.79618	28.07792	28.23688
28.17455	27.7961	28.07799	28.23665
28.17463	27.79627	28.07793	28.23671
28.17468	27.79603	28.07806	28.23681
28.17475	27.79608	28.07781	28.23684
28.17496	27.79614	28.07815	28.23697
28.17503	27.79606	28.07813	28.23699
28.17474	27.79613	28.07789	28.23687
28.17497	27.79614	28.07785	28.23675
28.1751	27.7961	28.07821	28.23664
28.17494	27.79608	28.07802	28.23646
28.17501	27.79618	28.07802	28.23658
28.17497	27.79604	28.07808	28.23641

28.17509	27.79602	28.07782	28.23638
28.17506	27.79609	28.07804	28.23653
28.17489	27.79608	28.07808	28.23676
28.1748	27.79592	28.0778	28.23701
28.17481	27.79599	28.07777	28.23674
28.17499	27.7963	28.07812	28.23698
28.17501	27.79626	28.07837	28.23685
28.17488	27.79608	28.07837	28.23709
28.17479	27.79606	28.07843	28.23694
28.17487	27.79628	28.0782	28.23678
28.17502	27.79612	28.07824	28.23686
28.17494	27.79604	28.07791	28.23688
28.17512	27.79596	28.07832	28.23666
28.17506	27.79612	28.07832	28.2368
28.17497	27.79622	28.0782	28.23704
28.17514	27.79611	28.07819	28.23707
28.17532	27.796	28.07825	28.23718
28.17544	27.79613	28.07825	28.23661
28.17528	27.79586	28.07821	28.23689
28.1753	27.79617	28.07828	28.2368
28.17549	27.79611	28.07836	28.23695
28.17526	27.79632	28.07843	28.23703
28.17539	27.7961	28.0783	28.23699
28.17535	27.79599	28.07832	28.23669
28.17506	27.79611	28.07827	28.23674
28.17525	27.79629	28.07822	28.23699
28.17539	27.79605	28.07832	28.23693
28.17499	27.79608	28.0785	28.23698
28.17515	27.79605	28.07866	28.23698
28.1752	27.79616	28.07846	28.237
28.17523	27.79619	28.07865	28.23693
28.17541	27.79623	28.07839	28.23701
28.17522	27.79601	28.07834	28.23693
28.17526	27.79623	28.07845	28.23684
28.17518	27.79625	28.07828	28.23646
28.17531	27.79627	28.07833	28.23696
28.17547	27.79631	28.07836	28.23671
28.17553	27.79606	28.0785	28.23684
28.17553	27.79595	28.07867	28.2369
28.17543	27.796	28.07845	28.23685
28.17535	27.79614	28.07877	28.23681
28.17564	27.79603	28.07864	28.23679
28.17557	27.79604	28.07853	28.23694
28.17579	27.79607	28.07857	28.23665
28.17561	27.79602	28.07852	28.2364
28.1757	27.79619	28.07858	28.23701

28.17554	27.79627	28.07875	28.23702
28.17571	27.79603	28.07881	28.2365
28.17573	27.79609	28.07882	28.23669
28.17586	27.79609	28.0785	28.23677
28.17577	27.79597	28.07872	28.23683
28.1757	27.79594	28.07859	28.23662
28.17577	27.79621	28.07878	28.23636
28.17578	27.79587	28.07879	28.23562
28.17556	27.79615	28.0787	28.23623
28.1758	27.79599	28.07874	28.23643
28.17586	27.79616	28.07862	28.23681
28.17578	27.79606	28.07881	28.23687
28.1758	27.796	28.07861	28.23656
28.17578	27.79614	28.07883	28.23684
28.17571	27.7961	28.07885	28.23627
28.17568	27.79604	28.07857	28.23684
28.1761	27.79595	28.07878	28.23677
28.17587	27.79605	28.07869	28.23686
28.17574	27.79624	28.07893	28.23694
28.1758	27.79615	28.07885	28.23706
28.17574	27.79604	28.07892	28.23682
28.17574	27.79627	28.07903	28.23681
28.17595	27.79606	28.07874	28.23714
28.17594	27.79609	28.079	28.23692
28.17602	27.79602	28.07873	28.23689
28.17553	27.79608	28.07913	28.23675
28.1759	27.79607	28.07921	28.23655
28.17599	27.79598	28.07883	28.23724
28.17612	27.79607	28.07901	28.23694
28.1761	27.79623	28.07921	28.23709
28.17568	27.79607	28.07909	28.237
28.17572	27.79577	28.07893	28.23698
28.17582	27.79598	28.0788	28.23675
28.17584	27.79605	28.07905	28.23654
28.17583	27.79625	28.07912	28.23709
28.17608	27.79598	28.07915	28.23697
28.17598	27.79605	28.07895	28.23674
28.17608	27.79595	28.07904	28.23655
28.17603	27.79604	28.07883	28.23687
28.17592	27.79619	28.07909	28.23681
28.17618	27.79606	28.07893	28.23679
28.17628	27.79613	28.07909	28.23687
28.1762	27.79608	28.07922	28.23699
28.17616	27.79599	28.07948	28.23696
28.17627	27.79604	28.07933	28.23712
28.17645	27.79599	28.07923	28.23691

28.17617	27.79626	28.07918	28.23704
28.17597	27.79623	28.07916	28.23706
28.17586	27.79621	28.07926	28.23718
28.17626	27.79588	28.07921	28.23698
28.17598	27.79609	28.07926	28.23727
28.17607	27.79602	28.07872	28.23696
28.1761	27.79588	28.07831	28.23707
28.17639	27.796	28.07911	28.23672
28.17641	27.79591	28.07931	28.23696
28.1764	27.79601	28.07905	28.23704
28.1763	27.79604	28.07925	28.23695
28.1764	27.79593	28.07928	28.23711
28.1766	27.79608	28.0793	28.23691
28.17649	27.796	28.07915	28.23706
28.17653	27.79613	28.07928	28.23697
28.17659	27.79573	28.07928	28.23685
28.17658	27.79631	28.07944	28.23683
28.17635	27.79591	28.0795	28.23705
28.17624	27.79576	28.07965	28.23691
28.17638	27.79596	28.07937	28.23706
28.17654	27.79597	28.07951	28.23686
28.1767	27.79584	28.07938	28.23683
28.17648	27.79614	28.07949	28.23687
28.17645	27.79602	28.07941	28.23697
28.17663	27.7959	28.07932	28.23701
28.17655	27.79602	28.07952	28.23695
28.17659	27.79593	28.07945	28.23681
28.1765	27.79598	28.07939	28.23722
28.17645	27.79594	28.0795	28.23689
28.17661	27.79595	28.07955	28.23699
28.17641	27.79604	28.07944	28.23699
28.17657	27.79597	28.07953	28.23692
28.17654	27.79592	28.07958	28.23674
28.17673	27.79584	28.07971	28.23685
28.1766	27.7962	28.0798	28.23719
28.17671	27.79609	28.07971	28.23697
28.17671	27.79608	28.07965	28.23699
28.17658	27.79604	28.07966	28.23697
28.17649	27.7961	28.07968	28.23695
28.1766	27.79611	28.07957	28.23683
28.1767	27.79587	28.07971	28.23708
28.17658	27.79604	28.07964	28.23707
28.17686	27.79641	28.07948	28.23696
28.17676	27.79594	28.0795	28.23698
28.17686	27.79604	28.0798	28.23702
28.17674	27.79608	28.07968	28.23704

28.17688	27.79601	28.07921	28.23694
28.17687	27.79594	28.07884	28.237
28.17681	27.79567	28.07956	28.23697
28.17699	27.79588	28.07942	28.23721
28.17688	27.79597	28.07967	28.23681
28.17659	27.79606	28.07967	28.23699
28.17672	27.79592	28.07962	28.23715
28.17677	27.7959	28.0798	28.2367
28.17681	27.79591	28.07978	28.23689
28.17672	27.79589	28.0799	28.23738
28.17691	27.79598	28.0798	28.23725
28.17691	27.79613	28.08015	28.23716
28.17704	27.79607	28.07986	28.237
28.17677	27.79614	28.07998	28.237
28.17669	27.7957	28.07983	28.23717
28.17685	27.79594	28.07965	28.23687
28.17684	27.796	28.08011	28.23707
28.17701	27.79613	28.07976	28.23704
28.17692	27.79607	28.07974	28.23711
28.17682	27.79596	28.07993	28.23658
28.17668	27.79607	28.08	28.23692
28.17695	27.79586	28.07984	28.2369
28.17677	27.79594	28.07999	28.23726
28.1769	27.79579	28.07977	28.23732
28.17683	27.796	28.07989	28.23684
28.17677	27.79598	28.08013	28.23717
28.17694	27.79597	28.08024	28.237
28.17703	27.79592	28.08022	28.23701
28.17704	27.79585	28.08005	28.23707
28.17699	27.79592	28.08013	28.23686
28.17706	27.79588	28.08018	28.23719
28.17684	27.79577	28.08002	28.23742
28.17701	27.79599	28.08006	28.23676
28.17711	27.79599	28.08024	28.23753
28.17706	27.79593	28.08031	28.23719
28.17724	27.79568	28.08015	28.23694
28.17716	27.79611	28.08015	28.23724
28.17696	27.79589	28.08019	28.23731
28.17706	27.79606	28.08027	28.23727
28.17707	27.79599	28.08043	28.23742
28.17707	27.79585	28.08033	28.23721
28.17673	27.79593	28.08031	28.23716
28.17691	27.796	28.08023	28.23706
28.17702	27.79584	28.07997	28.23676
28.17702	27.79598	28.08004	28.23731
28.17733	27.79594	28.08029	28.23709

28.17721	27.79573	28.0801	28.23724
28.17739	27.79572	28.08026	28.23723
28.17724	27.79613	28.08025	28.23714
28.17728	27.79596	28.08048	28.23712
28.17663	27.79593	28.07992	28.23703
28.17648	27.79599	28.07999	28.23706
28.175	27.7959	28.07912	28.23718
30.52363	27.796	28.07966	28.2369
27.58938	27.79611	28.07995	28.23706
40.61323	27.79602	28.08024	28.23707
22.6607	27.796	28.08025	28.23699
67.6491	27.79594	28.08032	28.23693
24.90972	27.79594	28.0802	28.23725
24.90717	27.79606	28.08026	28.23723
24.91044	27.79591	28.08035	28.23709
24.91297	27.7961	28.08035	28.23725
24.91415	27.79575	28.08018	28.23733
24.91427	27.79599	28.08037	28.23705
24.91489	27.796	28.08036	28.23689
	27.79593	28.08042	28.23715
	27.79613	28.0806	28.23726
	27.79606	28.08036	28.2371
	27.79598	28.08046	28.23725
	27.79589	28.08025	28.237
	27.7959	28.08051	28.23723
	27.79606	28.08064	28.237
	27.79602	28.0805	28.2367
	27.79584	28.08053	28.23725
	27.79586	28.0804	28.23724
	27.79595	28.08053	28.23671
	27.79583	28.08051	28.23725
	27.79616	28.08052	28.23702
	27.79613	28.08088	28.23703
	27.79584	28.08073	28.23703
	27.79604	28.08068	28.23713
	27.79587	28.0806	28.23711
	27.79574	28.08043	28.23724
	27.79583	28.08047	28.23716
	27.7958	28.08046	28.23707
	27.79571	28.08073	28.23723
	27.79574	28.08064	28.23713
	27.79594	28.08065	28.23711
	27.79617	28.08072	28.23693
	27.79624	28.0809	28.2372
	5.67648	28.08109	28.23699
	5.67624	28.08057	28.23719

18.08164	28.08077	28.23745
24.5323	28.08063	28.23733
24.53403	28.08066	28.2372
24.53575	28.0809	28.237
24.53651	28.08076	28.23727
24.53673	28.08045	28.23723
24.53682	28.08092	28.23733
24.53721	28.08089	28.23727
24.53681	28.0809	28.23685
24.53736	28.08105	28.23678
24.53742	28.08116	28.23695
24.53757	28.08082	28.23688
24.5376	28.08114	28.23717
24.53723	28.08098	28.23721
	28.08095	28.23735
	28.08111	28.23687
	28.08059	28.23733
	28.08088	28.23726
	28.08109	28.23707
	28.08102	28.23729
	28.08094	28.2374
	28.08085	28.23724
	28.08089	28.23748
	28.08106	28.2375
	28.08134	28.23706
	28.08123	28.23698
	28.08111	5.67684
	28.08118	5.67622
	28.08119	13.67391
	28.08113	24.97133
	28.081	24.97183
	28.08087	
	28.08068	
	28.08094	
	28.08097	
	28.081	
	28.08131	
	28.08105	
	28.08089	
	28.08119	
	28.08122	
	28.08114	
	28.08103	
	28.08119	
	28.08128	
	28.08105	

28.08073
28.08125
28.0813
28.08133
28.0815
28.08141
28.0814
28.08114
28.08117
13.56403
5.1962
5.66977
5.67088
24.89568
24.81051
24.8145

APPENDIX 6

Notes from the experiments are shown below:

