Gas flow

01/03/21

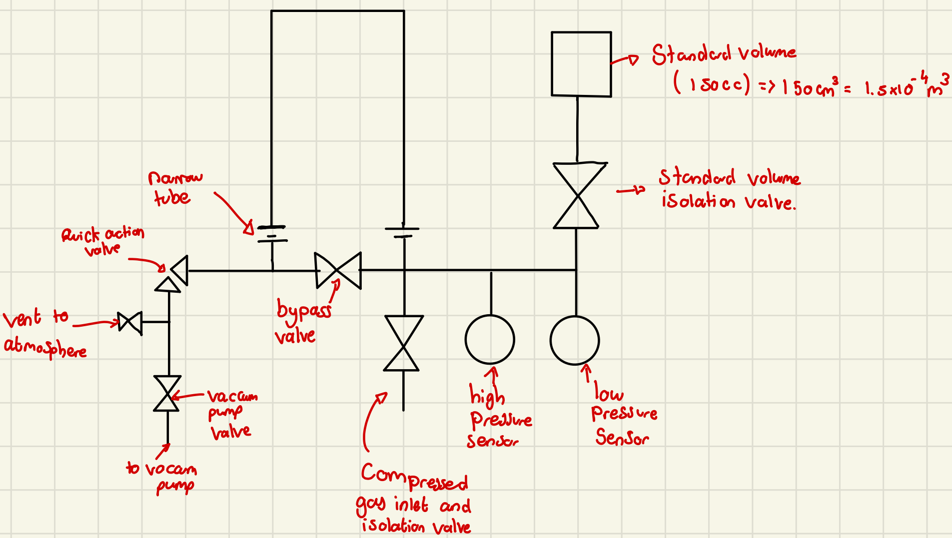
Aims:

- Determine and compare the viscosity of 2 ideal gases (Helium and Argon) by measuring their flow rates.
- Understand laminar, turbulent and molecular flow on both a microscopic and macroscopic level.

Objectives:

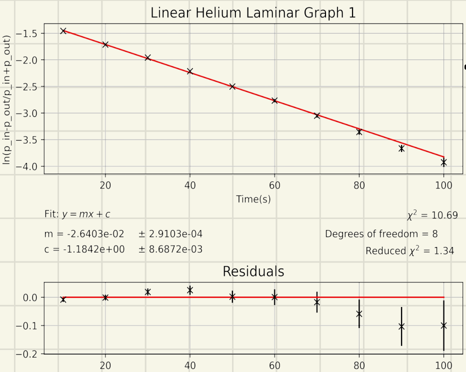
- To measure the rate of flow of Helium and Argon through narrow tubes from a constant volume to a constant pressure environment
- To measure the viscosity of each gas and calculate their respective mean free paths and collision cross sections.

Diagram:

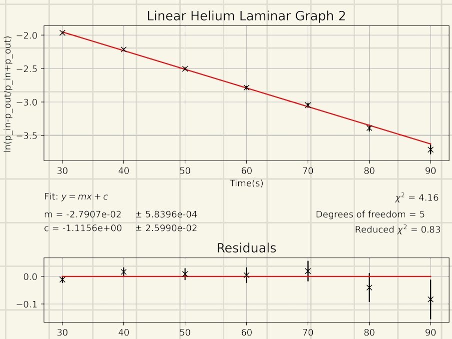


Helium through long tube - laminar flow:

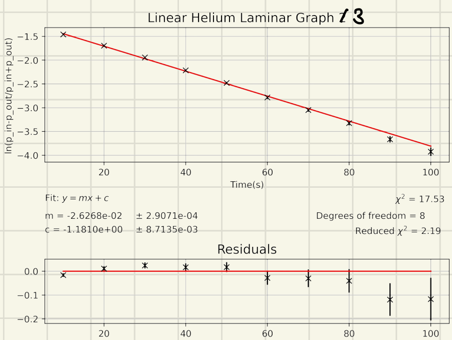
Time (s)	P_In(mbar)
0	2040.1354520
10	1660.5510600
20	1487.3179140
30	1372.6783330
40	1286.0617600
50	1217.2780110
60	1171.4221780
70	1135.7565310
80	1107.7335220
90	1087.3531520
100	1074.6154200
110	1061.8776890
120	1054.2350500
130	1046.5924120
140	1044.0448650
150	1038.9497730



