Pointing out valuable pieces

Electron Diffraction

10/10 rest of notebook

09/23/2

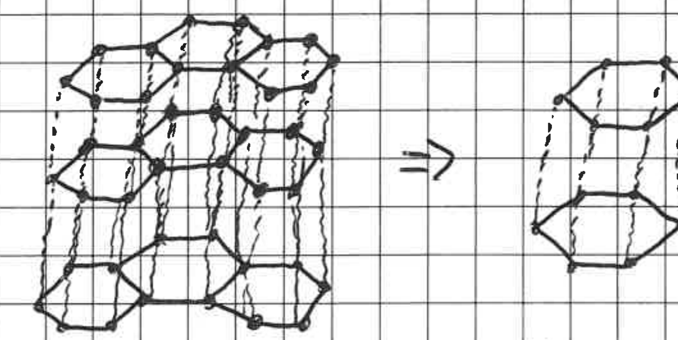
Pre-Lab

Purpose of lab

The purpose of this experiment is to determine the lattice constants and the ratio of lattice constants in graphite.

Introduction

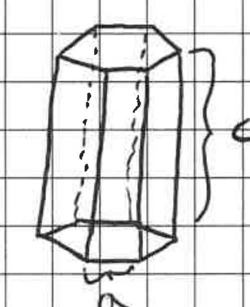
Graphite forms a crystalline structure with a hexagonal unit cell:



Definitions

The lattice constants of a crystalline structure are physical properties of distances between atoms in those structures. The following diagram details the physical interpretation of the lattice constants for the hexagonal unit cell:

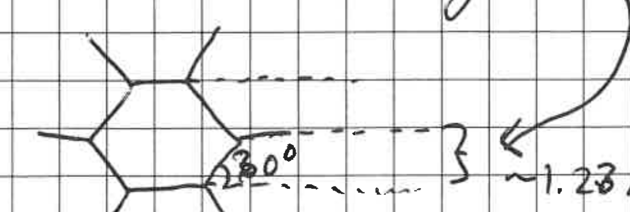
Diagrams to help explain concepts



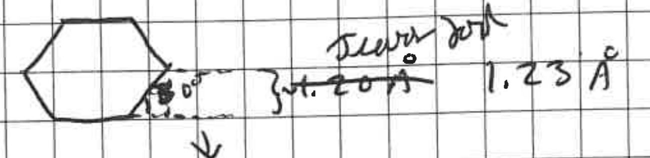
Discussion of main findings

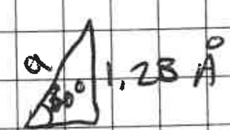
https://en.wikipedia.org/wiki/Lattice_constant

In graphite, the empirically-determined a is 2.461 Å and the c is 6.708 Å. Our experiment is able to determine the following value:



So the following triangle can be formed to relate this measured value to the lattice constant a:



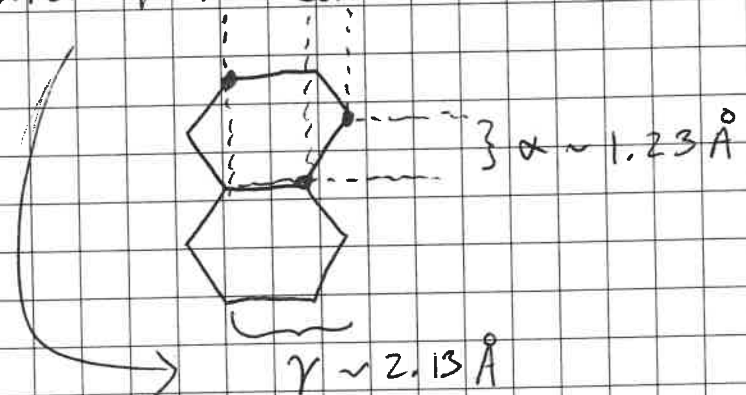


$$\Rightarrow a = \frac{1.23 \; \cancel{1.20} \text{ Å}}{\sin(30)^\circ}$$

consistent $\longrightarrow$ $a \approx 2.46$ Å

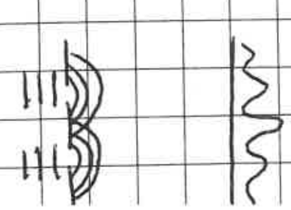
So the value we are able to measure can be directly related to the "a" lattice constant. The actual measurement details shall be discussed shortly.

The other lattice constant is shown on the following figure

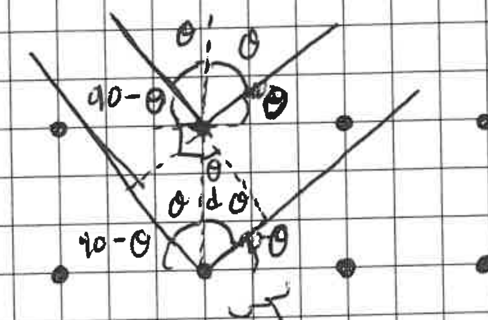


α and γ will be the lattice constants we will measure via this experiment.

Diffraction of waves leads to interference patterns if multiple diffraction events occur at once. The classic example of this is the double-slit experiment in which light diffracted through two slits interfere to create a pattern of light and dark fringes:



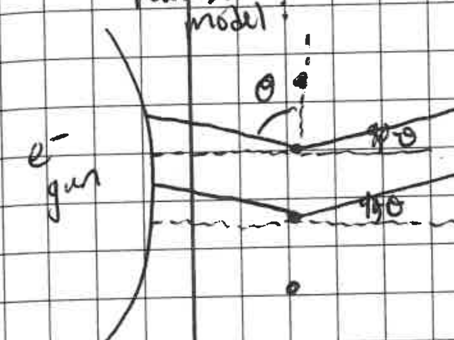
In a crystal, different diffraction events occur at different atoms in the structure.