Experiments TGA Helium + 0.5 % Oxygen	**400°C**
Photo:	Yes
Thickness 1:	2.95
Thickness 2:	2.94
Thickness 3:	2.93
Mean thickness:	**2.94**
Diameter 1:	19.99
Diameter 2:	19.98
Diameter 3:	19.97
Mean diameter:	19.98
Area sample: 2*pi*r*t+2*pi*r^2	**811.6034444**
Weight, links+cage (without sample):	9.5571
Weight, links+cage (with sample):	27.899
Mass sample (before oxidation):	**18.3419**
Weight of the two bottom links:	3.2601
Helium flow:	56
Total helium pressure (bar):	187
Voltmeter stabilized (start):	16.24
Voltmeter stabilized (30 min):	16.35
Oxygen flow (at start)	41
When desired oxygen flow is achieved, set start of oxidation (excel cell):	**431**
When desired oxygen flow is achieved, set start of oxidation (start time):	**kl 11.28**
Oxygen flow (after 45 min)	40
Oxygen flow (vid 90 min)	40
Tot. Oxygen pressure (bar):	145
Oxygen pressure out (bar)	0.41
When time is out (2h) note the final excel cell	**1129**
Weight of the bottom two links:	3.2599
Temp(Millivolt+23°C):	422°C

500°C	**600°C**	**700°C**	**750°C**	**800°C**	**500°C He only**	**900°C**
Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.01	2.99	3	3.02	2.99	3.02	3
3	2.99	3	3.03	2.98	3.02	3.01
3	2.99	3	3.01	2.98	3.01	2.98
3.003333333	**2.99**	**3**	**3.02**	**2.983333**	**3.016666667**	**2.996667**
20.03	20.05	20.02	20.02	20.03	20	20.02
20.04	20.04	20.01	20.02	20.04	20	20
20.03	20.02	20.03	20.02	20.03	20	20.01
20.03333333	20.03667	20.02	20.02	20.03333	20	20.01
819.4341782	**818.8361**	**818.2599**	**819.5177**	**818.1754**	**817.8612875**	**817.3273**
9.5446	9.6418	9.5237	9.4633	9.495	9.4384	9.4739
27.8818	27.9849	27.9262	27.7444	27.8076	27.7968	27.8117
18.3372	**18.3431**	**18.4025**	**18.2811**	**18.3126**	**18.3584**	**18.3378**
3.2576	3.2571	3.2571	3.2571	3.2572	3.2576	3.2574
41	42	41	49	49	46	49
195	195	195	195	195	195	195
20.62	24.8	28.9	30.83	32.89	20.59	36.73
	24.7	28.84	30.8	32.8	20.59	36.68
47	43	46	49	46	0	45
454	377	362	364	352	406	267
kl 11.16	kl 10.32	kl 10.13	kl 10.40	kl 10.46	kl 9.11	kl 12:22
36	42	42	46	43	47 (He)	45
27 (120min)	42	41	40	40	45(He)	43
150	150	148	148	148	0	147
	0.45	0.42	0.41	0.4	0.04 (He)	0.4
1143	**1069**	**1055**	**1053**	**1042**	**1097**	**955**
3.2578	3.256	3.2571	3.2571	3.2576	3.2574	3.2607
522°C	618°C	716°C	763°C	811°C	522°C	907°C

Experiments TGA Helium+Argon+water vapour	**400°C Extra**
Photo:	Yes
Thickness 1:	2.99
Thickness 2:	2.99
Thickness 3:	3
Mean thickness:	**2.993333333**
Diameter 1:	20
Diameter 2:	20.01
Diameter 3:	20
Mean diameter:	**20.00333333**
Area sample: 2*pi*r*t+2*pi*r^2	**816.636014**
Weight, links+cage (without sample):	9.7028
Weight, links+cage (with sample):	28.2002
Mass sample (before oxidation):	**18.4974**
Weight of the two bottom links:	3.2598
Helium flow (during warmup):	37
Total helium pressure (bar):	185
Helium pressure (bar):	0.04
Helium flow at oxidation (ca. 34.45):	35
Argon flow (50 ml/min):	50
Tot. Argon pressure (bar):	125
Argon pressure (bar):	0.5
Voltmeter stabilized (start):	15.99
Voltmeter stabilized (30 min):	16.05
When desired argon flow is achieved, set start of oxidation (excel cell):	**405**
When desired argon flow is achieved, set start of oxidation (start time):	**kl 11.36**
Argon flow (after 45 min,ca. 50 ml/min)	50
Helium flow (after 45 min,ca. 34,45)	35
Argon flow (after90 min,ca. 50 ml/min)	50
Helium flow (after 90 min,ca. 34,45)	34
När tiden är ute (2h) anteckna slutruta i excel	**1096**
Väg oxiderade länkar:	3.2599
Temp(Millivolt+23°C):	415°C

400°C	**500°C**	**600°C**	**700°C**	**750°C**	**800°C**	**900°C**
Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.04	2.95	3.03	2.96	3.01	2.98	3.01
3.04	2.96	3.03	2.98	3.01	2.99	3.01
3.01	2.96	3.01	2.99	3.01	2.95	3
3.03	**2.956667**	**3.023333**	**2.976667**	**3.01**	**2.973333**	**3.006667**
20.02	20.04	20.05	20.01	20.01	20.04	20.01
20.02	20.03	20.05	20	20.01	20.04	20
20.01	20.04	20.06	20	20.01	20.02	20.01
20.01667	**20.03667**	**20.05333**	**20.00333**	**20.01**	**20.03333**	**20.00667**
819.9053	**816.7379**	**822.1422**	**815.5886**	**818.1654**	**817.5461**	**817.7149**
9.5956	9.4897	9.5315	9.5429	9.6305	9.5961	9.5733
28.0394	27.5656	28.0075	27.9629	28.119	27.7614	27.9163
18.4438	**18.0759**	**18.476**	**18.42**	**18.4885**	**18.1653**	**18.343**
3.2598	3.2607	3.2603	3.2603	3.26	3.2598	3.2598
36	47	44	37	53	41	41
190	195	192	192	191	191	190
0.04	0.04	0.04	0.04	0.04	0.04	0.04
35	35	35	35	35	35	35
50	52	50	50	50	50	50
129	134	132	132	131	130	129
0.5	0.5	0.5	0.5	0.5	0.5	0.5
16.13	20.51	24.7	28.84	30.8	32.87	36.76
16.24	20.59	24.74	28.75	30.78	32.78	36.63
321	**361**	**341**	**371**	**308**	**376**	**299**
kl 09.11	**kl 12.03**	**kl 10.16**	**kl 11.31**	**kl 11.11**	**kl 11.18**	**kl 13.02**
50	50	50	50	50	50	50
35	34	35	35	35	35	35
50	50	50	50	50	50	50
35	34	35	35	34	34	35
1010	**1048**	**1029**	**1063**	**995**	**1065**	**987**
3.2598	3.2603	3.2603	3.26	3.2598	3.2598	3.25999
419°C	522°C	619°C	714°C	763°C	811°C	906°C

Experiments TGA Extra	**Extra 600°C Plansee**
Photo:	Yes
Thickness 1:	3.09
Thickness 2:	3.08
Thickness 3:	3.06
Mean thickness:	**3.076666667**
Diameter 1:	19.99
Diameter 2:	19.96
Diameter 3:	19.96
Mean diameter:	**19.97**
Area sample: 2*pi*r*t+2*pi*r^2	**819.4576878**
Weight, links+cage (without sample):	9.60623
Weight, links+cage (with sample):	28.1661
Mass sample (before oxidation):	**18.55987**
Weight of the two bottom links:	3.25999
Helium flow:	40
Total helium pressure (bar):	190
Voltmeter stabilized (start):	24.8
Voltmeter stabilized (30 min):	24.67
Tot. Oxygen pressure (bar):	145
Oxygen pressure out (bar)	0.4
Oxygen flow (at start)	41
When desired oxygen flow is achieved, set start of oxidation (excel cell):	**370**
When desired oxygen flow is achieved, set start of oxidation (start time):	11.45
Oxygen flow (after 45 min)	40
Oxygen flow (vid 90 min)	40
When time is out (2h) note the final excel cell	**1059**
Weight of the bottom two links:	3.2601
Temp(Millivolt+23°C):	617°C

Extra 600°C China He only	**Extra 500°C China He only**
Yes	Yes
2.95	3.04
2.96	3.03
2.96	3.03
2.956666667	**3.033333333**
20.01	20.06
20.02	20.05
20.02	20.04
20.01666667	**20.05**
815.2938209	**822.5304796**
9.5888	9.6826
28.0722	28.2355
18.4834	**18.5529**
3.2599	3.2598
45	46
187	186
24.9	20.21
24.8	20.23
-	-
-	-
Helium flow (41)	Helium flow (45)
452	**432**
11.23	kl 11.43
Helium flow (41)	Helium flow (44)
Helium flow(41)	Helium flow (43)
1152	**1125**
3.2598	3.2599
621°C	513°C

APPENDIX 7

Matlab code used in this thesis is shown below:

Calculation of amount of water in the STA:

```
format long
close all
clc
clear all

%% Amount of water in wet argon gas experiment at 500°C and 550°C in STA

p_vap = 2.3393E3/101.325E3;
%Vapour pressure at 20°C [atm]

V_wet_ar = 20E-6;
%Volume wet argon gas [m^3]
V_tot_ar = 70E-6;
%Total volume argon gas [m^3]

p_H2O = (p_vap*V_wet_ar)/V_tot_ar;
%Partialpressure water vapour [atm]

%% Amount of water in experiment with He+Ar+H2O in TGA

p_vap_tga = 3.1699E3/101.325E3;
%Vapour pressure at 25°C [atm]

V_wet_ar_tga = 50E-6;
%Volume wet argon gas [m^3]
V_tot_ar_tga = 200E-6;
%Total volume argon gas [m^3]

p_H2O_tga = (p_vap_tga*V_wet_ar_tga)/V_tot_ar_tga;
%Partialpressure water vapour [atm]
```

Calculation of conversion between millimetres to litres/min:

```
format long
close all
clc
clear all

%% Conversion from millimetres to liters/min (Gas flow) at 300 K

my_O2 = 20.8;
%Viscosity of oxygen
my_He = 20.0;
%Viscosity of helium

V_He = 0.15*60;
%Volume helium

V_O2_He = V_He*my_He/my_O2;
%Volume oxygen

millimetre_He = 17+V_O2_He*2.016;
%Millimetre on flow meter
```