Time (s)	P_In(mbar)
0	1897.473
10	1647.813
20	1487.318
30	1370.131
40	1286.062
50	1217.278
60	1168.875
70	1135.757
80	1105.186
90	1084.806
100	1074.615
110	1061.878
120	1054.235
130	1046.592
140	1046.592



Time (s)	P_In(mbar)
0	1925.496
10	1658.004
20	1497.508
30	1377.773
40	1286.062
50	1222.373
60	1168.875
70	1135.757
80	1110.281
90	1087.353
100	1074.615
110	1064.425
120	1056.783
130	1046.592



- Starting by evacuating the whole system using the vaccum pump to set the system to below 10^{-1} mbar using the low pressure sensor (ensuring all valves are open excluding the gas inlet, standard volume and atmospheric valve). Then, closing the bypass valve, the right hand side was filled with Helium to a pressure of 2000 mbar. The left hand side was set to atmospheric pressure (about 1000 mbar). Then letting the Helium flow through the narrow tube by opening the quick action valve readings of the pressure inside were taken in 10 second intervals until atmospheric pressure was reached.
- Atmospheric Pressure was measured at 1033 mbar ± 8.94
- Finding $\ln\left[\frac{P_{inside} - P_{outside}}{P_{inside} + P_{outside}}\right]$ this was then plotted against time. Then the gradient of the linear part of the graph was taken.
- This was repeated 3 times to find an average gradient.

$m_1 = -0.0264 \pm 2.91\times10^{-4}$

$m_2 = -0.0279 \pm 5.84\times10^{-4}$

$m_3 = -0.0262 \pm 2.91\times10^{-4}$

$L = 30 \pm 0.5\,mm = 30\times10^{-3}\,m$

$a = 0.1 \pm 0.005\,mm = 0.1\times10^{-3}\,m$

$m_{avg} = -0.0269$

$\sigma_m = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2}$

$= 7.14\times10^{-4}$

To find the volume inside the system we used PV = constant. The standard volume container ($1.5\times10^{-4}\,m^3$) as V_1 which was measured to be at $P_1 = 2022 \pm 20.2$ mbar. This volume of gas was then released into the system, therefore the new volume, V_2, was $V_2 = V_{in} + V_1$. Measuring the new pressure gave $P_2 = 435 \pm 2.9$ mbar. Then converting to SI units and rearranging for V_{in}:

$V_{in} = \frac{P_1 V_1}{P_2} - V_1$, $V_{in} = 5.47\times10^{-4}\,m^3$

$$\sigma_V = \left[5.47\times10^{-4}\sqrt{\left(\frac{2020}{202200}\right)^2 + \left(\frac{290}{43500}\right)^2}\right] = 6.57\times10^{-6}$$

$V_{in} = 5.47\times10^{-4} \pm 6.57\times10^{-6}\,m^3$

Rearranging $m = \frac{-\pi a^4 P_{out}}{8\eta L V_{in}}$ to: $\eta = \frac{-\pi a^4 P_{out}}{8 L V_{in} m}$

$$\eta_{He} = \frac{-\pi (0.1\times10^{-3})^4 (103300)}{8(30\times10^{-3})(5.47\times10^{-4})(-0.0269)}$$

$$\eta_{He} = 9.19\times10^{-6}\ Pa\ S$$

error on a^4: $\frac{\sigma_f}{f} = 4\left(\frac{0.005\times10^{-3}}{0.1\times10^{-3}}\right)$

$\frac{\sigma_f}{1\times10^{-16}} = 0.2$

$\sigma_f = 2\times10^{-17}$

↳ negligable

$$\sigma_\eta = \eta_{He}\sqrt{\left(\frac{894}{103300}\right)^2 + \left(\frac{0.5\times10^{-3}}{30\times10^{-3}}\right)^2 + \left(\frac{6.57\times10^{-6}}{5.47\times10^{-4}}\right)^2 + \left(\frac{7.14\times10^{-4}}{0.0269}\right)^2}$$

$$\sigma_\eta = 3.19\times10^{-7}$$

error on P_{out}: $\sigma_P = 894\ Pa$

L: $\sigma_L = 0.5\times10^{-3}\ m$

V_{in}: $\sigma_V = 6.57\times10^{-6}\ m^3$

m: $\sigma_m = 7.14\times10^{-4}$

$$\boxed{\eta_{He} = 9.19\times10^{-6} \pm 3.19\times10^{-7}\ Pa\ S}$$

Mean Speed of atoms:

$$\bar{C}_{He} = \sqrt{\frac{8kT}{\pi m}} = \sqrt{\frac{8\times1.38\times10^{-23}\times 292.4}{\pi\times(4\times1.66\times10^{-27})}}$$