This distance must be $n\lambda$ ($n \in \mathbb{N}$) for the waves to constructively interfere after the diffraction event.

$$\therefore \; d\sin\theta = n\lambda$$

More realistic model:



Chalk talk w/ Dr. Koopke

This equation $d\sin\theta = n\lambda$ is known as Bragg's diffraction law. In cases where the angle θ is small, this can be approximated by a Taylor series as:

$$d\theta = n\lambda$$

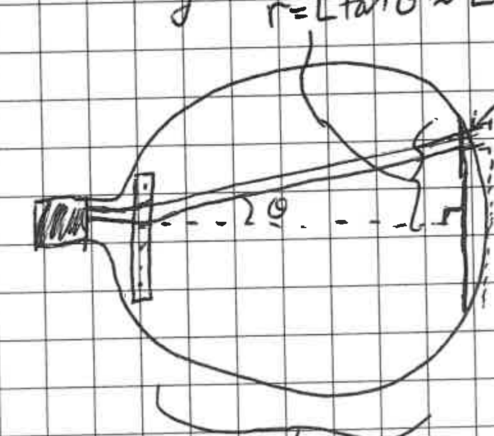
Further, in 2- and 3-dimensional lattices, diffraction orders above $n=1$ do not appear, so:

$$d\theta = \lambda$$

Formulas

Imagine then that the cone of waves with small θ after the diffraction event hits a screen a distance L away:

$r = L\tan\theta \approx L\theta$ since $\tan\theta \approx \theta$



one pair of constructively interfering waves after diffraction

The diameter of the ring formed by waves of θ (small) after diffraction is:

Combining $D = 2L\theta$ with $d\theta = \lambda$ gives:

$$\lambda = \frac{dD}{2L}$$

Now, up until this point I have been speaking of generic waves. The classic example of this would be light waves. However, in 1924, Louis de Broglie posed that matter also behaves as a wave with wavelength:

$$\lambda = \frac{h}{p} \leftarrow \text{momentum of object}$$

Now we will use this result to talk about electron diffraction. A electron accelerated through a potential difference Va has a given momentum by:

$$|eV_a| = \frac{1}{2} m_e v^2$$

$$\sqrt{\frac{2|eV_a|}{m_e}} = v$$

$$\therefore\ p = mv = \sqrt{2|eV_a|m_e}$$

This means that:

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2|eV_a|m_e}}$$

Formulas

These constants are:

$$e = 1.619 \cdot 10^{-19}\ C$$
$$m_e = 9.11 \cdot 10^{-31}\ kg$$
$$h = 6.626 \cdot 10^{-34}\ Js$$

So we can calculate their combined value to get a simpler equation for λ:

$$\lambda \approx \frac{12.1998\ \text{Å}}{V_a^{1/2}} \approx \frac{\sqrt{150}\ \text{Å}}{V_a^{1/2}}$$

And finally we can relate the ring diameter of a diffraction pattern to the accelerating voltage:

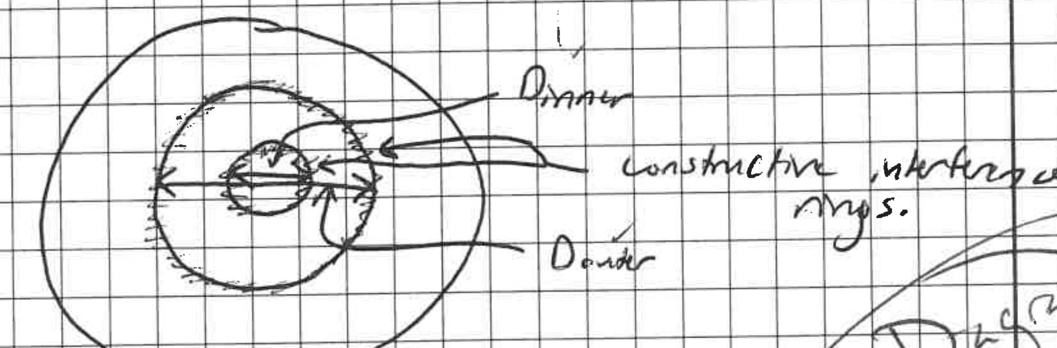
$$\lambda = \frac{dD}{2L} = \frac{\sqrt{150}\ \text{Å}}{V_a^{1/2}}$$

$$D = \frac{2L\sqrt{150}\ \text{Å}}{d} \cdot \frac{1}{V_a^{1/2}}$$

So we see that $D \propto V_a^{-1/2}$ and that the distance between atoms in the lattice, d, is related to a plot of D vs. $V_a^{-1/2}$ via the slope.

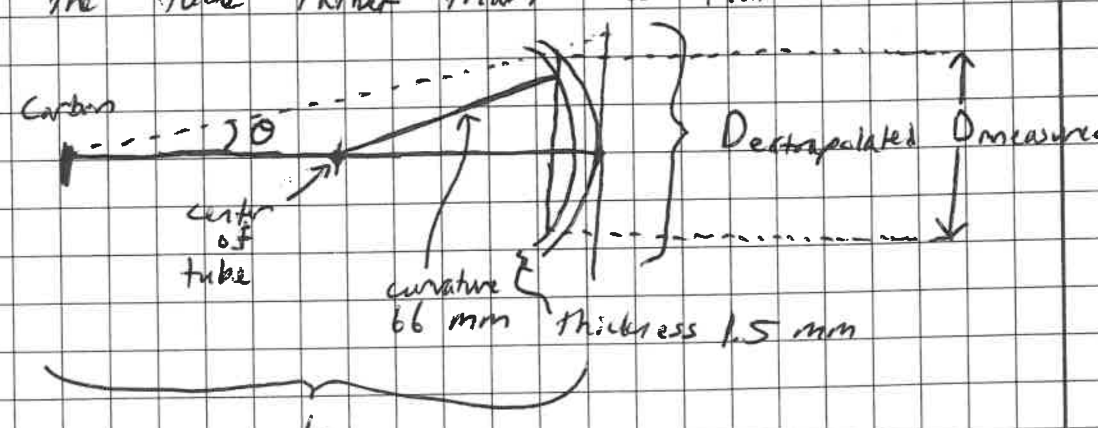
The lattice constants α and γ are determined by the different values of d we will obtain experimentally by the inner and outer diffraction rings.