Matlab code from the STA experiments:

```
format long
close all
clc
clf
clear all

data_STA = cell(14,1);
%Creates a cell
Area = 2*pi*((5.5E-1)/2)^2;
%Oxidation area

%% 500°C dry argon (raw data values)
% in mg

fileID1 = fopen('ExpDat_W_foil_500_dry_mg.txt');
data_STA{1,1} = textscan(fileID1,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID1);

for i=1:size(data_STA{1,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{1,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{1,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{1,1}{1,4}(j)==3;
%(End value)
        break
    end
end
for k=1:size(data_STA{1,1}{1,4});
%Subtracts every value with the starting value
    W_foil_500_dry_mg(k,1) = data_STA{1,1}{1,3}(k)-data_STA{1,1}{1,3}(i);
end

W_foil_500_dry_mg = W_foil_500_dry_mg(i:(j-1),1);
%Defines the proper length of the vector

for l=1:size(data_STA{1,1}{1,4});
%Subtracts every value with the starting value (time)
    time_500_dry(l,1) = data_STA{1,1}{1,2}(l)-data_STA{1,1}{1,2}(i);
end

time_500_dry = time_500_dry(i:(j-1),1);

% in percent [%]

fileID2 = fopen('ExpDat_W_foil_500_dry_%.txt');
data_STA{2,1} = textscan(fileID2,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID2);
```

```
for i=1:size(data_STA{2,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{2,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{2,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{2,1}{1,4}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{2,1}{1,4});
%Subtracts every value with the starting value
    W_foil_500_dry(k,1) = data_STA{2,1}{1,3}(k)-data_STA{2,1}{1,3}(i);
end

W_foil_500_dry = W_foil_500_dry(i:(j-1),1)+100;
%Defines the proper length of the vector

%% 500°C dry argon (experiment 2) (raw data values)
% in mg

fileID1 = fopen('ExpDat_W_foil_500_dry_mg_2.txt');
data_STA{9,1} = textscan(fileID1,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID1);

for i=1:size(data_STA{9,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{9,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{9,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{9,1}{1,4}(j)==3;
%(End value)
        break
    end
end
for k=1:size(data_STA{9,1}{1,4});
%Subtracts every value with the starting value
    W_foil_500_dry_mg_2(k,1) = data_STA{9,1}{1,3}(k)-data_STA{9,1}{1,3}(i);
end

W_foil_500_dry_mg_2 = W_foil_500_dry_mg_2(i:(j-1),1);
%Defines the proper length of the vector

for l=1:size(data_STA{9,1}{1,4});
%Subtracts every value with the starting value (time)
    time_500_dry_2(l,1) = data_STA{9,1}{1,2}(l)-data_STA{9,1}{1,2}(i);
end
```

```
time_500_dry_2 = time_500_dry_2(i:(j-1),1);

% in percent [%]

fileID2 = fopen('ExpDat_W_foil_500_dry_%_2.txt');
data_STA{10,1} = textscan(fileID2,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID2);

for i=1:size(data_STA{10,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{10,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{10,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{10,1}{1,4}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{10,1}{1,4});
%Subtracts every value with the starting value
    W_foil_500_dry_2(k,1) = data_STA{10,1}{1,3}(k)-data_STA{10,1}{1,3}(i);
end

W_foil_500_dry_2 = W_foil_500_dry_2(i:(j-1),1)+100;
%Defines the proper length of the vector

%% 500°C dry argon (experiment 3) (raw data values)
% in mg

fileID1 = fopen('ExpDat_W_foil_500_dry_mg_3try.txt');
data_STA{13,1} = textscan(fileID1,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID1);

for i=1:size(data_STA{13,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{13,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{13,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{13,1}{1,4}(j)==3;
%(End value)
        break
    end
end
for k=1:size(data_STA{13,1}{1,4});
%Subtracts every value with the starting value
```

```
    W_foil_500_dry_mg_3(k,1) = data_STA{13,1}{1,3}(k)-
data_STA{13,1}{1,3}(i);
end

W_foil_500_dry_mg_3 = W_foil_500_dry_mg_3(i:(j-1),1);
%Defines the proper length of the vector

for l=1:size(data_STA{13,1}{1,4});
%Subtracts every value with the starting value (time)
    time_500_dry_3(l,1) = data_STA{13,1}{1,2}(l)-data_STA{13,1}{1,2}(i);
end

time_500_dry_3 = time_500_dry_3(i:(j-1),1);

% in percent [%]

fileID14 = fopen('ExpDat_W_foil_500_dry_mg_3try_%.txt');
data_STA{14,1} = textscan(fileID14,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID14);

for i=1:size(data_STA{14,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{14,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{14,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{14,1}{1,4}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{14,1}{1,4});
%Subtracts every value with the starting value
    W_foil_500_dry_2(k,1) = data_STA{14,1}{1,3}(k)-data_STA{14,1}{1,3}(i);
end

W_foil_500_dry_2 = W_foil_500_dry_2(i:(j-1),1)+100;
%Defines the proper length of the vector

%% 550°C dry argon (raw data values) two runs, one in 48 h and one in 12 h
% in mg

% 24 h run
fileID3 = fopen('ExpDat_W_foil_550_dry_mg.txt');
data_STA{3,1} = textscan(fileID3,'%f %f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID3);

for i=1:size(data_STA{3,1}{1,5});
%Searches where the flow changes from segment one to two
    if data_STA{3,1}{1,5}(i)==2;
%(Start value)
        break
```

```
    end
end

for j=1:size(data_STA{3,1}{1,5});
%Searches where the flow changes from segment two to three
    if data_STA{3,1}{1,5}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{3,1}{1,4});
%Subtracts every value with the starting value
    W_foil_550_dry_mg(k,1) = data_STA{3,1}{1,4}(k)-data_STA{3,1}{1,4}(i);
end

W_foil_550_dry_mg = W_foil_550_dry_mg(i:(j-1),1);
%Defines the proper length of the vector

for l=1:size(data_STA{3,1}{1,4});
%Subtracts every value with the starting value (time)
    time_550_dry(l,1) = data_STA{3,1}{1,2}(l)-data_STA{3,1}{1,2}(i);
end

time_550_dry = time_550_dry(i:(j-1),1);
%Defines the proper length of the vector

% in percent [%]

fileID4 = fopen('ExpDat_W_foil_550_dry_%.txt');
data_STA{4,1} = textscan(fileID4,'%f %f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID4);

for i=1:size(data_STA{4,1}{1,5});
%Searches where the flow changes from segment one to two
    if data_STA{4,1}{1,5}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{4,1}{1,5});
%Searches where the flow changes from segment two to three
    if data_STA{4,1}{1,5}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{4,1}{1,4});
%Subtracts every value with the starting value
    W_foil_550_dry(k,1) = data_STA{4,1}{1,4}(k)-data_STA{4,1}{1,4}(i);
end

W_foil_550_dry = W_foil_550_dry(i:(j-1),1)+100;
%Defines the proper length of the vector

% 12 h run
```

```
fileID11 = fopen('ExpDat_W_foil_550_dry_mg_2.txt');
data_STA{11,1} = textscan(fileID11,'%f %f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID11);

for i=1:size(data_STA{11,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{11,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{11,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{11,1}{1,4}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{11,1}{1,4});
%Subtracts every value with the starting value
    W_foil_550_dry_mg_2(k,1) = data_STA{11,1}{1,3}(k)-
data_STA{11,1}{1,3}(i);
end

W_foil_550_dry_mg_2 = W_foil_550_dry_mg_2(i:(j-1),1);
%Defines the proper length of the vector

for l=1:size(data_STA{11,1}{1,4});
%Subtracts every value with the starting value (time)
    time_550_dry_2(l,1) = data_STA{11,1}{1,2}(l)-data_STA{11,1}{1,2}(i);
end

time_550_dry_2 = time_550_dry_2(i:(j-1),1);
%Defines the proper length of the vector

%% Polynomial fit to the 12 h run in mg

poly550 = polyfit(time_550_dry_2,W_foil_550_dry_mg_2,1);
%Polynomial fit (least squares)
f550 = polyval(poly550,time_550_dry_2);
%Returns the value of the polynomial evaluated at the different times
f550_2 = polyval(poly550,time_550_dry);
%Returns the value of the polynomial evaluated at the different times
%%
%percent

fileID12 = fopen('ExpDat_W_foil_550_dry_%_2.txt');
data_STA{12,1} = textscan(fileID12,'%f %f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID12);

for i=1:size(data_STA{12,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{12,1}{1,4}(i)==2;
%(Start value)
        break
```

```
    end
end

for j=1:size(data_STA{12,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{12,1}{1,4}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{12,1}{1,3});
%Subtracts every value with the starting value
    W_foil_550_dry_2(k,1) = data_STA{12,1}{1,3}(k)-data_STA{12,1}{1,3}(i);
end

W_foil_550_dry_2 = W_foil_550_dry_2(i:(j-1),1)+100;
%Defines the proper length of the vector

for l=1:size(data_STA{12,1}{1,4});
%Subtracts every value with the starting value (time)
    time_550_dry_2(l,1) = data_STA{12,1}{1,2}(l)-data_STA{12,1}{1,2}(i);
end

time_550_dry_2 = time_550_dry_2(i:(j-1),1);
%Defines the proper length of the vector

%% Polynomial fit to the 12 h run in %

poly550_pro = polyfit(time_550_dry_2,W_foil_550_dry_2,1);
%Polynomial fit (least squares)
f550_pro = polyval(poly550_pro,time_550_dry_2);
%Returns the value of the polynomial evaluated at the different times
f550_2_pro = polyval(poly550_pro,time_550_dry);
%Returns the value of the polynomial evaluated at the different times


%% 500°C wet argon (raw data values)
% in mg

fileID5 = fopen('ExpDat_W_foil_500_wet_mg.txt');
data_STA{5,1} = textscan(fileID5,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID5);

for i=1:size(data_STA{5,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{5,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{5,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{5,1}{1,4}(j)==3;
%(End value)
        break
    end
```

```
end

for k=1:size(data_STA{5,1}{1,4});
%Subtracts every value with the starting value
    W_foil_500_wet_mg(k,1) = data_STA{5,1}{1,3}(k)-data_STA{5,1}{1,3}(i);
end

W_foil_500_wet_mg = W_foil_500_wet_mg(i:(j-1),1);
%Defines the proper length of the vector

for l=1:size(data_STA{5,1}{1,4});
%Subtracts every value with the starting value (time)
    time_500_wet(l,1) = data_STA{5,1}{1,2}(l)-data_STA{5,1}{1,2}(i);
end

time_500_wet = time_500_wet(i:(j-1),1);

% in percent [%]

fileID6 = fopen('ExpDat_W_foil_500_wet_%.txt');
data_STA{6,1} = textscan(fileID6,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID6);

for i=1:size(data_STA{6,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{6,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{6,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{6,1}{1,4}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{6,1}{1,4});
%Subtracts every value with the starting value
    W_foil_500_wet(k,1) = data_STA{6,1}{1,3}(k)-data_STA{6,1}{1,3}(i);
end

W_foil_500_wet = W_foil_500_wet(i:(j-1),1)+100;
%Defines the proper length of the vector

%% 550°C wet argon (raw data values)
% in mg

fileID7 = fopen('ExpDat_W_foil_550_wet_mg.txt');
data_STA{7,1} = textscan(fileID7,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID7);

for i=1:size(data_STA{7,1}{1,4});
%Searches where the flow changes from segment one to two
```

```
    if data_STA{7,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{7,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{7,1}{1,4}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{7,1}{1,4});
%Subtracts every value with the starting value
    W_foil_550_wet_mg(k,1) = data_STA{7,1}{1,3}(k)-data_STA{7,1}{1,3}(i);
end

W_foil_550_wet_mg = W_foil_550_wet_mg(i:(j-1),1);
%Defines the proper length of the vector

for l=1:size(data_STA{7,1}{1,4});
%Subtracts every value with the starting value (time)
    time_550_wet(l,1) = data_STA{7,1}{1,2}(l)-data_STA{7,1}{1,2}(i);
end

time_550_wet = time_550_wet(i:(j-1),1);

% in percent [%]

fileID8 = fopen('ExpDat_W_foil_550_wet_%.txt');
data_STA{8,1} = textscan(fileID8,'%f %f %f %d','Delimiter',';');
%Imports data from .txt file to a cell
fclose(fileID8);

for i=1:size(data_STA{8,1}{1,4});
%Searches where the flow changes from segment one to two
    if data_STA{8,1}{1,4}(i)==2;
%(Start value)
        break
    end
end

for j=1:size(data_STA{8,1}{1,4});
%Searches where the flow changes from segment two to three
    if data_STA{8,1}{1,4}(j)==3;
%(End value)
        break
    end
end

for k=1:size(data_STA{8,1}{1,4});
%Subtracts every value with the starting value
    W_foil_550_wet(k,1) = data_STA{8,1}{1,3}(k)-data_STA{8,1}{1,3}(i);
end

W_foil_550_wet = W_foil_550_wet(i:(j-1),1)+100;
%Defines the proper length of the vector
```

```
%% Graphs of raw STA-values taken from where segment 2 starts until segment
3 starts (only high temperature segment)

figure(1)
plot(time_500_dry,W_foil_500_dry_mg/Area)
grid on
title('Tungsten foil in dry argon (500°C)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change [mg/cm^2]','fontsize',13)


figure(2)
plot(time_550_dry(1:14400),W_foil_550_dry_mg(1:14400)/Area,time_550_dry_2(1
:14400),W_foil_550_dry_mg_2(1:14400)/Area,'r',time_550_dry_2,f550/Area)
grid on
title('Tungsten foil in dry argon (550°C)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change [mg/cm^2]','fontsize',13)
legend('First try', 'Second try','Linear regression','Location',
'Northwest')

figure(3)
plot(time_500_wet,W_foil_500_wet_mg/Area)
grid on
title('Tungsten foil in wet argon (500°C)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change [mg/cm^2]','fontsize',13)


figure(4)
plot(time_550_wet,W_foil_550_wet_mg/Area)
grid on
title('Tungsten foil in wet argon (550°C)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change [mg/cm^2]','fontsize',13)

figure(5)
plot(time_500_dry_2,W_foil_500_dry_mg_2/Area)
grid on
title('Tungsten foil in dry argon, second experiment
(500°C)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change [mg/cm^2]','fontsize',13)

figure(6)
plot(time_550_dry,W_foil_550_dry_mg/Area)
grid on
title('Tungsten foil in dry argon (550°C)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change [mg/cm^2]','fontsize',13)

figure(7)
plot(time_500_dry_3,W_foil_500_dry_mg_3/Area)
grid on
title('Tungsten foil in dry argon, third experiment (500°C)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change [mg/cm^2]','fontsize',13)
```

```
figure(8)
plot(time_550_dry,
W_foil_550_dry_mg/Area,time_550_dry_2(1:14400),W_foil_550_dry_mg_2(1:14400)
/Area,'g',time_550_dry,f550_2/Area,'r')
grid on
title('Tungsten foil in dry argon (550°C) (extrapolated from 12 h
run)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change [mg/cm^2]','fontsize',13)
legend('First run 48 h', 'Second run 12 h','Linear regression, extrapolated
from 12 h run','Location', 'Northwest')
```