$T = 19.4 \pm 0.2\ ^\circ C$

$= 292.4 \pm 0.2\ K$ ⇒ only uncertainty.

$$= 1244 \pm 0.425\ ms^{-1}$$

$\sigma_c = 1244\times\frac{1}{2}\times\left(\frac{0.2}{292.4}\right)$

$= 0.425$

number density:

$n_v = \frac{n N_a}{V_{in}}$; $n = \frac{PV}{RT}$

$$n_v = \frac{P N_a}{RT} = \frac{19540(6.022\times10^{23})}{8.315\times292.4}$$

$\sigma_{nv} = 4.85\times10^{25}\sqrt{\left(\frac{846}{195400}\right)^2 + \left(\frac{0.2}{292.4}\right)^2}$

$\sigma_{nv} = 2.12\times10^{23}$

$n_v = 4.85\times10^{25} \pm 2.12\times10^{23}$ atoms per m^3

Mean free path:

$\eta = \frac{1}{3} n_v m \lambda \bar{c}$

$$\lambda = \frac{3\eta}{n_v m \bar{c}} = \frac{3(9.19\times10^{-6})}{(4.85\times10^{25})(4\times1.66\times10^{-27})(1244)}$$

$$\lambda = 6.88\times10^{-8} \pm 2.41\times10^{-9}\ m$$

$$\sigma_\lambda = 6.88\times10^{-8}\sqrt{\left(\frac{3.19\times10^{-7}}{9.19\times10^{-6}}\right)^2 + \left(\frac{2.12\times10^{23}}{4.85\times10^{25}}\right)^2 + \left(\frac{0.425}{1244}\right)^2}$$

$$= 2.41\times10^{-9}$$

Collision cross section:

$$\lambda = \frac{1}{\sqrt{2}} \frac{1}{n_v \sigma}$$

$$\sigma = \frac{1}{\sqrt{2}} \frac{1}{n_v \lambda} = \frac{1}{\sqrt{2}} \times \frac{1}{(4.85\times10^{25})(6.88\times10^{-8})}$$

$$\sigma_\sigma = 2.12\times10^{-19} \sqrt{\left(\frac{2.12\times10^{23}}{4.85\times10^{25}}\right)^2 + \left(\frac{2.41\times10^{-9}}{6.88\times10^{-8}}\right)^2}$$

$$= 7.48\times10^{-21}$$

$$\sigma = 2.12\times10^{-19} \pm 7.48\times10^{-21}\ m^2$$

Diameter of atom:

$$\sigma = \pi d^2$$

$$d = \sqrt{\frac{\sigma}{\pi}}$$

$$= \sqrt{\frac{2.12\times10^{-19}}{\pi}} = 2.60\times10^{-10} \pm 4.59\times10^{-12}\ m$$

$$\sigma_d = 2.60\times10^{-10} \times \frac{1}{2} \times \left(\frac{7.48\times10^{-21}}{2.12\times10^{-19}}\right)$$

$$= 4.59\times10^{-12}$$

Argon laminar flow:

Data 1

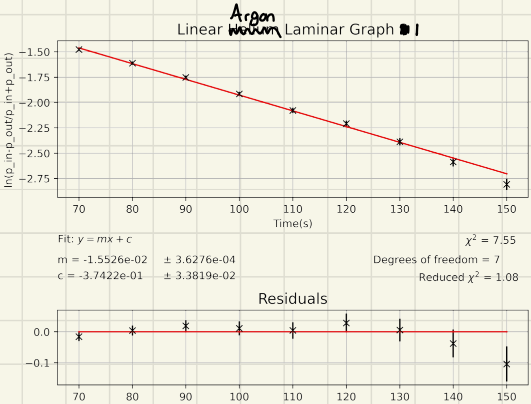
Time (s)	P_In(mbar)
0	1856.712
10	1744.62
20	1655.456
30	1576.482
40	1505.151
50	1441.462
60	1385.416
70	1337.013
80	1288.609
90	1247.849
100	1209.635
110	1179.065
120	1158.684
130	1135.757
140	1115.376
150	1097.543
160	1082.258
170	1074.615
180	1064.425
190	1059.33
200	1049.14
210	1049.14
220	1041.497
230	1041.497