*looking down apparatus tube

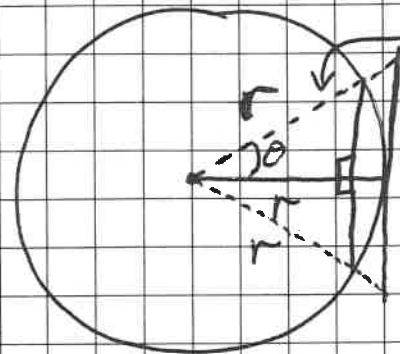


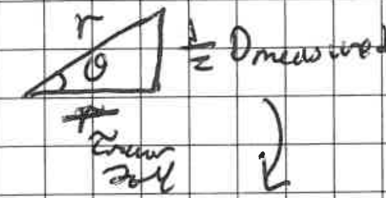
Diagrams

The following diagram details complications arising when the interference pattern falls on the spherical body of the tube rather than a flat surface.



Consider a circle w/ radius r:

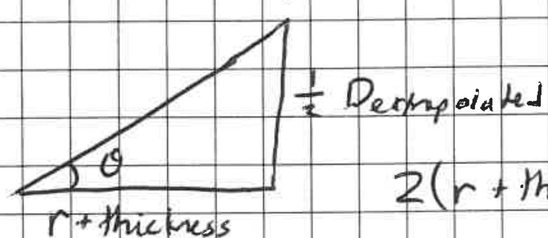




~~$2r\tan\theta = D_{measured}$~~

$$2r\sin\theta = D_{measured}$$

The distance at which $D_{extrapolated}$ occurs is r + thickness and this can be related by:



$$2(r+\text{thickness})\tan\theta = D_{extrapolated}$$

So:

$$D_{ex} = 2(r+\text{thickness})\tan\theta$$
$$D_{me} = 2r\sin\theta$$
$$\Downarrow$$
$$\frac{D_{ex}}{D_{me}} = \frac{(r+\text{thickness})\tan\theta}{r\sin\theta}$$

$$D_{ex} = \frac{(r+\text{thickness})\tan\theta}{r\sin\theta} D_{me}$$

For small θ, $\tan\theta \approx \theta$ and $\sin\theta \approx \theta$, so:

$$D_{ex} = \left(1 + \frac{\text{thickness}}{r}\right) D_{me}$$

The thickness of the tube and the radius of curvature, r, will be determined via measurement. The manual claims thickness = 1.5 mm & r = 66 mm which would mean $D_{ex} = 1.023\, D_{me}$

09/28/2021

Returning to our $D \propto V_a^{-1/2}$ relationship, we substitute D_{ex} for D: & and L with L + thickness

$$D_{ex} = \frac{2(L+\text{thickness})\sqrt{150}\,\text{Å}}{d\,V_a^{+1/2}}$$

$$\left(1+\frac{\text{thickness}}{r}\right) D_{me} = 1.023\, D_{me} = \frac{2(L+0.0015\,m)\sqrt{150}\,\text{Å}}{d\,V_a^{+1/2}}$$

$$D_{me} = \frac{2(L+\text{thickness})\sqrt{150}\,\text{Å}}{1.023\cdot d\cdot V_a^{+1/2}}$$

$$D_{me} = \frac{2(L+\text{thickness})\sqrt{150}\,\text{Å}}{(1+\text{thickness}/r)\,d\,V_a^{+1/2}}$$

$$D_{me} = \frac{2r(L+\text{thickness})\sqrt{150}\,\text{Å}}{(r+\text{thickness})\,d\,V_a^{+1/2}}$$

We see that this equation for D_{me} limits to

Error fixed ~~D_{ex} as~~ $D = \frac{2L\sqrt{150}\,\text{Å}}{d\,V_a^{+1/2}}$ as the thickness → 0

So there aren't any immediate flaws in consistency for this model including the thickness. Note that the radius of curvature also drops out since (to first approximation of θ) the glass sphere does not drastically separate from the central diameter.

We will plot D_{me} versus $V_a^{-1/2}$ for each set of ring diameters, ± D. The slopes of these lines will be:

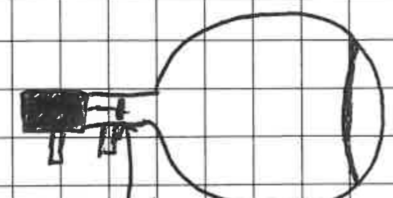
$$\text{slope} = \frac{2L\sqrt{150}\,\text{Å} + 2\,\text{thickness}\sqrt{150}\,\text{Å}}{\left(1+\frac{\text{thickness}}{r}\right) d}$$

$$\text{slope} = \frac{2(L+\text{thickness})\sqrt{150}\,\text{Å}}{\left(1+\frac{\text{thickness}}{r}\right) d}$$

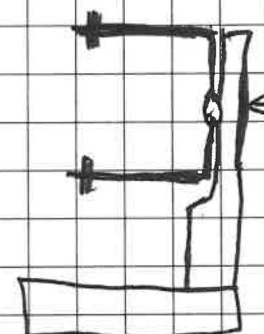
The lattice constants can then be determined by solving for d:

Equipment

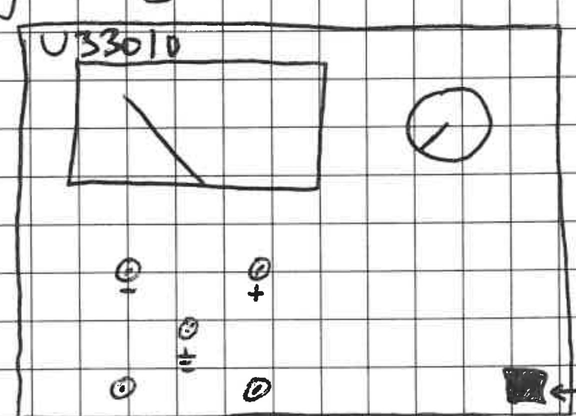
- Teltron 555 electron diffraction tube (TEL 555)



- Teltron universal stand



- (2x) High Voltage Power Supplies 5 kV (U33010 by 3B)