Matlab code from the TGA experiments with oxygen:

```
format long
close all
clc
clear all

R = 8.314;
%Gas constant

% load('logfit.m')

%% Experiment with  pure tungsten sample at 422°C 120 min (He+0.5%O2)

data_TGA_400 = xlsread('13_aug_120min_400.xlsx');
%Imports the data from excel
masschange_400 = ((data_TGA_400(431:1129,1)-
data_TGA_400(431))*1000)/(811.6034E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_400 = zeros(length(masschange_400),1);

for i = 1:length(masschange_400);
%Creates a timevector
    time_400(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly400 = polyfit(time_400,masschange_400,n);
    f400 = polyval(poly400,time_400);
    residual = masschange_400-f400;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly400 = polyfit(time_400,masschange_400,n);
%Polynomial fit (least squares)
f400 = polyval(poly400,time_400);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly400(j) = poly400(j+1)*j;
end

figure(1)
[slope_400, intercept_400] = logfit(time_400,masschange_400,'loglog');
yApprox_400 = (10^intercept_400)*time_400.^(slope_400);

figure(2)
plot(time_400,masschange_400,'.',time_400,f400,time_400,yApprox_400,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (422°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
```

```
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','SouthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 522°C 120 min (He+0.5%O2)

data_TGA_500 = xlsread('23juli_tungsten_500_120min.xlsx');
%Imports the data from excel
masschange_500 = ((data_TGA_500(454:1143,1)-
data_TGA_500(454))*1000)/(819.4342E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_500 = zeros(length(masschange_500),1);

for i = 1:length(masschange_500);
%Creates a timevector
    time_500(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly500 = polyfit(time_500,masschange_500,n);
    f500 = polyval(poly500,time_500);
    residual = masschange_500-f500;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly500 = polyfit(time_500,masschange_500,n);
%Polynomial fit (least squares)
f500 = polyval(poly500,time_500);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly500(j) = poly500(j+1)*j;
end

figure(3)
[slope_500, intercept_500] = logfit(time_500,masschange_500,'loglog');
yApprox_500 = (10^intercept_500)*time_500.^(slope_500);

figure(4)
plot(time_500,masschange_500,'.',time_500,f500,time_500,yApprox_500,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (522°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 618°C 120 min (He+0.5%O2)
```

```
data_TGA_600 = xlsread('24juli_600_120min.xlsx');
%Imports the data from excel
masschange_600 = ((data_TGA_600(377:1069,1)-
data_TGA_600(377))*1000)/(818.8361E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_600 = zeros(length(masschange_600),1);

for i = 1:length(masschange_600);
%Creates a timevector
    time_600(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly600 = polyfit(time_600,masschange_600,n);
    f600 = polyval(poly600,time_600);
    residual = masschange_600-f600;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly600 = polyfit(time_600,masschange_600,n);
%Polynomial fit (least squares)
f600 = polyval(poly600,time_600);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly600(j) = poly600(j+1)*j;
end

figure(5)
[slope_600, intercept_600] = logfit(time_600,masschange_600,'loglog');
yApprox_600 = (10^intercept_600)*time_600.^(slope_600);

figure(6)
plot(time_600,masschange_600,'.',time_600,f600,time_600,yApprox_600,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (618°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 716°C 120 min (He+0.5%O2)

data_TGA_700 = xlsread('25_juli_120min_700.xlsx');
%Imports the data from excel
masschange_700 = ((data_TGA_700(362:1055,1)-
data_TGA_700(362))*1000)/(818.2599E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_700 = zeros(length(masschange_700),1);
```

```
for i = 1:length(masschange_700);
%Creates a timevector
    time_700(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly700 = polyfit(time_700,masschange_700,n);
    f700 = polyval(poly700,time_700);
    residual = masschange_700-f700;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly700 = polyfit(time_700,masschange_700,n);
%Polynomial fit (least squares)
f700 = polyval(poly700,time_700);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly700(j) = poly700(j+1)*j;
end

figure(7)
[slope_700, intercept_700] = logfit(time_700,masschange_700,'loglog');
yApprox_700 = (10^intercept_700)*time_700.^(slope_700);

figure(8)
plot(time_700,masschange_700,'.',time_700,f700,time_700,yApprox_700,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (716°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 763°C 120 min (He+0.5%O2)

data_TGA_750 = xlsread('26_juli_120min_750.xlsx');
%Imports the data from excel
masschange_750 = ((data_TGA_750(364:1053,1)-
data_TGA_750(364))*1000)/(819.5177E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_750 = zeros(length(masschange_750),1);

for i = 1:length(masschange_750);
%Creates a timevector
    time_750(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
```

```
for n = 1:10;
    poly750 = polyfit(time_750,masschange_750,n);
    f750 = polyval(poly750,time_750);
    residual = masschange_750-f750;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly750 = polyfit(time_750,masschange_750,n);
%Polynomial fit (least squares)
f750 = polyval(poly750,time_750);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly750(j) = poly750(j+1)*j;
end

figure(9)
[slope_750, intercept_750] = logfit(time_750,masschange_750,'loglog');
yApprox_750 = (10^intercept_750)*time_750.^(slope_750);

figure(10)
plot(time_750,masschange_750,'.',time_750,f750,time_750,yApprox_750,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (763°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 811°C 120 min (He+0.5%O2)

data_TGA_800 = xlsread('29_juli_120min_800.xlsx');
%Imports the data from excel
masschange_800 = ((data_TGA_800(352:1042,1)-
data_TGA_800(352))*1000)/(818.1754E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_800 = zeros(length(masschange_800),1);

for i = 1:length(masschange_800);
%Creates a timevector
    time_800(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly800 = polyfit(time_800,masschange_800,n);
    f800 = polyval(poly800,time_800);
    residual = masschange_800-f800;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
```

```
    end
end

poly800 = polyfit(time_800,masschange_800,n);
%Polynomial fit (least squares)
f800 = polyval(poly800,time_800);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly800(j) = poly800(j+1)*j;
end

figure(11)
[slope_800, intercept_800] = logfit(time_800,masschange_800,'loglog');
yApprox_800 = (10^intercept_800)*time_800.^(slope_800);

figure(12)
plot(time_800,masschange_800,'.',time_800,f800,time_800,yApprox_800,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (811°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 907°C 120 min (He+0.5%O2)

data_TGA_900 = xlsread('30_juli_120min_900.xlsx');
%Imports the data from excel
masschange_900 = ((data_TGA_900(267:955,1)-
data_TGA_900(267))*1000)/(817.3273E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_900 = zeros(length(masschange_900),1);

for i = 1:length(masschange_900);
%Creates a timevector
    time_900(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly900 = polyfit(time_900,masschange_900,n);
    f900 = polyval(poly900,time_900);
    residual = masschange_900-f900;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly900 = polyfit(time_900,masschange_900,n);
%Polynomial fit (least squares)
f900 = polyval(poly900,time_900);
%Returns the value of the polynomial evaluated at the different times
```

```
for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly900(j) = poly900(j+1)*j;
end

figure(13)
[slope_900, intercept_900] = logfit(time_900,masschange_900,'loglog');
yApprox_900 = (10^intercept_900)*time_900.^(slope_900);

figure(14)
plot(time_900,masschange_900,'.',time_900,f900,time_900,yApprox_900,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (907°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 522°C 120 min (Dried He)

data_TGA_500_He = xlsread('30_juli_120min_500_He_only.xlsx');
%Imports the data from excel
masschange_500_He = ((data_TGA_500_He(406:1097,1)-
data_TGA_500_He(406))*1000)/(817.8613E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
time_500_He = zeros(length(masschange_500_He),1);

for i = 1:length(masschange_500_He);
%Creates a timevector
    time_500_He(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly500_He = polyfit(time_500_He,masschange_500_He,n);
    f500_He = polyval(poly500_He,time_500_He);
    residual = masschange_500_He-f500_He;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly500_He = polyfit(time_500_He,masschange_500_He,n);
%Polynomial fit (least squares)
f500_He = polyval(poly500_He,time_500_He);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly500_He(j) = poly500_He(j+1)*j;
end

figure(15)
```

```
plot(time_500_He,masschange_500_He,'.',time_500_He,f500_He)
grid on
title('Pure tungsten in dried He (522°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)

%% Figures

figure(16)
plot(time_400,f400,'.b')
hold on
plot(time_500,f500,'.b')
hold on
plot(time_600,f600,'.g')
hold on
plot(time_700,f700,'.y')
hold on
plot(time_750,f750,'.r')
hold on
plot(time_800,f800,'.m')
hold on
plot(time_900,f900,'.k')
grid on
title('Pure tungsten in He+0.5% O_2 (10th degree polynomial
fit)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 =
legend('422°C','522°C','618°C','716°C','763°C','811°C','907°C','Location','
NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

figure(17)
plot(time_400,masschange_400,'.b')
hold on
plot(time_500,masschange_500,'.b')
hold on
plot(time_600,masschange_600,'.g')
hold on
plot(time_700,masschange_700,'.y')
hold on
plot(time_750,masschange_750,'.r')
hold on
plot(time_800,masschange_800,'.m')
hold on
plot(time_900,masschange_900,'.k')
grid on
title('Pure tungsten in He+0.5% O_2','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_2 =
legend('422°C','522°C','618°C','716°C','763°C','811°C','907°C','Location','
NorthWest');
set(legend_2,'FontSize',14)
set(gca,'FontSize',15)

figure(18)
plot(time_400,masschange_400,'.',time_400,f400,'r')
title('Pure tungsten in He+0.5% O_2 (422°C,120 min)','fontsize',13)
```

```
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
grid on
legend_2 = legend('Data','Polynomial','Location','SouthEast');
set(legend_2,'FontSize',14)
set(gca,'FontSize',15)

figure(19)
plot(time_500,masschange_500,'.',time_500,f500,'r')
title('Pure tungsten in He+0.5% O_2 (522°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
grid on
legend_2 = legend('Data','Polynomial','Location','SouthEast');
set(legend_2,'FontSize',14)
set(gca,'FontSize',15)

figure(20)
plot(time_600,masschange_600,'.',time_600,f600,'r')
title('Pure tungsten in He+0.5% O_2 (618°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
grid on
legend_2 = legend('Data','Polynomial','Location','SouthEast');
set(legend_2,'FontSize',14)
set(gca,'FontSize',15)

%% Temperature dependence of the rate of oxidation

% r_dot_null(1) = polyval(derivpoly400,0); Inaccurate
r_dot_null(1) = polyval(derivpoly500,4);
%Rate of oxidation (estimated zero time and 522°C)4
r_dot_null(2) = polyval(derivpoly600,5);
%Rate of oxidation (estimated zero time and 618°C)5
r_dot_null(3) = polyval(derivpoly700,3);
%Rate of oxidation (estimated zero time and 716°C)3
r_dot_null(4) = polyval(derivpoly750,4);
%Rate of oxidation (estimated zero time and 763°C)4
r_dot_null(5) = polyval(derivpoly800,5);
%Rate of oxidation (estimated zero time and 811°C)5
r_dot_null(6) = polyval(derivpoly900,5);
%Rate of oxidation (estimated zero time and 907°C)5


r_dot(1) = polyval(derivpoly500,60);
%Rate of oxidation (at 60 min and 522°C)
r_dot(2) = polyval(derivpoly600,60);
%Rate of oxidation (at 60 min and 618°C)
r_dot(3) = polyval(derivpoly700,60);
%Rate of oxidation (at 60 min and 716°C)
r_dot(4) = polyval(derivpoly750,60);
%Rate of oxidation (at 60 min and 763°C)
r_dot(5) = polyval(derivpoly800,60);
%Rate of oxidation (at 60 min and 811°C)
r_dot(6) = polyval(derivpoly900,60);
%Rate of oxidation (at 60 min and 907°C)

% 1/Temperature vector
temp = [1/(522+273.15), 1/(618+273.15), 1/(716+273.15), 1/(763+273.15),
1/(811+273.15), 1/(907+273.15)];
```

```
temp2 = [1/(522+273.15), 1/(618+273.15), 1/(716+273.15)];
temp3 = [1/(763+273.15), 1/(811+273.15), 1/(907+273.15)];
%% Activation energies

p = polyfit(temp, log(r_dot_null),1);
%Linear regression
yfit = polyval(p,temp);
%Returns the value of the linear regression
Q_O = p(1)*R;
%Activation energy at zero time (Chemical reaction between tungsten and
oxygen)

p2 = polyfit(temp2, log(r_dot(1:3)),1);
%Linear regression
yfit2 = polyval(p2,temp2);
%Returns the value of the linear regression
Q2 = p2(1)*R;
%Activation energy for diffusion-controlled oxidation under the
volatilization temperature

p3 = polyfit(temp3, log(r_dot(4:6)),1);
%Linear regression
yfit3 = polyval(p3,temp3);
%Returns the value of the linear regression
Q3 = p3(1)*R;
%Activation energy for the oxidation over the volatilization temperature

figure(21)
plot(temp, log(r_dot_null),'*', temp, yfit)
grid on
title('Pure tungsten in He+0.5% O_2 at zero time','fontsize',13)
xlabel('1/Temperature [1/K]','fontsize',13)
ylabel('Natural logarithm of the rate of oxidation','fontsize',13)
legend_3 = legend('Points','Linear regression (least squares)');
set(legend_3,'FontSize',14)
set(gca,'FontSize',15)

%% Modeling

A_500 = r_dot(1)/(exp(Q2/(R*(522+273.15))));
%Calculates the A constant in the arrhenius equation
A_600 = r_dot(2)/(exp(Q2/(R*(618+273.15))));
%Calculates the A constant in the arrhenius equation

A_medel_under_vol = (A_500+A_600)/2;
%Calculates the A constant in the arrhenius equation

K_p_700_empirical = A_medel_under_vol*exp(Q2/(R*(716+273.15)));
%Parabolic rate constant extrapolated from lower temp. range
K_p_750_empirical = A_medel_under_vol*exp(Q2/(R*(763+273.15)));
%Parabolic rate constant extrapolated from lower temp. range
K_p_800_empirical = A_medel_under_vol*exp(Q2/(R*(811+273.15)));
%Parabolic rate constant extrapolated from lower temp. range
K_p_900_empirical = A_medel_under_vol*exp(Q2/(R*(907+273.15)));
%Parabolic rate constant extrapolated from lower temp. range

masschange700 = masschange_700*(818.2599E-2);
%Masschange
```

```
masschange750 = masschange_750*(819.5177E-2);
%Masschange
masschange800 = masschange_800*(818.1754E-2);
%Masschange
masschange900 = masschange_900*(817.3273E-2);
%Masschange
```