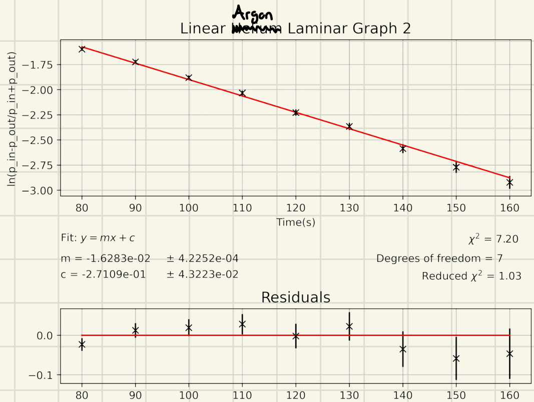
Data 2

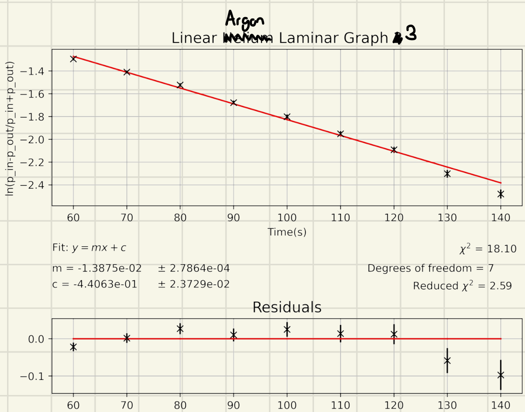
Time (s)	P_In(mbar)
0	1864.355
10	1749.715
20	1660.551
30	1579.03
40	1512.793
50	1446.557
60	1387.964
70	1337.013
80	1293.704
90	1255.491
100	1217.278
110	1186.707
120	1156.137
130	1138.304
140	1115.376
150	1100.091
160	1089.901
170	1072.068
180	1066.973
190	1059.33
200	1051.688
210	1049.14
220	1044.045

Data 3

Time (s)	P_In(mbar)
0	1963.709
10	1808.309
20	1706.407
30	1617.243
40	1545.911
50	1479.675
60	1421.082
70	1365.036
80	1319.18
90	1268.229
100	1235.111
110	1201.993
120	1176.517
130	1145.947
140	1125.566
150	1105.186
160	1092.448
170	1079.711
180	1066.973
190	1059.33
200	1051.688
210	1051.688
220	1044.045
230	1038.95
240	1038.95
250	1033.855
260	1033.855







- First we vaccumed out the system to remove any excess Helium from the preview experiment.
- We then followed the exact same procedure as the Helium experiment.

$m_1 = -0.0155 \pm 3.63\times10^{-4}$

$m_2 = -0.0162 \pm 4.23\times10^{-4}$

$m_3 = -0.0139 \pm 2.78\times10^{-4}$

$m_{avg} = -0.0152 \qquad \sigma_m = \sqrt{(\sigma_1)^2 + (\sigma_2)^2 + (\sigma_3)^2}$

$\sigma_m = 6.19\times10^{-4}$

As the readings for Argon were taken at a different time of day we meaured P_{out} again. The average over 15 seconds gave: $P_{out} = 1031$ mbar
$\sigma_p = 9.98$ mbar

All other constants stay the same.

$$\eta_{Ar} = \frac{-\pi(0.1\times10^{-3})^4(103100)}{8(30\times10^{-3})(5.47\times10^{-4})(-0.0152)}$$

$$= 1.62\times10^{-5} \text{ Pa s}$$

$$\sigma_\eta = \eta_{Ar}\sqrt{\left(\frac{998}{103100}\right)^2 + \left(\frac{0.5}{30}\right)^2 + \left(\frac{6.57\times10^{-6}}{5.47\times10^{-4}}\right)^2 + \left(\frac{6.19\times10^{-4}}{0.0152}\right)^2}$$

$$\sigma_\eta = 7.55\times10^{-7}$$

$$\eta_{Ar} = 1.62\times10^{-5} \pm 7.55\times10^{-7} \text{ Pa s}$$

Mean Speed:

$$\bar{c} = \sqrt{\frac{8RT}{\pi m}} = \sqrt{\frac{8(1.38\times10^{-23})(292.4)}{\pi(40\times1.66\times10^{-27})}}$$

$$= 393.4 \pm 0.135 \ ms^{-1}$$

$$\sigma_c = 393.4 \times \frac{1}{2} \times \left(\frac{0.2}{292.4}\right)$$
$$= 0.135$$