- Plastic Vernier Calipers

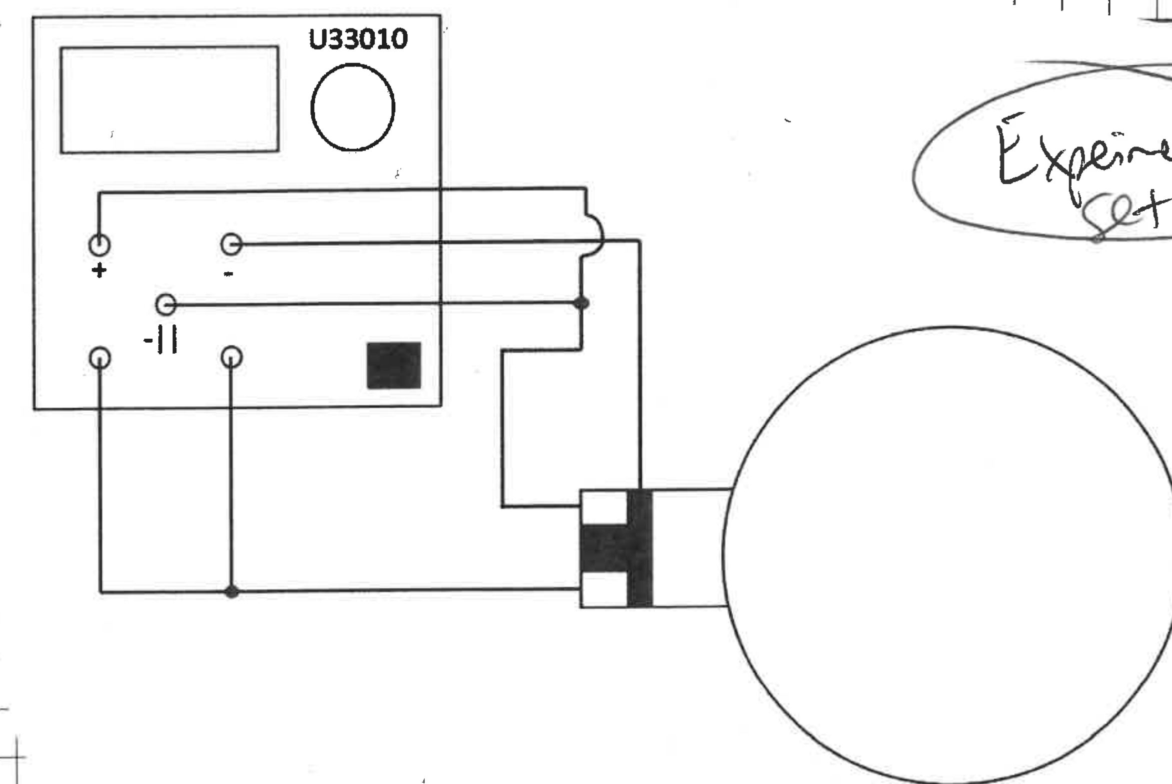
The following page details a circuit diagram for the experimental set-up.

$\delta L = 0.3$ cm

Hughes & Mase

09/28/2021

Experimental Setup



← improved circuit diagram

Trevor 2021

Sample Data Analysis

The data from the TEL 555 diffraction tube manual will be analyzed via Excel.

V_a (kV)	Outer Diameter (mm)	Inner Diameter (mm)
2.5	50	29
4.0	43	25
6.0	39	24
6.9	36	21

$L = 13.5$ cm thickness = 1 mm $\delta V_a = 0.2$ kV $\delta OD = 1$ mm $\delta ID = 1$ mm

The linear regression is forced to pass through the intercept to match the physical observation that no diffractions occur at $V_a = 0$.

$$m = \frac{N\sum_i x_i y_i - \sum_i x_i \sum_i y_i}{\Delta} \qquad c = 0$$

$$\delta_m = \alpha_{cu}\sqrt{\frac{N}{\Delta}} \qquad \delta_c = \alpha_{cu}\sqrt{\frac{\sum_i x_i^2}{\Delta}}$$

$$\alpha_{cu} = \sqrt{\frac{1}{N-2}\sum (y_i - m x_i - c)^2} \qquad \Delta = N\sum_i x_i^2 - \left(\sum_i x_i\right)^2$$

Uncertainty propagation:

$$\delta(V_a^{-1/2}) = \left|\frac{d(V_a^{-1/2})}{dV_a}\right| \delta V_a$$

$$\delta(V_a^{-1/2}) = \left|-\frac{1}{2V_a^{3/2}}\right| \delta V_a$$

$$\boxed{\delta(V_a^{-1/2}) = \frac{\delta V_a}{2V_a^{3/2}}}$$

Since our regression is $D = \frac{2L\sqrt{150}}{d\,V_a^{1/2}}$ Å our d is:

$$d = \frac{2L\sqrt{150}}{\text{slope}\cdot \cancel{V_a^{1/2}}}$$ ~~Treat as zero~~

Thus:

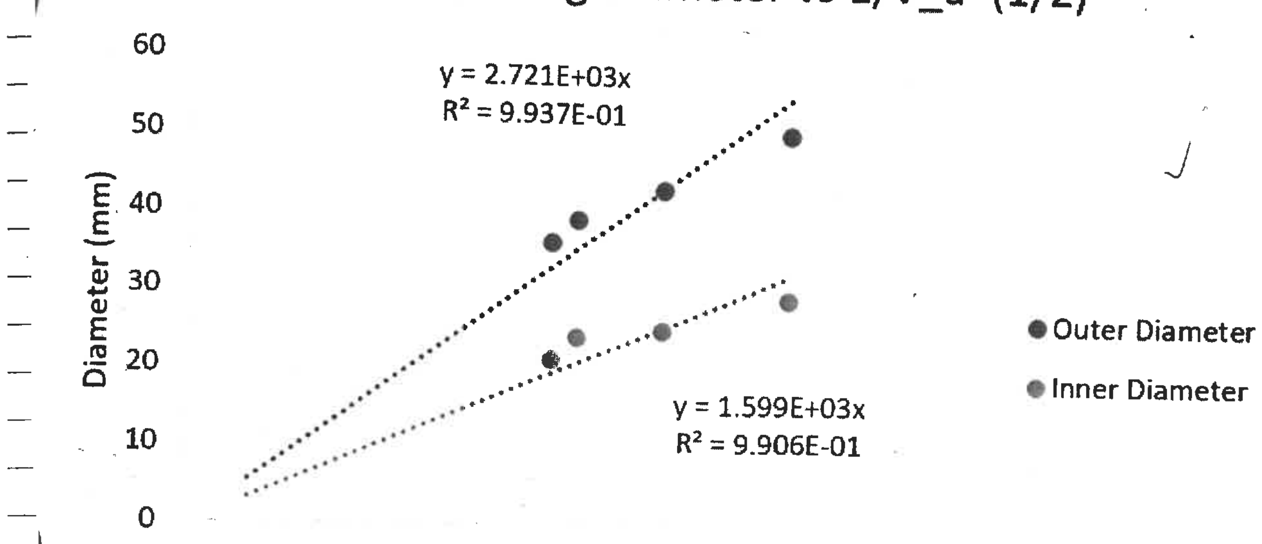
$$\boxed{\delta d = \sqrt{\left(\frac{d(d)}{dL}\right)^2 \delta L^2 + \left(\frac{d(d)}{d\,\text{slope}}\right)^2 \delta \text{slope}^2}}$$

~~$+\left(\frac{d(d)}{dV_a^{1/2}}\right)$~~ ~~Treat as zero~~

δslope " δm uncertainty in linear regression slope

Factorial plot of D vs $V_a^{-1/2}$ as done via Excel:

Interference Ring Diameter vs 1/V_a^(1/2)



And our output for the analysis is:

Outer Diameter:	
Linear Regression	
Slope	2721.28
Common Uncertainty	4.745875
Slope Uncertainty	763.3587
d	1.215233
Uncertainty in d	0.34194
Inner Diameter:	
Linear Regression	
Slope	1599.36
Common Uncertainty	3.412699
Slope Uncertainty	548.9217
d	2.067586
Uncertainty in d	0.711108

} Å

} Å

To summarize these results:

Error

$$\boxed{\begin{aligned} d(\text{outer}) &= 1.22 \text{ Å} \quad \leftarrow d_o \\ \delta d(\text{outer}) &= 0.34 \text{ Å} \\ d(\text{inner}) &= 2.07 \text{ Å} \quad \leftarrow d_i \\ \delta d(\text{inner}) &= 0.71 \text{ Å} \end{aligned}}$$

These are within uncertainty of the actual values of d(outer) = 1.23 Å and d(inner) = 2.13 Å. Note that the uncertainty in d(inner) is considerably larger than in d(outer).

We can compare these d's to see if $\frac{d_i}{d_o} = \sqrt{3}$ ← condition for hexagonal lattice structure is true within uncertainty:

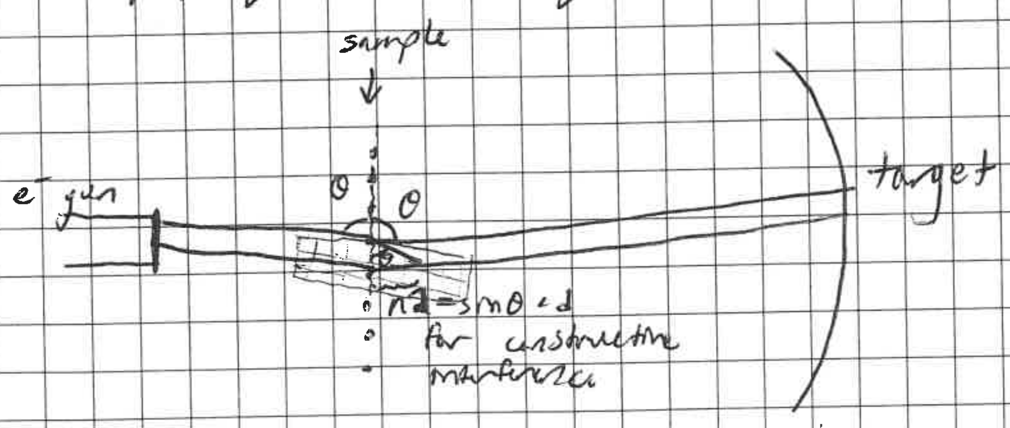
$$\frac{d_i}{d_o} = 1.697 \qquad \delta\left(\frac{d_i}{d_o}\right) = \sqrt{\left(\frac{1}{d_o}\right)^2 \delta d_i^2 + \left(-\frac{d_i}{d_o^2}\right)^2 \delta d_o^2} = 0.75$$

10/5/2021

Pre-Lab Procedure Plan:

1) Connect circuit as shown on page 39
2) Measure L, thickness, and determine radius of curvature for apparatus.
3) Measure inner and outer diffraction ring diameters at multiple values of V_a (the number of points to be determined).
4) Construct D vs. $V_a^{-1/2}$ plot and perform linear regression with ~~s~~ intercept fixed at zero (to match the model).
5) Propagate uncertainty as outlined in sample data analysis.
6) Compare d values to ~~theoretical values~~ from 2A literature values
7) Determine if d_i/d_o ratio is within uncertainty of $\sqrt{3}$ to provide evidence for the lattice structure of graphite being hexagonal.

As an aside, Dr. Koepke doesn't like the standard picture given in the manual for diffraction, so I'm proposing a potentially better model diagram.



This diagram is better since it demonstrates how electrons reach the target surface after diffraction and is not as confusing with its angles.