Matlab code from the experiments in the TGA with water vapour:

```
format long
close all
clc
clear all

R = 8.314;
%Gas constant

%% Experiment with  pure tungsten sample at 415°C 120 min (He+Ar+H2O)
REDONE

data_TGA_400_H2O_redo = xlsread('20_aug_120min_400_water_redone.xlsx');
%Imports the data from excel
masschange_400_H2O_redo = ((data_TGA_400_H2O_redo(405:1096,1)-
data_TGA_400_H2O_redo(405))*1000)/(816.6360E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_400_percentage_H2O = masschange_400_H2O*100/18.4438;
time_400_H2O_redo = zeros(length(masschange_400_H2O_redo),1);

for i = 1:length(masschange_400_H2O_redo);
%Creates a timevector
    time_400_H2O_redo(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly400_H2O_redo =
polyfit(time_400_H2O_redo,masschange_400_H2O_redo,n);
    f400_H2O_redo = polyval(poly400_H2O_redo,time_400_H2O_redo);
    residual = masschange_400_H2O_redo-f400_H2O_redo;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly400_H2O_redo = polyfit(time_400_H2O_redo,masschange_400_H2O_redo,n);
%Polynomial fit (least squares)
f400_H2O_redo = polyval(poly400_H2O_redo,time_400_H2O_redo);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly400_H2O_redo(j) = poly400_H2O_redo(j+1)*j;
end

figure(18)
[slope_400_redo, intercept_400_redo] =
logfit(time_400_H2O_redo,masschange_400_H2O_redo,'loglog');
yApprox_400_redo =
(10^intercept_400_redo)*time_400_H2O_redo.^(slope_400_redo);

figure(19)
plot(time_400_H2O_redo,masschange_400_H2O_redo,'.',time_400_H2O_redo,f400_H
2O_redo,time_400_H2O_redo,yApprox_400_redo,'r')
```

```
grid on
title('Pure tungsten in He+Ar+H_2O (415°C,120 min) REDONE','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 419°C 120 min (He+Ar+H2O)

data_TGA_400_H2O = xlsread('8_aug_120min_400_water.xlsx');
%Imports the data from excel
masschange_400_H2O = ((data_TGA_400_H2O(321:1010,1)-
data_TGA_400_H2O(321))*1000)/(819.9053E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_400_percentage_H2O = masschange_400_H2O*100/18.4438;
time_400_H2O = zeros(length(masschange_400_H2O),1);

for i = 1:length(masschange_400_H2O);
%Creates a timevector
    time_400_H2O(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly400_H2O = polyfit(time_400_H2O,masschange_400_H2O,n);
    f400_H2O = polyval(poly400_H2O,time_400_H2O);
    residual = masschange_400_H2O-f400_H2O;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly400_H2O = polyfit(time_400_H2O,masschange_400_H2O,n);
%Polynomial fit (least squares)
f400_H2O = polyval(poly400_H2O,time_400_H2O);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly400_H2O(j) = poly400_H2O(j+1)*j;
end

figure(1)
[slope_400, intercept_400] =
logfit(time_400_H2O,masschange_400_H2O,'loglog');
yApprox_400 = (10^intercept_400)*time_400_H2O.^(slope_400);

figure(2)
plot(time_400_H2O,masschange_400_H2O,'.',time_400_H2O,f400_H2O,time_400_H2O
,yApprox_400,'r')
grid on
title('Pure tungsten in He+Ar+H_2O (419°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
```

```
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 522°C 120 min (He+Ar+H2O)

data_TGA_500_H2O = xlsread('1_aug_120min_500_water.xlsx');
%Imports the data from excel
masschange_500_H2O = ((data_TGA_500_H2O(361:1048,1)-
data_TGA_500_H2O(361))*1000)/(816.7379E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_500_percentage_H2O = masschange_500_H2O*100/18.0759;
time_500_H2O = zeros(length(masschange_500_H2O),1);

for i = 1:length(masschange_500_H2O);
%Creates a timevector
    time_500_H2O(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly500_H2O = polyfit(time_500_H2O,masschange_500_H2O,n);
    f500_H2O = polyval(poly500_H2O,time_500_H2O);
    residual = masschange_500_H2O-f500_H2O;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly500_H2O = polyfit(time_500_H2O,masschange_500_H2O,n);
%Polynomial fit (least squares)
f500_H2O = polyval(poly500_H2O,time_500_H2O);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly500_H2O(j) = poly500_H2O(j+1)*j;
end

figure(3)
[slope_500, intercept_500] =
logfit(time_500_H2O,masschange_500_H2O,'loglog');
yApprox_500 = (10^intercept_500)*time_500_H2O.^(slope_500);

figure(4)
plot(time_500_H2O,masschange_500_H2O,'.',time_500_H2O,f500_H2O,time_500_H2O
,yApprox_500,'r')
grid on
title('Pure tungsten in He+Ar+H_2O (522°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)
```

```
%% Experiment with  pure tungsten sample at 619°C 120 min (He+Ar+H2O)

data_TGA_600_H2O = xlsread('2_aug_120min_600_water.xlsx');
%Imports the data from excel
masschange_600_H2O = ((data_TGA_600_H2O(341:1029,1)-
data_TGA_600_H2O(341))*1000)/(822.1422E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_600_percentage_H2O = masschange_600_H2O*100/18.476;
time_600_H2O = zeros(length(masschange_600_H2O),1);

for i = 1:length(masschange_600_H2O);
%Creates a timevector
    time_600_H2O(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly600_H2O = polyfit(time_600_H2O,masschange_600_H2O,n);
    f600_H2O = polyval(poly600_H2O,time_600_H2O);
    residual = masschange_600_H2O-f600_H2O;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly600_H2O = polyfit(time_600_H2O,masschange_600_H2O,n);
%Polynomial fit (least squares)
f600_H2O = polyval(poly600_H2O,time_600_H2O);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly600_H2O(j) = poly600_H2O(j+1)*j;
end

figure(5)
[slope_600, intercept_600] =
logfit(time_600_H2O,masschange_600_H2O,'loglog');
yApprox_600 = (10^intercept_600)*time_600_H2O.^(slope_600);

figure(6)
plot(time_600_H2O,masschange_600_H2O,'.',time_600_H2O,f600_H2O,time_600_H2O
,yApprox_600,'r')
grid on
title('Pure tungsten in He+Ar+H_2O (619°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 714°C 120 min (He+Ar+H2O)
```

```
data_TGA_700_H2O = xlsread('5_aug_120min_700_water.xlsx');
%Imports the data from excel
masschange_700_H2O = ((data_TGA_700_H2O(371:1063,1)-
data_TGA_700_H2O(371))*1000)/(815.5886E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_700_percentage_H2O = masschange_700_H2O*100/18.42;
time_700_H2O = zeros(length(masschange_700_H2O),1);

for i = 1:length(masschange_700_H2O);
%Creates a timevector
    time_700_H2O(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly700_H2O = polyfit(time_700_H2O,masschange_700_H2O,n);
    f700_H2O = polyval(poly700_H2O,time_700_H2O);
    residual = masschange_700_H2O-f700_H2O;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly700_H2O = polyfit(time_700_H2O,masschange_700_H2O,n);
%Polynomial fit (least squares)
f700_H2O = polyval(poly700_H2O,time_700_H2O);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly700_H2O(j) = poly700_H2O(j+1)*j;
end

figure(7)
[slope_700, intercept_700] =
logfit(time_700_H2O,masschange_700_H2O,'loglog');
yApprox_700 = (10^intercept_700)*time_700_H2O.^(slope_700);

figure(8)
plot(time_700_H2O,masschange_700_H2O,'.',time_700_H2O,f700_H2O,time_700_H2O
,yApprox_700,'r')
grid on
title('Pure tungsten in He+Ar+H_2O (714°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 763°C 120 min (He+Ar+H2O)

data_TGA_750_H2O = xlsread('6_aug_120min_750_water.xlsx');
%Imports the data from excel
masschange_750_H2O = ((data_TGA_750_H2O(308:995,1)-
data_TGA_750_H2O(308))*1000)/(818.1654E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
```

```
% masschange_750_percentage_H2O = masschange_750_H2O*100/18.4885;
time_750_H2O = zeros(length(masschange_750_H2O),1);

for i = 1:length(masschange_750_H2O);
%Creates a timevector
    time_750_H2O(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly750_H2O = polyfit(time_750_H2O,masschange_750_H2O,n);
    f750_H2O = polyval(poly750_H2O,time_750_H2O);
    residual = masschange_750_H2O-f750_H2O;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly750_H2O = polyfit(time_750_H2O,masschange_750_H2O,n);
%Polynomial fit (least squares)
f750_H2O = polyval(poly750_H2O,time_750_H2O);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly750_H2O(j) = poly750_H2O(j+1)*j;
end

figure(9)
[slope_750, intercept_750] =
logfit(time_750_H2O,masschange_750_H2O,'loglog');
yApprox_750 = (10^intercept_750)*time_750_H2O.^(slope_750);

figure(10)
plot(time_750_H2O,masschange_750_H2O,'.',time_750_H2O,f750_H2O)
grid on
title('Pure tungsten in He+Ar+H_2O (763°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 811°C 120 min (He+Ar+H2O)

data_TGA_800_H2O = xlsread('7_aug_120min_800_water.xlsx');
%Imports the data from excel
masschange_800_H2O = ((data_TGA_800_H2O(376:1065,1)-
data_TGA_800_H2O(376))*1000)/(817.5461E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_800_percentage_H2O = masschange_800_H2O*100/18.1653;
time_800_H2O = zeros(length(masschange_800_H2O),1);

for i = 1:length(masschange_800_H2O);
%Creates a timevector
    time_800_H2O(i,1) = i*10/60;
```

```
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly800_H2O = polyfit(time_800_H2O,masschange_800_H2O,n);
    f800_H2O = polyval(poly800_H2O,time_800_H2O);
    residual = masschange_800_H2O-f800_H2O;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly800_H2O = polyfit(time_800_H2O,masschange_800_H2O,n);
%Polynomial fit (least squares)
f800_H2O = polyval(poly800_H2O,time_800_H2O);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly800_H2O(j) = poly800_H2O(j+1)*j;
end

figure(11)
[slope_800, intercept_800] =
logfit(time_800_H2O,masschange_800_H2O,'loglog');
yApprox_800 = (10^intercept_800)*time_800_H2O.^(slope_800);

figure(12)
plot(time_800_H2O,masschange_800_H2O,'.',time_800_H2O,f800_H2O)
grid on
title('Pure tungsten in He+Ar+H_2O (811°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)


%% Experiment with  pure tungsten sample at 906°C 120 min (He+Ar+H2O)

data_TGA_900_H2O = xlsread('8_aug_120min_900_water.xlsx');
%Imports the data from excel
masschange_900_H2O = ((data_TGA_900_H2O(299:987,1)-
data_TGA_900_H2O(299))*1000)/(817.7149E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_900_percentage_H2O = masschange_900_H2O*100/18.343;
time_900_H2O = zeros(length(masschange_900_H2O),1);

for i = 1:length(masschange_900_H2O);
%Creates a timevector
    time_900_H2O(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
```

```
    poly900_H2O = polyfit(time_900_H2O,masschange_900_H2O,n);
    f900_H2O = polyval(poly900_H2O,time_900_H2O);
    residual = masschange_900_H2O-f900_H2O;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly900_H2O = polyfit(time_900_H2O,masschange_900_H2O,n);
%Polynomial fit (least squares)
f900_H2O = polyval(poly900_H2O,time_900_H2O);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly900_H2O(j) = poly900_H2O(j+1)*j;
end

figure(13)
[slope_900, intercept_900] =
logfit(time_900_H2O,masschange_900_H2O,'loglog');
yApprox_900 = (10^intercept_900)*time_900_H2O.^(slope_900);

figure(14)
plot(time_900_H2O,masschange_900_H2O,'.',time_900_H2O,f900_H2O)
grid on
title('Pure tungsten in He+Ar+H_2O (906°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)


%% Figures

figure(15)
plot(time_400_H2O_redo,f400_H2O_redo,'.b')
hold on
plot(time_400_H2O,f400_H2O,'.b')
hold on
plot(time_500_H2O,f500_H2O,'.g')
hold on
plot(time_600_H2O,f600_H2O,'.g')
hold on
plot(time_700_H2O,f700_H2O,'.y')
hold on
plot(time_750_H2O,f750_H2O,'.r')
hold on
plot(time_800_H2O,f800_H2O,'.m')
hold on
plot(time_900_H2O,f900_H2O,'.k')
grid on
title('Pure tungsten in He+Ar+H_2O (Polynomial fit)','fontsize',17)
xlabel('Time [min]','fontsize',17)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',17)
```

```
legend_1 =
legend('415°C','419°C','522°C','619°C','714°C','763°C','811°C','906°C','Loc
ation','NorthWest');
set(legend_1,'FontSize',14);
set(gca,'FontSize',15)

figure(16)
plot(time_400_H2O_redo,masschange_400_H2O_redo,'.b')
hold on
plot(time_400_H2O,masschange_400_H2O,'.b')
hold on
plot(time_500_H2O,masschange_500_H2O,'.g')
hold on
plot(time_600_H2O,masschange_600_H2O,'.g')
hold on
plot(time_700_H2O,masschange_700_H2O,'.y')
hold on
plot(time_750_H2O,masschange_750_H2O,'.r')
hold on
plot(time_800_H2O,masschange_800_H2O,'.m')
hold on
plot(time_900_H2O,masschange_900_H2O,'.k')
grid on
title('Pure tungsten in He+Ar+H_2O','fontsize',17)
xlabel('Time [min]','fontsize',17)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',17)
legend_2 =
legend('415°C','419°C','522°C','619°C','714°C','763°C','811°C','906°C','Loc
ation','NorthWest');
set(legend_2,'FontSize',14);
set(gca,'FontSize',15)

figure(21)
plot(time_400_H2O,masschange_400_H2O,'.',time_400_H2O,f400_H2O,'r')
title('Pure tungsten in He+Ar+H_2O (419°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
grid on
legend_2 = legend('Data','Polynomial','Location','NorthEast');
set(legend_2,'FontSize',14)
set(gca,'FontSize',15)

figure(22)
plot(time_400_H2O_redo,masschange_400_H2O_redo,'.',time_400_H2O_redo,f400_H
2O_redo,'r')
title('Pure tungsten in He+Ar+H_2O (415°C,120 min) Redone
exp.','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
grid on
legend_2 = legend('Data','Polynomial','Location','SouthEast');
set(legend_2,'FontSize',14)
set(gca,'FontSize',15)

figure(23)
plot(time_500_H2O,masschange_500_H2O,'.',time_500_H2O,f500_H2O,'r')
title('Pure tungsten in He+Ar+H_2O (522°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
grid on
```

```
legend_2 = legend('Data','Polynomial','Location','SouthEast');
set(legend_2,'FontSize',14)
set(gca,'FontSize',15)

figure(24)
plot(time_600_H2O,masschange_600_H2O,'.',time_600_H2O,f600_H2O,'r')
title('Pure tungsten in He+Ar+H_2O (619°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
grid on
legend_2 = legend('Data','Polynomial','Location','SouthEast');
set(legend_2,'FontSize',14)
set(gca,'FontSize',15)


%% Temperature dependence of the rate of oxidation

% r_dot_0min(1) = polyval(derivpoly400_H2O,0); Inaccurate
%Rate of oxidation (at zero time and 415°C)
% r_dot_0min(2) = polyval(derivpoly500_H2O,0); Inaccurate
%Rate of oxidation (at zero time and 522°C)
r_dot_0min(1) = polyval(derivpoly600_H2O,1);
%Rate of oxidation (at zero time and 619°C)
r_dot_0min(2) = polyval(derivpoly700_H2O,1);
%Rate of oxidation (at zero time and 714°C)
r_dot_0min(3) = polyval(derivpoly750_H2O,1);
%Rate of oxidation (at zero time and 763°C)
r_dot_0min(4) = polyval(derivpoly800_H2O,1);
%Rate of oxidation (at zero time and 811°C)
r_dot_0min(5) = polyval(derivpoly900_H2O,1);
%Rate of oxidation (at zero time and 906°C)

r_dot(1) = polyval(derivpoly400_H2O,60);
%Rate of oxidation (at 60 min and 415°C)
r_dot(2) = polyval(derivpoly500_H2O,60);
%Rate of oxidation (at 60 min and 522°C)
r_dot(3) = polyval(derivpoly600_H2O,60);
%Rate of oxidation (at 60 min and 619°C)
r_dot(4) = polyval(derivpoly700_H2O,60);
%Rate of oxidation (at 60 min and 714°C)
r_dot(5) = polyval(derivpoly750_H2O,60);
%Rate of oxidation (at 60 min and 763°C)
r_dot(6) = polyval(derivpoly800_H2O,60);
%Rate of oxidation (at 60 min and 811°C)
r_dot(7) = polyval(derivpoly900_H2O,60);
%Rate of oxidation (at 60 min and 906°C)

% 1/Temperature vector
temp = [1/(619+273.15), 1/(714+273.15), 1/(763+273.15), 1/(811+273.15),
1/(906+273.15)];
temp2 = [1/(522+273.15), 1/(619+273.15), 1/(714+273.15)];
temp3 = [1/(763+273.15), 1/(811+273.15), 1/(906+273.15)];

%% Activation energies

p = polyfit(temp, log(r_dot_0min),1);
%Linear regression
yfit = polyval(p,temp);
%Returns the value of the linear regression
```

```
Q_O = p(1)*R;
%Activation energy at zero time (Chemical reaction between tungsten and
oxygen)

p2 = polyfit(temp2, log(r_dot(2:4)),1);
%Linear regression
yfit2 = polyval(p2,temp2);
%Returns the value of the linear regression
Q2 = p2(1)*R;
%Activation energy for diffusion-controlled oxidation under the
volatilization temperature

p3 = polyfit(temp3, log(r_dot(5:7)),1);
%Linear regression
yfit3 = polyval(p3,temp3);
%Returns the value of the linear regression
Q3 = p3(1)*R;
%Activation energy for the oxidation over the volatilization temperature

figure(17)
plot(temp, log(r_dot_0min),'*', temp, yfit)
grid on
title('Pure tungsten in He+Ar+H_2O at zero time','fontsize',13)
xlabel('1/Temperature [1/K]','fontsize',13)
ylabel('Natural logarithm of the rate of oxidation','fontsize',13)
legend_3 = legend('Points','Linear regression (least squares)');
set(legend_3,'FontSize',14)
set(gca,'FontSize',15)
```