Number density:

$$n_v = \frac{PN_a}{RT} = \frac{189400(6.022\times10^{23})}{8.315\times292.4}$$

$$= 4.69\times10^{25} \pm 2.06\times10^{23} \text{ atoms per } m^3$$

$$\sigma_n = 4.69\times10^{25}\sqrt{\left(\frac{820}{189400}\right)^2 + \left(\frac{0.2}{292.4}\right)^2}$$
$$= 2.06\times10^{23}$$

Mean free path:

$$\lambda = \frac{3\eta}{n_v m \bar{c}} = \frac{3(1.62\times10^{-5})}{4.69\times10^{25}(40\times1.66\times10^{-27})(393.4)}$$

$$= 3.97\times10^{-8} \pm 1.86\times10^{-9} m$$

$$\sigma_\lambda = 3.97\times10^{-8}\sqrt{\left(\frac{7.55\times10^{-7}}{1.62\times10^{-5}}\right)^2 + \left(\frac{2.06\times10^{23}}{4.69\times10^{25}}\right)^2 + \left(\frac{0.135}{393.4}\right)^2}$$
$$= 1.86\times10^{-9} m$$

Collision Cross section:

$$\sigma = \frac{1}{\sqrt{2}}\frac{1}{n_v\lambda} = \frac{1}{\sqrt{2}}\frac{1}{4.69\times10^{25}\times3.97\times10^{-8}}$$

$$= 3.80\times10^{-19} \pm 1.79\times10^{-20} \ m^2$$

$$\sigma_\sigma = 3.80\times10^{-19}\sqrt{\left(\frac{2.06\times10^{23}}{4.69\times10^{25}}\right)^2 + \left(\frac{1.86\times10^{-9}}{3.97\times10^{-8}}\right)^2}$$
$$= 1.79\times10^{-20}$$

Diameter of atom:

$$d = \sqrt{\frac{\sigma}{\pi}} = \sqrt{\frac{3.8\times10^{-19}}{\pi}}$$

$$= 3.48\times10^{-10} \pm 8.2\times10^{-12} m$$

$$\sigma_d = 3.48\times10^{-10}\times\frac{1}{2}\times\left(\frac{1.79\times10^{-20}}{3.8\times10^{-19}}\right)$$
$$= 8.20\times10^{-12}$$

Conclusion for laminar flow:

The aim of this part of the experiment was to determine the viscosity of helium and argon gas. Using this, the diameter of the diameter of the atoms can be found.

$\eta_{He} = 9.19 \times 10^{-6} \pm 3.19 \times 10^{-7}$ Pa S
Comparing this to the real value of the viscosity of helium gas:
$\eta_{real,H} = 20 \times 10^{-6}$ Pa S
This is roughly a factor of 2 out.

$\eta_{Ar} = 1.62 \times 10^{-5} \pm 7.55 \times 10^{-7}$ Pa S
Comparing this to the real value:
$\eta_{real,A} = 20 \times 10^{-6}$ Pa S
This is close to the true value than Helium but the true value still isn't in the region

The ratio of the two viscosities gives:

$\frac{\eta_{He}}{\eta_{Ar}} = 0.57 \pm 0.033$ $\quad \sigma = 0.57\sqrt{\left(\frac{3.19\times10^{-7}}{9.19\times10^{-6}}\right)^2 + \left(\frac{7.55\times10^{-7}}{1.62\times10^{-5}}\right)^2} = 0.033$

This is not as expected, the ratio should be closer to 1 as the viscosities are roughly the same.
This comes from the calculated viscosity of Helium being a factor of 2 too small with the error range not covering the true value.
Considering that all major uncertainties were accounted for, the most likely source of this discrepancy is the choice of the linear region. As this was chosen by eye, the accuracy will not be high. Also readings were taken in 10 second intervals, 5 second intervals would allow a more accurate linear gradient to be calculated. On top of this, the 3 repeats had different starting pressures, a constant initial pressure may cause more accurate results.