"never draw a

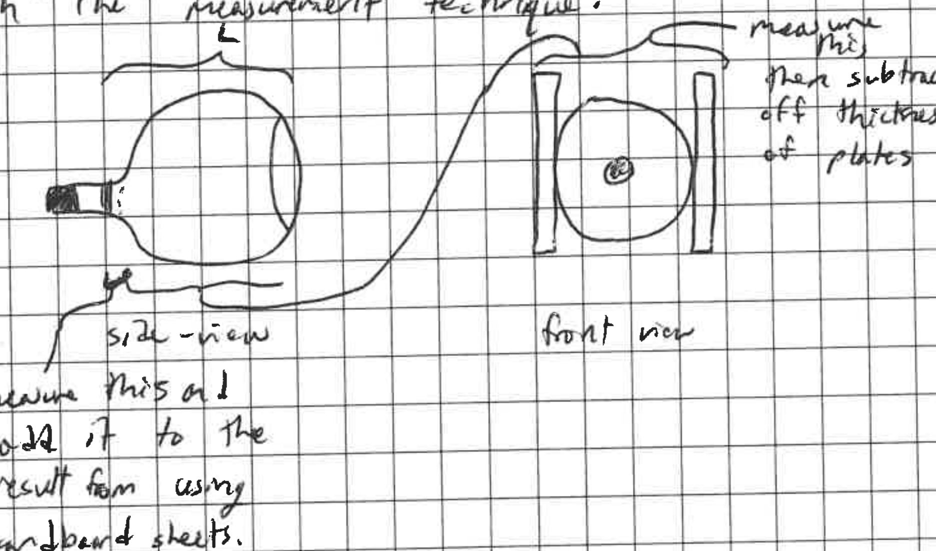
Experiment Documentation

We first measured the length L of the tube to be ~~12.45 cm~~ Typo 10/5/2021 ~~12.55~~ cm ± 0.5 cm

remeasured to actually be 13.37 cm

The uncertainty in L is large due to the uncertainty associated with the measurement technique:

We took two cardboard sheets to measure the distance



$L = (\cancel{12.55}\ 13.37 \pm 0.5)$ cm

thickness = ~~±0.2 cm~~ (0.1 ± 0.1) cm ← can't directly measure, use error bars wisely

← Dr. Koepke talk 10/5

All of this info is presented better on next page

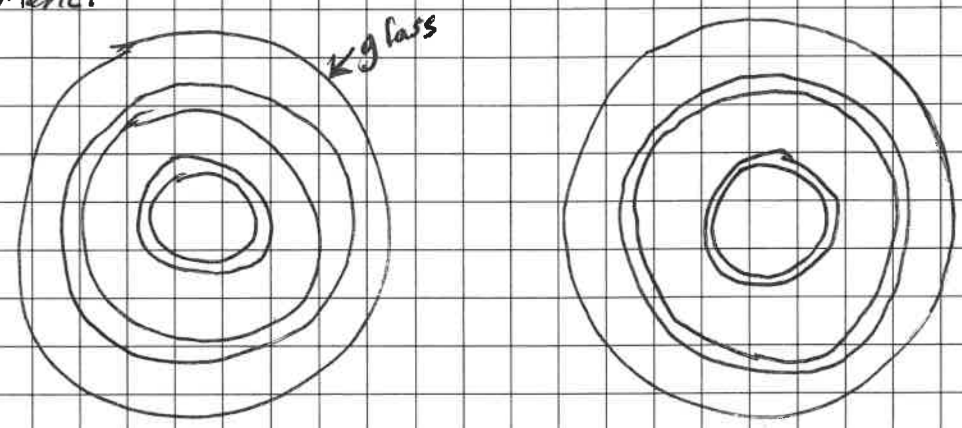
We then hooked up the circuit according to our diagram on page 39. switch these! wrote down wrong

D_o (mm)	δD_o (mm)	D_i (mm)	δD_i (mm)	V (kV)	δV (kV)
65	37.3	0.160		2	0.1
57.8	34.4	0.140		2.2	0.1
53.4	31.1	0.115		2.6	0.1
50.3	29.5	0.100		3.0	0.1
48.8	28.8	0.115		3.2	0.1
45.5	26.6	0.080		3.8	0.1
41.9	24.6	0.075		4.4	0.1

Messy table; corrected on next page!

We did not attach the ~~fine-tuning~~ 0-50 ~~kV~~ $\frac{\text{tungsten}}{}$ V potential, so we were unable to alter the sharpness of our diffraction rings. However, upon speaking with Dr. Koepke we decided that this error should have a minimal impact on our experimental values of the lattice constants.

He said that we should consider the uncertainty in the measurements and demonstrate the fine-tuning difference in future poster presentations of this experiment.



Un-tuned   Tuned

Pictures of data

Photos OK too
Graphs better when appropriate

The uncertainties are determined by half the diffraction band width, thus fine-tuning should decrease our uncertainty accordingly.

V_a (kV)	δV_a (kV)	D_i (mm)	δD_i (mm)	D_o (mm)	δD_o (mm)
2.0	0.1	37.3	1.35	65.0	1.60
2.2	0.1	34.4	1.30	57.8	1.50
2.6	0.1	31.1	1.15	53.4	1.40
3.0	0.1	29.5	1.00	50.3	1.15
3.2	0.1	28.8	1.15	48.8	1.15
3.8	0.1	26.6	0.80	~~45~~ 44.5	1.10
4.4	0.1	24.6	0.75	41.9	0.85

$L = 13.37$ cm $\delta L = 0.5$ cm

Thickness = 0.1 cm δ thickness = 0.1 cm

10/12/2021

Data Analysis / Uncertainty Propagation: (Post-Lab)

We find the $V_a^{-1/2}$ values from the experimental V_a's:

V_a (kV)	V_a (V)	$V_a^{-1/2}$ ($V^{-1/2}$)
2.0	2000	0.0224
2.2	2200	0.0213
2.6	2600	0.0196
3.0	3000	0.0183
3.2	3200	0.0177
3.8	3800	0.0162
4.4	4400	0.0151

I will construct a linear regression plot of the ring diameters versus $V_a^{-1/2}$. The equations used to construct the linear regression are given by Hughes and Hase: (pg. 64)

$$m = \frac{N\Sigma_i x_i y_i - \Sigma_i x_i \Sigma_i y_i}{\Delta}$$

$$c = \frac{\Sigma_i x_i^2 \Sigma_i y_i - \Sigma_i x_i \Sigma_i x_i y_i}{\Delta}$$

$$\Delta = N\Sigma_i x_i^2 - (\Sigma_i x_i)^2$$

$$\delta_{cu} = \alpha_{cu} = \sqrt{\frac{1}{N-2}\sum_i (y_i - mx_i - c)^2}$$

$$\delta c = \alpha_c \; \cancel{\delta m = \alpha_m} = \alpha_{cu}\sqrt{\frac{\Sigma_i x_i^2}{\Delta}}$$

$$\delta m = \alpha_m = \alpha_{cu}\sqrt{\frac{N}{\Delta}}$$

These calculations are performed via Excel and the results are attached on the next page for both the inner and outer ring diameters.