Matlab code from the experiments with pure helium:

```
format long
close all
clc
clear all

R = 8.314;
%Gas constant

%% Experiment with  pure tungsten sample at 522°C 120 min (Dried He)

data_TGA_500_He = xlsread('30_juli_120min_500_He_only.xlsx');
%Imports the data from excel
masschange_500_He = ((data_TGA_500_He(406:1097,1)-
data_TGA_500_He(406))*1000)/(817.8613E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_500_percentage_He = masschange_500_He*100/18.3584;
time_500_He = zeros(length(masschange_500_He),1);

for i = 1:length(masschange_500_He);
%Creates a timevector
    time_500_He(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly500_He = polyfit(time_500_He,masschange_500_He,n);
    f500_He = polyval(poly500_He,time_500_He);
    residual = masschange_500_He-f500_He;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly500_He = polyfit(time_500_He,masschange_500_He,n);
%Polynomial fit (least squares)
f500_He = polyval(poly500_He,time_500_He);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly500_He(j) = poly500_He(j+1)*j;
end

figure(1)
[slope_500, intercept_500] =
logfit(time_500_He,masschange_500_He,'loglog');
yApprox_500 = (10^intercept_500)*time_500_He.^(slope_500);

figure(2)
plot(time_500_He,masschange_500_He,'.',time_500_He,f500_He,time_500_He,yApp
rox_500,'r')
grid on
title('Pure tungsten in dried He (522°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
```

```
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','SouthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 621°C 120 min (Dried He)

data_TGA_600_He = xlsread('14_aug_120min_600_He_only.xlsx');
%Imports the data from excel
masschange_600_He = ((data_TGA_600_He(452:1152,1)-
data_TGA_600_He(452))*1000)/(815.2938E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_600_percentage_He = masschange_600_He*100/18.4834;
time_600_He = zeros(length(masschange_600_He),1);

for i = 1:length(masschange_600_He);
%Creates a timevector
    time_600_He(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly600_He = polyfit(time_600_He,masschange_600_He,n);
    f600_He = polyval(poly600_He,time_600_He);
    residual = masschange_600_He-f600_He;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly600_He = polyfit(time_600_He,masschange_600_He,n);
%Polynomial fit (least squares)
f600_He = polyval(poly600_He,time_600_He);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly600_He(j) = poly600_He(j+1)*j;
end

figure(3)
[slope_600, intercept_600] =
logfit(time_600_He,masschange_600_He,'loglog');
yApprox_600 = (10^intercept_600)*time_600_He.^(slope_600);

figure(4)
plot(time_600_He,masschange_600_He,'.',time_600_He,f600_He,time_600_He,yApp
rox_600,'r')
grid on
title('Pure tungsten in dried He (621°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)
```

```
%% Experiment with  pure tungsten sample at 513°C 120 min (Dried He)

data_TGA_500_He_2 = xlsread('15_aug_120min_500_He_only.xlsx');
%Imports the data from excel
masschange_500_He_2 = ((data_TGA_500_He_2(432:1125,1)-
data_TGA_500_He_2(432))*1000)/(822.5305E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
% masschange_500_percentage_He = masschange_500_He*100/18.3584;
time_500_He_2 = zeros(length(masschange_500_He_2),1);

for i = 1:length(masschange_500_He_2);
%Creates a timevector
    time_500_He_2(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly500_He_2 = polyfit(time_500_He_2,masschange_500_He_2,n);
    f500_He_2 = polyval(poly500_He_2,time_500_He_2);
    residual = masschange_500_He_2-f500_He_2;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly500_He_2 = polyfit(time_500_He_2,masschange_500_He_2,n);
%Polynomial fit (least squares)
f500_He_2 = polyval(poly500_He_2,time_500_He_2);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly500_He_2(j) = poly500_He_2(j+1)*j;
end

figure(5)
[slope_500_2, intercept_500_2] =
logfit(time_500_He_2,masschange_500_He_2,'loglog');
yApprox_500_2 = (10^intercept_500_2)*time_500_He_2.^(slope_500_2);

figure(6)
plot(time_500_He_2,masschange_500_He_2,'.',time_500_He_2,f500_He_2,time_500
_He_2,yApprox_500_2,'r')
grid on
title('Pure tungsten in dried He (513°C,120 min) second
experiment','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','NorthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)
%% Figures

figure (7)
```

```
plot(time_500_He,f500_He,'.g')
hold on
plot(time_600_He,f600_He,'.r')
hold on
plot(time_500_He_2,f500_He_2,'.b')
grid on
title('Pure tungsten in He','fontsize',17)
xlabel('Time [min]','fontsize',17)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',17)
legend_2 = legend('522°C','621°C','513°C Redone
exp.','Location','NorthWest');
set(legend_2,'FontSize',14)
```