- The major sources of error for this experiment come from the measurements of the tube, the error on the pressure sensor, the calculation of the gradient and the calculation for the interior volume. The error on the diameter of the tube is about 5% but as this was raised to the fourth power in calculation, the uncertainty was neglected as it was so small. The uncertainty on the high pressure sensor was 0.25%. Despite this being small, it was accounted for but won't be the factor that contributes to the overall error the most. Calculating the average gradient and the interior volume both gave an uncertainty of about 1%. Therefore these contributed to the overall uncertainty the most.

Using the viscosity the diameter of a Helium and Argon atom was calculated:

$d_{He} = 2.60 \times 10^{-10} \pm 4.59 \times 10^{-12}$ m $\quad d_{Ar} = 3.48 \times 10^{-10} \pm 8.2 \times 10^{-12}$ m

The Van der Walls radius is an approximation of the radius of an atom by treating the atom as a hard sphere and using the distance of closest approach. This is an appropriate model to use as we found the diameter using the mean free path and therefore collisions.

$r_{w,He} = 1.40 \times 10^{-10}$ m $\quad r_{w,Ar} = 1.88 \times 10^{-10}$ m
$d_{w,He} = 2.80 \times 10^{-10}$ m $\quad d_{w,Ar} = 3.76 \times 10^{-10}$ m

$\frac{d_{Ar}}{d_{He}} = 1.34 \pm 0.039$ $\quad \sigma = 1.34\sqrt{\left(\frac{4.59\times10^{-12}}{2.6\times10^{-10}}\right)^2 + \left(\frac{8.2\times10^{-12}}{3.48\times10^{-10}}\right)^2} = 0.039$

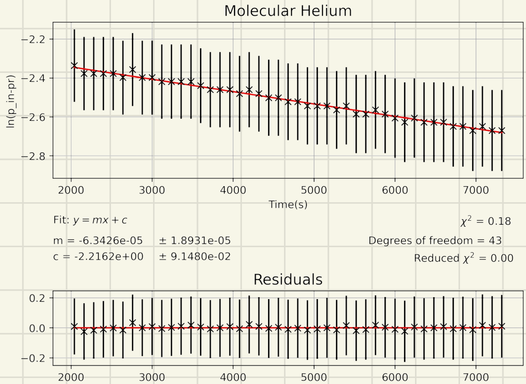
The real VDW ratio (1.34) lies within the error range.

Both calculated diameters are very close to the true value but the true value isn't in the error range. The most likely source of this error is that the VDW radius is only an approximation. The calculated value for Helium is closer than Argon, this can be explained by Helium being more ideal than Argon as it is smaller and an underlying assumption in this experiment is the gasses are ideal.

The reduced Chi Squared for the 6 graphs lie roughly in the region of 0.5-2.0, with the exception of the third graph on Helium and Argon with $\chi^2 = 2.19$ and 2.59 respectively. These values are 2 Show that less than two thirds of the error bars cross the line of best fit. Therefore this implies that the region I chose does not have a strong enough linear relationship. So to improve this, the third graph should be re-calculated with a different region for each gas to obtain a set of data with a reduced chi squared between 0.5 and 2.0. The gradients of these new graphs might produce a final viscosity closer to the true value.

Molecular flow - Helium:

Time(s)	ln(p_in-pr)	Error
2040	-1.969140019	0.1628466577
2160	-1.969140019	0.1628466577
2280	-1.969140019	0.1628466577
2400	-1.988906833	0.1631119402
2520	-1.988906833	0.1631119402
2640	-1.988906833	0.1631119402
2760	-1.969140019	0.1628466577
2880	-2.008704734	0.1633832752
3000	-2.008704734	0.1633832752
3120	-2.008704734	0.1633832752
3240	-2.02852763	0.1636607276
3360	-2.02852763	0.1636607276
3480	-2.008704734	0.1633832752
3600	-2.02852763	0.1636607276
3720	-2.02852763	0.1636607276
3840	-2.02852763	0.1636607276
3960	-2.048395395	0.1639447344
4080	-2.02852763	0.1636607276
4200	-2.02852763	0.1636607276
4320	-2.048395395	0.1639447344
4440	-2.068289255	0.1642351905
4560	-2.068289255	0.1642351905
4680	-2.068289255	0.1642351905
4800	-2.088202704	0.1645321572
4920	-2.088202704	0.1645321572
5040	-2.068289255	0.1642351905
5160	-2.108170798	0.1648363313
5280	-2.108170798	0.1648363313
5400	-2.108170798	0.1648363313
5520	-2.128160148	0.1651473837
5640	-2.108170798	0.1648363313
5760	-2.108170798	0.1648363313
5880	-2.108170798	0.1648363313
6000	-2.148192973	0.1654658393
6120	-2.108170798	0.1648363313
6240	-2.148192973	0.1654658393
6360	-2.148192973	0.1654658393
6480	-2.168263679	0.1657918018