LINEAR REGRESSIONS ✓

OUTER

Slope	2902.572702	m
Intercept	-2.308396172	c
Common Uncertainty	1.504995424	δCU
Slope Uncertainty	233.3574471	δm
Intercept Uncertainty	4.38831216	δc
d	1.119921901	

INNER

Slope	1654.626	m
Intercept	-0.52434	c
Common Uncertainty	0.572653	δCU
Slope Uncertainty	88.79285	δm
Intercept Uncertainty	1.669759	δc
d	1.964585	

The lattice constant values, d, are calculated using the following result from page 37:

$$d = \frac{2(L + \text{thickness})\sqrt{150}\ \text{Å}}{\left(1 + \frac{\text{thickness}}{r}\right)\cdot \text{slope}}$$

~~We approx measure~~ Treva Ford 14/12/2021

We measured r to be (6.25 ± 0.1) cm and this value is used in Excel to determine the d's for the above output.

Corresponding data are provided on the following page to give a more in-depth view of the analysis in Excel. A figure is also provided.

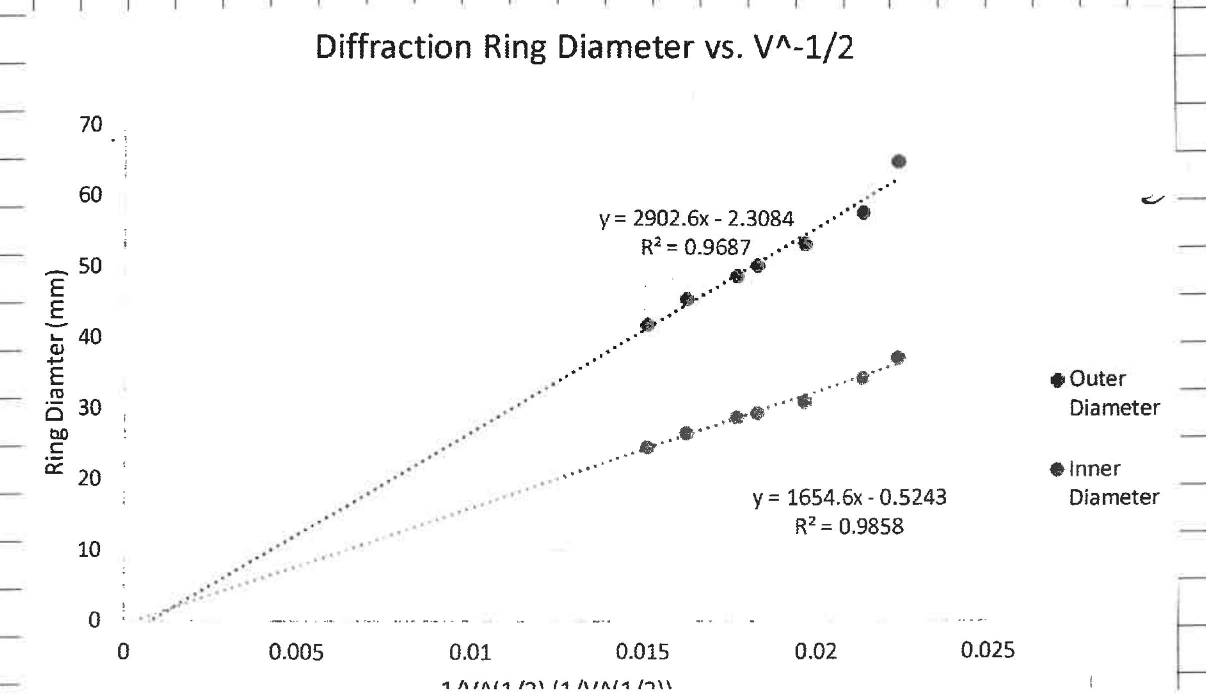
Doesn't lead to much difference in results; instead use $\frac{2L\sqrt{150}}{\text{slope}} = d$ to simplify future calculations

Outer

Slope	Intercept	Data	Residuals	Residuals^2	x	x^2
2902.573	-2.3084	65	2.404897	5.783531823	0.022361	0.0005
2902.573	-2.3084	57.8	-1.77466	3.149424345	0.02132	0.000455
2902.573	-2.3084	53.4	-1.21574	1.478018517	0.019612	0.000385
2902.573	-2.3084	50.3	-0.38509	0.148293239	0.018257	0.000333
2902.573	-2.3084	48.8	-0.20232	0.040935338	0.017678	0.000313
2902.573	-2.3084	45.5	0.722449	0.521933008	0.016222	0.000263
2902.573	-2.3084	41.9	0.450466	0.202919862	0.015076	0.000227
			SUM	11.32505613	0.130525	0.002475
			Delta	0.000291156		

Inner

Slope	Intercept	Data	Residuals	Residuals^2	x	x^2
1654.626	-0.52434	37.3	0.825769	0.681893662	0.022361	0.0005
1654.626	-0.52434	34.4	-0.35241	0.124195402	0.02132	0.000455
1654.626	-0.52434	31.1	-0.82555	0.681538776	0.019612	0.000385
1654.626	-0.52434	29.5	-0.18487	0.03417574	0.018257	0.000333
1654.626	-0.52434	28.8	0.074401	0.005535557	0.017678	0.000313
1654.626	-0.52434	26.6	0.282756	0.079950697	0.016222	0.000263
1654.626	-0.52434	24.6	0.179909	0.032367147	0.015076	0.000227
			SUM	1.639656981	0.130525	0.002475
			Delta	0.000291156		