Matlab code of the modeling:

```
format long
close all
clc
clear all

R = 8.314;
%Gas constant

% load('logfit.m')

%% Experiment with  pure tungsten sample at 422°C 120 min (He+0.5%O2)

data_TGA_400 = xlsread('13_aug_120min_400.xlsx');
%Imports the data from excel
masschange_400 = ((data_TGA_400(431:1129,1)-
data_TGA_400(431))*1000)/(811.6034E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_400 = zeros(length(masschange_400),1);

for i = 1:length(masschange_400);
%Creates a timevector
    time_400(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly400 = polyfit(time_400,masschange_400,n);
    f400 = polyval(poly400,time_400);
    residual = masschange_400-f400;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly400 = polyfit(time_400,masschange_400,n);
%Polynomial fit (least squares)
f400 = polyval(poly400,time_400);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly400(j) = poly400(j+1)*j;
end

figure(1)
[slope_400, intercept_400] = logfit(time_400,masschange_400,'loglog');
yApprox_400 = (10^intercept_400)*time_400.^(slope_400);

figure(2)
plot(time_400,masschange_400,'.',time_400,f400,time_400,yApprox_400,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (422°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
```

```
legend_1 = legend('Datapoints','Polynomial fit','Power
law','Location','SouthWest');
set(legend_1,'FontSize',14)
set(gca,'FontSize',15)

%% Experiment with  pure tungsten sample at 522°C 120 min (He+0.5%O2)

data_TGA_500 = xlsread('23juli_tungsten_500_120min.xlsx');
%Imports the data from excel
masschange_500 = ((data_TGA_500(454:1143,1)-
data_TGA_500(454))*1000)/(819.4342E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_500 = zeros(length(masschange_500),1);

for i = 1:length(masschange_500);
%Creates a timevector
    time_500(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly500 = polyfit(time_500,masschange_500,n);
    f500 = polyval(poly500,time_500);
    residual = masschange_500-f500;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly500 = polyfit(time_500,masschange_500,n);
%Polynomial fit (least squares)
f500 = polyval(poly500,time_500);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly500(j) = poly500(j+1)*j;
end

%% Experiment with  pure tungsten sample at 618°C 120 min (He+0.5%O2)

data_TGA_600 = xlsread('24juli_600_120min.xlsx');
%Imports the data from excel
masschange_600 = ((data_TGA_600(377:1069,1)-
data_TGA_600(377))*1000)/(818.8361E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_600 = zeros(length(masschange_600),1);

for i = 1:length(masschange_600);
%Creates a timevector
    time_600(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
```

```
    poly600 = polyfit(time_600,masschange_600,n);
    f600 = polyval(poly600,time_600);
    residual = masschange_600-f600;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly600 = polyfit(time_600,masschange_600,n);
%Polynomial fit (least squares)
f600 = polyval(poly600,time_600);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly600(j) = poly600(j+1)*j;
end

%% Experiment with  pure tungsten sample at 716°C 120 min (He+0.5%O2)

data_TGA_700 = xlsread('25_juli_120min_700.xlsx');
%Imports the data from excel
masschange_700 = ((data_TGA_700(362:1055,1)-
data_TGA_700(362))*1000)/(818.2599E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_700 = zeros(length(masschange_700),1);

for i = 1:length(masschange_700);
%Creates a timevector
    time_700(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly700 = polyfit(time_700,masschange_700,n);
    f700 = polyval(poly700,time_700);
    residual = masschange_700-f700;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly700 = polyfit(time_700,masschange_700,n);
%Polynomial fit (least squares)
f700 = polyval(poly700,time_700);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly700(j) = poly700(j+1)*j;
end

%% Experiment with  pure tungsten sample at 763°C 120 min (He+0.5%O2)
```

```
data_TGA_750 = xlsread('26_juli_120min_750.xlsx');
%Imports the data from excel
masschange_750 = ((data_TGA_750(364:1053,1)-
data_TGA_750(364))*1000)/(819.5177E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_750 = zeros(length(masschange_750),1);

for i = 1:length(masschange_750);
%Creates a timevector
    time_750(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly750 = polyfit(time_750,masschange_750,n);
    f750 = polyval(poly750,time_750);
    residual = masschange_750-f750;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly750 = polyfit(time_750,masschange_750,n);
%Polynomial fit (least squares)
f750 = polyval(poly750,time_750);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly750(j) = poly750(j+1)*j;
end

%% Experiment with  pure tungsten sample at 811°C 120 min (He+0.5%O2)

data_TGA_800 = xlsread('29_juli_120min_800.xlsx');
%Imports the data from excel
masschange_800 = ((data_TGA_800(352:1042,1)-
data_TGA_800(352))*1000)/(818.1754E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_800 = zeros(length(masschange_800),1);

for i = 1:length(masschange_800);
%Creates a timevector
    time_800(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly800 = polyfit(time_800,masschange_800,n);
    f800 = polyval(poly800,time_800);
    residual = masschange_800-f800;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
```

```
end

poly800 = polyfit(time_800,masschange_800,n);
%Polynomial fit (least squares)
f800 = polyval(poly800,time_800);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly800(j) = poly800(j+1)*j;
end

%% Experiment with  pure tungsten sample at 907°C 120 min (He+0.5%O2)

data_TGA_900 = xlsread('30_juli_120min_900.xlsx');
%Imports the data from excel
masschange_900 = ((data_TGA_900(267:955,1)-
data_TGA_900(267))*1000)/(817.3273E-2); %Masschange/area for the experiment
with the D176 sample at 600°C
time_900 = zeros(length(masschange_900),1);

for i = 1:length(masschange_900);
%Creates a timevector
    time_900(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly900 = polyfit(time_900,masschange_900,n);
    f900 = polyval(poly900,time_900);
    residual = masschange_900-f900;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly900 = polyfit(time_900,masschange_900,n);
%Polynomial fit (least squares)
f900 = polyval(poly900,time_900);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly900(j) = poly900(j+1)*j;
end


%% Experiment with  pure tungsten sample at 522°C 120 min (Dried He)

data_TGA_500_He = xlsread('30_juli_120min_500_He_only.xlsx');
%Imports the data from excel
masschange_500_He = ((data_TGA_500_He(406:1097,1)-
data_TGA_500_He(406))*1000)/(817.8613E-2); %Masschange/area for the
experiment with the D176 sample at 600°C
time_500_He = zeros(length(masschange_500_He),1);
```

```
for i = 1:length(masschange_500_He);
%Creates a timevector
    time_500_He(i,1) = i*10/60;
end

norm_residual_former = 1;
%Finds the polynomial with the smallest residual
for n = 1:10;
    poly500_He = polyfit(time_500_He,masschange_500_He,n);
    f500_He = polyval(poly500_He,time_500_He);
    residual = masschange_500_He-f500_He;
    norm_residual = norm(residual);
    if norm_residual < norm_residual_former
        norm_residual_former = norm_residual;
        right_poly = n;
    end
end

poly500_He = polyfit(time_500_He,masschange_500_He,n);
%Polynomial fit (least squares)
f500_He = polyval(poly500_He,time_500_He);
%Returns the value of the polynomial evaluated at the different times

for j = 1:10;
%Derivates the polynomial with respect to time
    derivpoly500_He(j) = poly500_He(j+1)*j;
end

%% Temperature dependence of the rate of oxidation

% r_dot_null(1) = polyval(derivpoly400,0); Inaccurate
r_dot_null(1) = polyval(derivpoly500,4);
%Rate of oxidation (estimated zero time and 522°C)4
r_dot_null(2) = polyval(derivpoly600,5);
%Rate of oxidation (estimated zero time and 618°C)5
r_dot_null(3) = polyval(derivpoly700,3);
%Rate of oxidation (estimated zero time and 716°C)3
r_dot_null(4) = polyval(derivpoly750,4);
%Rate of oxidation (estimated zero time and 763°C)4
r_dot_null(5) = polyval(derivpoly800,5);
%Rate of oxidation (estimated zero time and 811°C)5
r_dot_null(6) = polyval(derivpoly900,5);
%Rate of oxidation (estimated zero time and 907°C)5


r_dot(1) = polyval(derivpoly500,60);
%Rate of oxidation (at 60 min and 522°C)
r_dot(2) = polyval(derivpoly600,60);
%Rate of oxidation (at 60 min and 618°C)
r_dot(3) = polyval(derivpoly700,60);
%Rate of oxidation (at 60 min and 716°C)
r_dot(4) = polyval(derivpoly750,60);
%Rate of oxidation (at 60 min and 763°C)
r_dot(5) = polyval(derivpoly800,60);
%Rate of oxidation (at 60 min and 811°C)
r_dot(6) = polyval(derivpoly900,60);
%Rate of oxidation (at 60 min and 907°C)

% 1/Temperature vector
```

```
temp = [1/(522+273.15), 1/(618+273.15), 1/(716+273.15), 1/(763+273.15),
1/(811+273.15), 1/(907+273.15)];
temp2 = [1/(522+273.15), 1/(618+273.15), 1/(716+273.15)];
temp3 = [1/(763+273.15), 1/(811+273.15), 1/(907+273.15)];
%% Activation energies

k_p_500 = (masschange_500^2)/time_500;



p = polyfit(temp, log(r_dot_null),1);
%Linear regression
yfit = polyval(p,temp);
%Returns the value of the linear regression
Q_O = p(1)*R;
%Activation energy at zero time (Chemical reaction between tungsten and
oxygen)

p2 = polyfit(temp2, log(r_dot(1:3)),1);
%Linear regression
yfit2 = polyval(p2,temp2);
%Returns the value of the linear regression
Q2 = p2(1)*R;
%Activation energy for diffusion-controlled oxidation under the
volatilization temperature

p3 = polyfit(temp3, log(r_dot(4:6)),1);
%Linear regression
yfit3 = polyval(p3,temp3);
%Returns the value of the linear regression
Q3 = p3(1)*R;
%Activation energy for the oxidation over the volatilization temperature

figure(21)
plot(temp, log(r_dot_null),'*', temp, yfit)
grid on
title('Pure tungsten in He+0.5% O_2 at zero time','fontsize',13)
xlabel('1/Temperature [1/K]','fontsize',13)
ylabel('Natural logarithm of the rate of oxidation','fontsize',13)
legend_3 = legend('Points','Linear regression (least squares)');
set(legend_3,'FontSize',14)
set(gca,'FontSize',15)

%% Modeling

A_500 = r_dot(1)/(exp(Q2/(R*(522+273.15))));
%Calculates the A constant in the arrhenius equation
A_600 = r_dot(2)/(exp(Q2/(R*(618+273.15))));
%Calculates the A constant in the arrhenius equation
A_700 = r_dot(3)/(exp(Q2/(R*(716+273.15))));
%Calculates the A constant in the arrhenius equation

A_medel_under_vol = (A_500+A_600+A_700)/3;
%Calculates the A constant in the arrhenius equation

K_p_750_empirical = A_medel_under_vol*exp(Q2/(R*(763+273.15)));
%Parabolic rate constant extrapolated from lower temp. range
K_p_800_empirical = A_medel_under_vol*exp(Q2/(R*(811+273.15)));
%Parabolic rate constant extrapolated from lower temp. range
```

```
K_p_900_empirical = A_medel_under_vol*exp(Q2/(R*(907+273.15)));
%Parabolic rate constant extrapolated from lower temp. range

masschange750 = masschange_750*(819.5177E-2);
%Masschange
masschange800 = masschange_800*(818.1754E-2);
%Masschange
masschange900 = masschange_900*(817.3273E-2);
%Masschange

K_v_750 = 0.728;
%Startvalue of volatilization rate constant
K_v_800 = 0.6;
%Startvalue of volatilization rate constant
K_v_900 = 0.6;
%Startvalue of volatilization rate constant

model_750 = zeros(length(masschange750),1);
model_800 = zeros(length(masschange800),1);
model_900 = zeros(length(masschange900),1);
K_p_750_num = K_p_750_empirical;
%Startvalue of parabolic rate constant
K_p_800_num = K_p_800_empirical;
%Startvalue of parabolic rate constant
K_p_900_num = K_p_900_empirical;
%Startvalue of parabolic rate constant

% Calculates the model by changing both the kv and the kp value until the
% model and the real datapoints converge

while (abs(masschange750(600))-abs(model_750(600)))>0.1
    for i=1:length(time_750)
        model_750(i,1) = -
K_v_750*time_750(i)+sqrt((K_v_750^2)*(time_750(i)^2)+2*K_p_750_num*time_750
(i));
    end
    K_v_750 = K_v_750-0.000001;
    K_p_750_num = abs(((masschange750(600)^2-
(2*K_v_750^2)*(time_750(600)^2))/(2*time_750(600))));
end

while (abs(masschange800(50))-abs(model_800(50)))>0.1
    for i=1:length(time_800)
        model_800(i,1) = -
K_v_800*time_800(i)+sqrt((K_v_800^2)*(time_800(i)^2)+2*K_p_800_num*time_800
(i));
    end
    K_v_800 = K_v_800-0.01;
    K_p_800_num = abs(((masschange800(50)^2-
(2*K_v_800^2)*(time_800(50)^2))/(2*time_800(50))));
end

while (abs(masschange900(50))-abs(model_900(50)))>0.1
    for i=1:length(time_900)
        model_900(i,1) = -
K_v_900*time_900(i)+sqrt((K_v_900^2)*(time_900(i)^2)+2*K_p_900_num*time_900
(i));
    end
    K_v_900 = K_v_900-0.01;
```

```
    K_p_900_num = abs(((masschange900(50)^2-
(2*K_v_900^2)*(time_900(50)^2))/(2*time_900(50))));
end

figure(22)
plot(time_750,masschange750,'.',time_750,model_750,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (763°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_3 = legend('Points','Tedmon model','Location','NorthWest');
set(legend_3,'FontSize',14)
set(gca,'FontSize',15)

figure(23)
plot(time_800,masschange_800,'.',time_800,model_800,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (811°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_3 = legend('Points','Tedmon model','Location','NorthWest');
set(legend_3,'FontSize',14)
set(gca,'FontSize',15)

figure(24)
plot(time_900,masschange_900,'.',time_900,model_900,'r')
grid on
title('Pure tungsten in He+0.5% O_2 (907°C,120 min)','fontsize',13)
xlabel('Time [min]','fontsize',13)
ylabel('Weight change per unit area [mg/cm^2]','fontsize',13)
legend_3 = legend('Points','Tedmon model','Location','NorthWest');
set(legend_3,'FontSize',14)
set(gca,'FontSize',15)
```