We replaced the long narrow tube with the short tube $(10 \pm 0.5mm)$

We started by evacuating the whole System (all valves open apart from Standard Volume, gas inlet and atmospheric valve) by using the vacuum pump until the low pressure Sensor gives a reading below 10^{-1}mb. We then seperated the two sides of the System by Shutting the bypass valve, then the right hand Side could be filled to 5-8mbar of Helium (using the low pressure Sensor).

- By allowing the Helium to escape into a vaccum by opening the valve, measurements of the pressure as a function of time were taken - in two minute intervals until the System reaches equilibrium at around vaccum pressure. Vaccum pressure was measured at: $P_r = 0.0115 \pm 0.0079$
- Finding $\ln(P_{in} - P_r)$, this was then plotted against time.

Extracting only the linear Segment gives the graph Shown with gradient: $m = 6.34 \times 10^{-5} \pm 1.89 \times 10^{-5}$

The gradient is related to the pumping Speed by:

$$m = -\frac{S}{V_{in}}$$

Using the value of V_{in} from the previous experiment:

$$S = 6.34 \times 10^{-5} \times 5.47 \times 10^{-4}$$

$$S = 3.47 \times 10^{-8} \pm 1.04 \times 10^{-8} \ m^3 s^{-1}$$

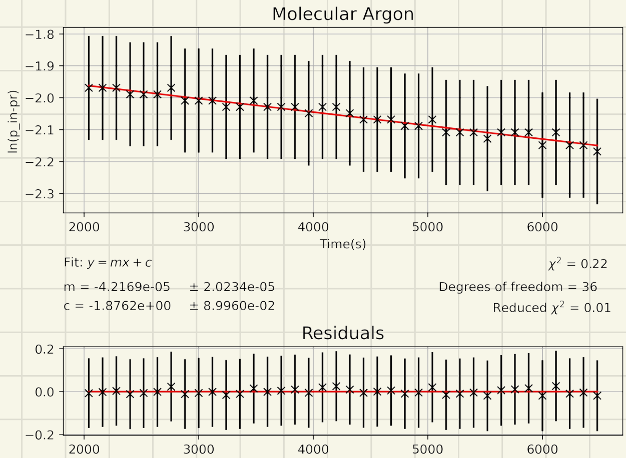
$$\sigma_S = 3.47 \times 10^{-8} \sqrt{\left(\frac{1.89 \times 10^{-5}}{6.34 \times 10^{-5}}\right)^2 + \left(\frac{6.57 \times 10^{-6}}{5.47 \times 10^{-4}}\right)^2}$$

$$\sigma_S = 1.04 \times 10^{-8}$$

Note that all readings for the pressure of Helium using the low pressure Sensor are Calibrated by a factor of 0.8

Molecular flow - Argon

Time(s)	ln(p_in-pr)	Error
2040	-1.969140019	0.1628466577
2160	-1.969140019	0.1628466577
2280	-1.969140019	0.1628466577
2400	-1.988906833	0.1631119402
2520	-1.988906833	0.1631119402
2640	-1.988906833	0.1631119402
2760	-1.969140019	0.1628466577
2880	-2.008704734	0.1633832752
3000	-2.008704734	0.1633832752
3120	-2.008704734	0.1633832752
3240	-2.02852763	0.1636607276
3360	-2.02852763	0.1636607276
3480	-2.008704734	0.1633832752
3600	-2.02852763	0.1636607276
3720	-2.02852763	0.1636607276
3840	-2.02852763	0.1636607276
3960	-2.048395395	0.1639447344
4080	-2.02852763	0.1636607276
4200	-2.02852763	0.1636607276
4320	-2.048395395	0.1639447344
4440	-2.068289255	0.1642351905
4560	-2.068289255	0.1642351905
4680	-2.068289255	0.1642351905
4800	-2.088202704	0.1645321572
4920	-2.088202704	0.1645321572
5040	-2.068289255	0.1642351905
5160	-2.108170798	0.1648363313
5280	-2.108170798	0.1648363313
5400	-2.108170798	0.1648363313
5520	-2.128160148	0.1651473837
5640	-2.108170798	0.1648363313
5760	-2.108170798	0.1648363313
5880	-2.108170798	0.1648363313
6000	-2.148192973	0.1654658393
6120	-2.108170798	0.1648363313
6240	-2.148192973	0.1654658393
6360	-2.148192973	0.1654658393
6480	-2.168263679	0.1657918018