2/2021

This analysis requires error propagation, completed below. First we find the uncertainty in $V_a^{-1/2}$ given uncertainties in V_a:

$$\delta V_a^{-1/2} = \left| \frac{d}{dV_a}\left(V_a^{-1/2}\right) \right| \delta V_a$$

$$\delta V_a^{-1/2} = \frac{1}{2 V_a^{3/2}}\, \delta V_a$$

V_a (V)	δV_a (V)	$\delta V_a^{-1/2}$ ($V^{-1/2}$)
2000	100	$5.59 \cdot 10^{-4}$
2200	100	$4.85 \cdot 10^{-4}$
2600	100	$3.77 \cdot 10^{-4}$
3000	100	$3.04 \cdot 10^{-4}$
3200	100	$2.76 \cdot 10^{-4}$
3800	100	$2.13 \cdot 10^{-4}$
4400	100	$1.71 \cdot 10^{-4}$

The remainder of the errors are propagated in Excel using quadrature addition:

Lattice constant uncertainty →

$$\delta d = \sqrt{\sum_i \left(\underbrace{\left(\frac{-L_i\sqrt{150}}{D_i V_{a_i}^{3/2}}\right)^2}_{\frac{\partial d}{\partial V_{a_i}}} \delta V_{a,i}^2 + \underbrace{\left(\frac{2\sqrt{150}}{D_i V_{a,i}^{1/2}}\right)^2}_{\frac{\partial d}{\partial L_o}} \delta L_i^2 + \underbrace{\left(-\frac{2L_i\sqrt{150}}{D_i^2 V_{a_i}^{1/2}}\right)^2}_{\frac{\partial d}{\partial D_i}} \delta D_i^2 \right) + \underbrace{\left(-\frac{2L\sqrt{250}}{m^2}\right)^2}_{\frac{\partial d}{\partial m}} \delta m^2}$$

ensemble uncertainty² + regression uncertainty²

We apply this expression for both d_i and d_o to find:

$$\boxed{\begin{array}{ll} d_i = 1.96\,\text{Å} & \delta d_i = 0.18\,\text{Å} \\ d_o = 1.12\,\text{Å} & \delta d_o = 0.31\,\text{Å} \end{array}}$$

agree with 2.13 Å + 1.23 Å from

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D_o	D_i	V	L	mi	mo	dD	1st term	2nd term	3rd term	4th term
65	37.3	2000	133.7	1654.626	2902.573	1.6	0.0007933	0.001775148	0.000769	0.008228581
57.8	34.4	2200	133.7	1654.626	2902.573	1.5	0.000753755	0.002040859	0.000983	0.008228581
53.4	31.1	2600	133.7	1654.626	2902.573	1.4	0.000534997	0.002023184	0.000994	0.008228581
50.3	29.5	3000	133.7	1654.626	2902.573	1.15	0.000392513	0.001976214	0.000739	0.008228581
48.8	28.8	3200	133.7	1654.626	2902.573	1.15	0.000343609	0.001968347	0.000782	0.008228581
45.5	26.6	3800	133.7	1654.626	2902.573	1.1	0.000236037	0.001906711	0.000797	0.008228581
41.9	24.6	4400	133.7	1654.626	2902.573	0.85	0.000179295	0.001941827	0.000571	0.008228581
37.3		2000	133.7	1654.626		1.35	0.002409053	0.005390681	0.005049	0.011281586
34.4		2200	133.7	1654.626		1.3	0.002127988	0.005761714	0.005884	0.011281586
31.1		2600	133.7	1654.626		1.15	0.001577296	0.005964817	0.005832	0.011281586
29.5		3000	133.7	1654.626		1	0.001141159	0.005745475	0.004721	0.011281586
28.8		3200	133.7	1654.626		1.15	0.00098655	0.005651403	0.006443	0.011281586
26.6		3800	133.7	1654.626		0.8	0.000690621	0.005578846	0.003608	0.011281586
24.6		4400	133.7	1654.626		0.75	0.000520147	0.005633371	0.003744	0.011281586
						SUMOUTE	0.003233507	0.01363229	0.005635	
						SUMINNEF	0.009452815	0.039726308	0.03528	

	Uncertainties
0.030729	[illegible]
0.095741	[illegible]

δd_i $\qquad$ δd_o

The final step is to compare $\frac{d_i}{d_o}$ to $\sqrt{3} \sim 1.73$ to show that our data are consistent with hexagonal crystal structure.

$$\frac{d_i}{d_o} = \frac{1.96\,\text{Å}}{1.12\,\text{Å}} = 1.75$$

The uncertainty is given by:

Trevor

$$\delta\left(\frac{d_i}{d_o}\right) = \sqrt{\underbrace{\frac{1}{d_o^2}}_{\left(\frac{\partial\left(\frac{d_i}{d_o}\right)}{\partial d_i}\right)^2} \delta d_i^2 + \Big(\underbrace{-\frac{d_i}{d_o^2}}_{\frac{\partial\left(\frac{d_i}{d_o}\right)}{\partial d_o}}\Big)^2 \delta d_o^2}$$

Using this equation, we find:

$$\frac{d_i}{d_o} = 1.75 \qquad \delta\left(\frac{d_i}{d_o}\right) = 0.51$$

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Results / Conclusion:

We found the following two lattice constants for graphite:

$$\boxed{\begin{aligned} d_i &= (1.96 \pm 0.18)\ \text{Å} \\ d_o &= (1.12 \pm 0.31)\ \text{Å} \end{aligned}}$$

And the ratio we found was:

$$\boxed{\frac{d_i}{d_o} = 1.75 \pm 0.51}$$

These results are consistent with the accepted values 1.23 Å and 2.13 Å on page 32. Since the ratio d_i/d_o is also within error of $\sqrt{3} \sim 1.73$ there is additional supporting evidence for both the success of this project and the lattice structure of graphite being hexagonal (consistent with previous claims on its structure. The analysis was performed neglecting the curvature of the glass since the added complications provided a minimal amount of additional accuracy relative to the work required (compare the sample data analysis to true data analysis to see differences between results obtained with and without this correction). In future experiments, incorporating the ability to fine-tune the diffraction rings (which was accidentally neglected in this experiment ~~in error~~) and accounting for curvature should be utilized to determine their true effects on experimental results.

Don't forget references