Matlab code of the function logfit used when fitting a power law:

```
%% function [slope, intercept, R2, S] = logfit(x,y,varargin)
% This function plots the data with a power law, logarithmic, exponential
% or linear fit.
%
%   logfit(X,Y,graphType),  where X is a vector and Y is a vector or a
%               matrix will plot the data with the axis scaling determined
%               by graphType as follows: graphType-> xscale, yscale
%                  loglog-> log, log
%                    logx -> log, linear
%                    logy -> linear, log
%                  linear -> linear, linear
%               A line is then fit to the scaled data in a least squares
%               sense.
%               See the 'notes' section below for help choosing a method.
%
%   logfit(X,Y), will search through all the possible axis scalings and
%               finish with the one that incurs the least error (with error
%               measured as least squares on the linear-linear data.)
%
%   [slope, intercept, R2, S] = logfit(X,Y,graphType), returns the
following:
%                slope: The slope of the line in the log-scale units.
%            intercept: The intercept of the line in the log-scale units.
%                   R2: The mean square error between the 'y' data and the
%                       approximation in linear units.
%                    S: This is returned by 'polyfit' and it allows you to
%                       be much fancier with your error estimates in the
%                       following way: (see polyfit for more information)
%                    >> S contains fields R, df, and normr, for the
%                    >> triangular factor from a QR decomposition of the
%                    >> Vandermonde matrix of x, the degrees of freedom,
%                    >> and the norm of the residuals, respectively. If the
%                    >> data y are random, an estimate of the covariance
%                    >> matrix of p is (Rinv*Rinv')*normr^2/df, where Rinv
%                    >> is the inverse of R. If the errors in the data y
%                    >> are independent normal with constant variance,
%                    >> polyval produces error bounds that contain at least
%                    >> 50% of the predictions.
%
%   [graphType, slope, intercept, R2, S] = logfit(X,Y), if you choose
%                       not to pass a 'graphType' variable, then it will go
%                       ahead and select the one with the least square
%                       error. The firt parameter returned will be the
%                       graphType, with the following parameters in the
%                       usual order.
%
%   logfit(X,Y,'PropertyName',PropertyValue), or
%   logfit(X,Y,graphType,'PropertyName',PropertyValue)
%
%               see parameter options below
%__________________________________________________________________________
% USER PARAMETERS:
%
% For skipping part of the data set:
%       'skip': skip 'n' rows from the beginning of the data set when
%               calculating the linear fit. Must be integer. Pass a
negative
%               number to skip rows from the end instead of from the
%               beginning. All points will be plotted. 'num2skip'
```

```
%  'skipBegin': skip 'n' rows from the beginning when calculating the
%               linear fit similar to skip n. 'beginSkip'
%    'skipEnd': skip 'n' rows from the end, similar to skip -n 'endSkip'
%
%____________________________________________________________________________
% For plotting in different styles
%   'fontsize': The fontsize of the axis, for axis tick labels and legend.
%               'font','fsize'
% 'markersize': The size of the marker for the points,
% 'markertype': The type of marker for the points, such as 'o--' or '.r'
%               'markerstyle','markertype','marker'
%
%  'linewidth': The width of the dashed line for the approximation
%
%       'ftir': The approximation is plotted for a range around the
%               endpoints of the data set. By default it is 1/20 of the
%               range of the points. You may change this default by using
%               this parameter.
%               'fraction_to_increase_range','fractiontoincreaserange'
%____________________________________________________________________________
% Note the following sytax may also be used to specify 'graphtype'
%         'loglog','log','powerlaw'
%         'logx','logarithmic'
%         'logy','exponential','exp'
%         'linear','lin'
%____________________________________________________________________________
% Notes:
% The notes here will explain what the output means in terms of fitting
% functions depending on which method you use,
%
% [slope, intercept] = logfit(x,y,'loglog');
%            yApprox = (10^intercept)*x.^(slope);
%
% [slope, intercept] = logfit(x,y,'logy');
%            yApprox = (10^intercept)*(10^slope).^x;
%
% [slope, intercept] = logfit(x,y,'logx');
%            yApprox = (intercept)+(slope)*log10(x);
%
% [slope, intercept] = logfit(x,y,'linear');
%            yApprox = (intercept)+(slope)*x;
%
%____________________________________________________________________________
% Examples:
% A power law, power 'a'
% a=2;
% x=(1:20)+rand(1,20); y=x.^a;
% power = logfit(x,y);
% %
% A exponential relationship
% a=3; x=(1:30)+10*rand(1,30); y=a.^x+100*rand(1,30);
% [graphType a] = logfit(x,y)
% base = 10^(a)
%
%
% Thanks to Aptima inc. for  for giving me a reason to write this function.
% Thanks to Avi and Eli for help with designing and testing logfit.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Jonathan Lansey November 2010,                       All rights reserved. %
%                   questions to Lansey at gmail.com                        %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
function [slope, intercept,R2, S, extra] = logfit(x,y,varargin)
% The 'extra' is here in case 'graphtype' is not passed and needs to be
% returned.
extra=[];

%% Check user inputed graphType, and standardize its value
k=1;
if isempty(varargin)
    [slope, intercept,R2, S, extra] = findBestFit(x,y);
    return;

else % interpret all these possible user parameters here, so we can be more
specific later.
    switch lower(varargin{1}); % make all lowercase in case someone put in
something different.
        case {'logy','exponential','exp'}
            graphType = 'logy';
        case {'logx','logarithmic'}
            graphType = 'logx';
        case {'loglog','log','powerlaw'}
            graphType = 'loglog';
        case {'linear','lin'}
            graphType = 'linear';
        otherwise
            [slope, intercept,R2, S, extra] = findBestFit(x,y,varargin{:});
            return;
    end
    k=k+1; % will usually look at varargin{2} later because of this
end

%% Set dynamic marker type defaults
% for example, 'o' or '.' as well as size

yIsMatrixFlag = size(y,1)>1 && size(y,2)>1; % There is more than one data
point per x value
markerSize=5;
markerType = '.k';

if ~yIsMatrixFlag % check how many points there are
    if length(y)<80 % relatively few points
        markerType = 'ok';
        markerSize=5;
    %   the following will overwrite markersize
        if length(y)<30 % this number '30' is completely arbitrary
            markerSize=7; % this '12' is also rather arbitrary
        end
%   else % there are many points, keep above defaults
%         lineWidth=1;
%         markerSize=5;
    end
end

% markerLineWidth is always 2.

%% Set static some defaults
% before interpreting user parameters.
fSize=15;
num2skip=0; skipBegin = 0; skipEnd=0;
ftir=20; %  = fraction_To_Increase_Range, for increasing where the green
line is plotted
```

```
lineColor = [.3 .7 .3]; % color of the line
lineWidth=2;  % width of the approximate line

%% Interpret extra user parameters

while k <= length(varargin) && ischar(varargin{k})
    switch (lower(varargin{k}))
%       skipping points from beginning or end
        case {'skip','num2skip'}
            num2skip = varargin{k+1};
            k = k + 1;
        case {'skipbegin','beginskip'}
            skipBegin = varargin{k+1};
            k = k + 1;
        case {'skipend','endskip'}
            skipEnd = varargin{k+1};
            k = k + 1;

%       Adjust font size
        case {'fontsize','font','fsize'}
            fSize = varargin{k+1};
            k = k+1;

%       Approx, line plotting
        case
{'ftir','fraction_to_increase_range','fractiontoincreaserange'}
            ftir = varargin{k+1};
            k = k+1;

%       Plotting style parameters
        case {'markersize'}
            markerSize = varargin{k+1}; %forceMarkerSizeFlag=1;
            k = k + 1;
        case {'markertype','markerstyle','marker'}
            markerType = varargin{k+1}; %forceMarkerTypeFlag=1;
            k = k+1;
        case {'linecolor','color'}
            lineColor = varargin{k+1};
            k = k+1;
        case 'linewidth'
            lineWidth = varargin{k+1};
            k = k+1;
        otherwise
            warning(['user entered parameter ''' varargin{k} ''' not
recognized']);
    end
    k = k + 1;
end

%% Checks for user mistakes in input

% data size and skip related errors/warnings
    % Check they skipped an integer number of rows.
    if round(skipBegin)~=skipBegin || round(skipEnd)~=skipEnd ||
round(num2skip)~=num2skip
        error('you can only skip an integer number of data rows');
    end
    if (skipEnd~=0 || skipBegin~=0) && num2skip~=0
        warning('you have entered ambigious parameter settings,
''skipBegin'' and ''skipEnd'' will take priority');
```

```
        num2skip=0;
    end

    if num2skip>0
        skipBegin=num2skip;
    elseif num2skip<0
        skipEnd=-num2skip;
    % else
    %     num2skip==0; % so do nothing
    end

    % Check that the user has not skipped all of his/her data
    if length(x)<1+skipEnd+skipBegin
        error('you don''t have enough points to compute a linear fit');
    end
    if length(x)<3+skipEnd+skipBegin
        warning('your data are meaningless, please go collect more 
points');
    end

% Data formatting errors and warnings
    % Check that 'x' is a vector
    if size(x,1)>1 && size(x,2)>1 % something is wrong
        error('Your x values must be a vector, it cannot be a matrix');
    end

    if yIsMatrixFlag % There is more than one data point per x value
        if size(y,1)~=length(x)
            error('the length of ''x'' must equal the number of rows in 
y');
        end
    else % y and x must be vectors by now
        if length(x)~=length(y)
            error('the length of ''x'' must equal the length of y');
        end
    end

    if ~isnumeric(markerSize)
        error('marker size must be numeric');
    end

% Helpful warning
    if markerSize<=1
        warning(['Your grandma will probably not be able to read your plot, 
'...
                 'the markersize is just too small!']);
    end



%% Prepare y data by making it a properly oriented vector
% skip rows as requested and create standard vectors (sometimes from 
matrices)

x=x(:);
x2fit=x(skipBegin+1:end-skipEnd);

if yIsMatrixFlag % There is more than one data point per x value
% note the '+1' so it can be used as an index value
```

```
% This is the ones that will be used for fitting, rather than for plotting.
    y2fit = y(skipBegin+1:end-skipEnd,:);

    [x2fit,y2fit]= linearify(x2fit,y2fit);
    [x,y]        = linearify(x,y);

else % no need to linearify further
    y=y(:);
    y2fit=y(skipBegin+1:end-skipEnd);
%     Note that 'x' is already forced to be a standard vector above
end

%% Check here for data that is zero or negative on a log scaled axis.
% This is a problem because log(z<=0) is not a real number
% This cell will remove it with a warning and helpful suggestion.
%
% This warning can suggest you choose a different plot, or perhaps add 1 if
% your data are large enough.
%
% Note that this is done in order, so if by removing the 'y==0' values, you
% also delete the 'x==0' values, then the 'x' warning won't show up. I
% don't think this is of any concern though.
%
switch graphType
    case {'logy','loglog'}
        yMask=(y<=0);
        if sum(yMask)>0
            yNegMask=(y<0);
            if sum(yNegMask)>0 % there are proper negative values
                warning(['values with y<=0 were removed.'...
                         'Are you sure that ''logy'' is smart to take? '...
                         'some ''y'' values were negative in your data.']);

            else % just some zero values
                if sum(y<10)/length(y) < (1/2) % if less than half your
data is below than 10.
                    warning(['values with y==0 were removed. '...
                             'you may wish to add +1 to your data to make
these points visible.']);
                else % The numbers are pretty small, you don't want to add
one.
                    warning(['values with y==0 were removed. '...
                             'Nothing you can really do about it sorry.']);
                end

            end

            y=y(~yMask); y2Mask=(y2fit<=0); y2fit=y2fit(~y2Mask);
            x=x(~yMask);                    x2fit=x2fit(~y2Mask);
%              warning('values with y<=0 were removed. It may make suggest
you add 1 to your data.')
        end
end

switch graphType
    case {'logx','loglog'}
        xMask=(x<=0);
        if sum(xMask)>0

            xNegMask=(x<0);
```

```
            if sum(xNegMask)>0 % there are proper negative values
                warning(['values with x<=0 were removed.'...
                         'Are you sure that ''logx'' is smart to take? '...
                         'some ''x'' values were negative in your data.']);

            else % just some zero values
                if sum(x<10)/length(x) < (1/2) % if less than half your
data is below than 10.
                    warning(['values with x==0 were removed. '...
                             'you may wish to add +1 to your data to make
these points visible.']);
                else % The numbers are pretty small, you don't want to add
one.
                    warning(['values with x==0 were removed. '...
                             'Nothing you can really do about it sorry.']);
                end

            end

            x=x(~xMask); x2Mask=(x2fit<=0); x2fit=x2fit(~x2Mask);
            y=y(~xMask);                    y2fit=y2fit(~x2Mask);
        end
end

%% FUNCTION GUTS BELOW
%% set and scale the data values for linear fitting
switch graphType
    case 'logy'
        logY=log10(y2fit);
        logX=x2fit;
    case 'logx'
        logX=log10(x2fit);
        logY=y2fit;
    case 'loglog'
        logX=log10(x2fit); logY=log10(y2fit);
    case 'linear'
        logX=x2fit; logY=y2fit;
end

%% Set the range that the approximate line will be displayed for

if isempty(x2fit) || isempty(y2fit)
    warning(['cannot fit any of your points on this ' graphType ' scale']);
    slope=NaN; intercept=NaN; R2= NaN;
    S=inf; % so that this is not used.
    return;
end


range=[min(x2fit) max(x2fit)];
% make this compatible with skipping some points.... don't know how yet....
switch graphType
    case {'logx','loglog'}
        logRange=log10(range);
        totRange=diff(logRange)+10*eps; % in case its all zeros...
        logRange = [logRange(1)-totRange/ftir, logRange(2)+totRange/ftir];
        ex = linspace(logRange(1),logRange(2),100); % note this is in log10
space
```

```
    otherwise % logy, linear
        totRange=diff(range);
        range= [range(1)-totRange/ftir, range(2)+totRange/ftir];
        ex=linspace(range(1),range(2),100);
end

%% Do the linear fitting and evaluating
[p, S] = polyfit(logX,logY,1);
yy = polyval(p,ex);
estY=polyval(p,logX); % the estimate of the 'y' value for each point.

%% rescale the approximation results for plotting
switch lower(graphType)
    case 'logy'
        yy=10.^yy;
        estY=10.^estY; logY=10.^logY;% need to do this for error estimation
    case 'logx'
        ex=10.^ex;
    case 'loglog'
        yy=10.^yy;
        ex=10.^ex;
        estY=10.^estY; logY=10.^logY;% need to do this for error estimation
    case 'linear'
%           'do nothing';
    otherwise
%           'There is no otherwise at this point';
end

%% Calculate R2
% Note that this is done after the data re-scaling is finished.
R2 = mean((logY-estY).^2);

%% Ready the axis for plotting
% create or grab an axis before setting the scales
a=gca;
set(a,'fontsize',fSize);
holdState=ishold;

%% Plot the data
% This one is just to get the legend right
plot(x,y,markerType,'markersize',markerSize,'linewidth',2);

%% Plot the approximate line
hold('on'); % in case hold off was on before
plot(ex,yy,'--','linewidth',lineWidth,'color',lineColor);

%% Plot the points
% This time again just so it appears on top of the other line.
plot(x,y,markerType,'markersize',markerSize,'linewidth',2);

%% Set the axis and to scale correctly
switch graphType
    case 'logy'
        set(a,'yscale','log');
     case 'logx'
        set(a,'xscale','log');
    case 'loglog'
        set(a,'xscale','log','yscale','log');
    case 'linear'
        set(a,'xscale','linear','yscale','linear');
```

```
end

%% Finish up some graph niceties
% fix the graph limits.
% no idea why this is always needed
axis('tight');

legend('data',[graphType ' fit'],'location','best'); legend('boxoff');

% reset hold state
if ~holdState
    hold('off');
end

%% set output data
% before returning
slope=p(1);
intercept = p(2);

end % function logfit over

%% linearify
% This function will take a vector x, and matrix y and arrange them so that
% y is a vector where each number in the i'th row of y has the value of the
% i'th number in 'x'
% This only works when the number of rows in y equals the number of
% elements in x. The new 'x' vector will be have length(y(:)) elements
function [x,y] = linearify(x,y)
x=x(:); % just in case its not already a vector pointing this way.
x=repmat(x,size(y,2),1);
y=y(:);
% if length(y)~=length(x)
%     warning(['Look what you doin son, the length of ''x'' must equal the
'...
%             'number of rows in y to make this function useful'
]);
% end
end

%% this checks to see which type of plot has the smallest error
% Then it will return and plot the results from the one with the least
% error. Note that 'graphType' is returned first, making all the following
% outputs shifted.
function [graphType, slope, intercept,R2, S] = findBestFit(x,y,varargin)
% List of graph types to check
testList={'loglog','logx','logy','linear'};
R=zeros(4,1);

warning('off'); hold('off'); % just so you don't have it repeating the
warnings a million times
for ii=1:4
    [a,b,R(ii),c]=logfit(x,y,testList{ii},varargin{:});
end
warning('on')

%% check for winning graphtype
% the one with the minimum error wins.

graphType=testList(R==min(R));
```

```
switch length(graphType)
    case 1
%          no warning, nothing
    case 2
        warning([graphType{1} ' and ' graphType{2} ' had equal error, so '
graphType{1} ' was chosen)']);
    case 3
        warning([graphType{1} ', ' graphType{2} ' and ' graphType{3} ' had
equal errors, so ' graphType{1} ' was chosen)']);
    otherwise
%          wow this will probably never happen
        warning(['all graph types had equal error, ' graphType{1} ' was
chosen']);
end
graphType=graphType{1};

%% run it a last time to get results
[slope, intercept,R2, S]=logfit(x,y,graphType,varargin{:});

end
```