- We vaccumed the whole system to remove any excess helium from the previous experiment.

- We then followed the same procedure as the molecular helium experiment to yield the data and graph shown.

- Following the same process to find the pumping speed:

$m = -4.22\times10^{-5} \pm 2.02\times10^{-5}$

$m = -\frac{S}{V_{in}}$; $S = -m \times V_{in}$

$= 4.22\times10^{-5} \times 5.47\times10^{-4}$

$= 2.31\times10^{-8} \pm 1.11\times10^{-8}\, m^3 s^{-1}$

$\sigma_S = 2.31\times10^{-8}\sqrt{\left(\frac{6.57\times10^{-6}}{5.47\times10^{-4}}\right)^2 + \left(\frac{2.02\times10^{-5}}{4.22\times10^{-5}}\right)^2}$

$= 1.11\times10^{-8}$

Note that all readings for the pressure of Argon using the low pressure sensor are calibrated by a factor of 1.7

Conclusion for molecular flow:

· The aims of this experiment were to determine the pumping speeds for Helium and Argon

$S_{He} = 3.47 \times 10^{-8} \pm 1.04 \times 10^{-8}\ m^3 s^{-1}$

Compared to the real value calculated by: $S = \frac{2\pi a^3}{3L}\sqrt{\frac{8kT}{\pi m}}$

$S_{real}: 8.68 \times 10^{-8}\ m^3 s^{-1}$

This does not lie within the error region.

Calculated value is roughly a factor of 2 out.

$S_{Ar} = 2.31 \times 10^{-8} \pm 1.11 \times 10^{-8}\ m^3 s^{-1}$

Compared to the real value:

$S_{real}: 2.75 \times 10^{-8}\ m^3 s^{-1}$

This is within the range of error.

The ratio of the pumping speeds should be equal to the square root of the invese ratio of masses: $\frac{S_{He}}{S_{Ar}} = \sqrt{\frac{M_{Ar}}{M_{He}}}$

So the calculated ratio is:

$$\frac{S_{He}}{S_{Ar}} = \frac{3.47}{2.31} = 1.50 \pm 0.851$$

$$\sigma = 1.50\sqrt{\left(\frac{1.04 \times 10^{-8}}{3.47 \times 10^{-8}}\right)^2 + \left(\frac{1.11 \times 10^{-8}}{2.31 \times 10^{-8}}\right)^2} = 0.851$$

And the expected ratio is:

$$\sqrt{\frac{40u}{4u}} = 3.16$$

This does not lie within the region of error.

The largest source of error in this experiment is the uncertainty on the low pressure sensor. This was 15% as all readings were between 1×10^{-3} and 100 mbar.

Despite this, the chi squared for both graphs were very low. For Helium, 0, and for Argon 0.01. This implies that the error bars are too big as more than two thirds of the error bars cross the line of best fit. A possible reason for this is the sources of error were over estimated. Another reason is the pressure sensor was not accurate enough.

This leads to a possible improvement for the experiment, a pressure sensor with a finer scale. This would give more accurate readings with a smaller uncertainty. This will give an answer closer to the true value. Ontop of this, we only took one set of readings for each gas. If repeat measurements were taken and a mean gradient was calculated, the pumping speed would be more accurate.

The calculation for the interior volume also had a 1% error, this is small compared to the error on the pressure gauge but will still contribute. This could be improved by using a high pressure sensor with a better precision.

All raw data and full calculations can be found at:

iCloud Drive → Desktop → Uni Year 1 → Semester 2 → labs → Gasflow → main spreadsheet.