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\usepackage{amssymb}

\usepackage{esint}

\usepackage{graphicx}

\usepackage{bbold}

\usepackage[normalem]{ulem}

\usepackage{setspace}

\usepackage{breakurl}

\usepackage{seqsplit}

\usepackage[hidelinks,colorlinks]{hyperref}

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\hypersetup{urlcolor=[rgb]{0.25,0.14,0.63}}

\hypersetup{linkcolor=black}

\makeatletter

\usepackage[utf8]{inputenc}

\usepackage{mathrsfs}

\usepackage{xspace}

\usepackage[T1]{fontenc}

\usepackage{dcolumn}% Align table columns on decimal point

\usepackage{bm}% bold math

%\usepackage{hyperref}

\usepackage{float}% add hypertext capabilities

%\usepackage[mathlines]{lineno}% Enable numbering of text and display math

%\linenumbers\relax % Commence numbering lines

\usepackage[capitalise]{cleveref}

\usepackage[normalem]{ulem}

\usepackage{color}

\usepackage{esint}

\usepackage{setspace}

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\usepackage{seqsplit}

\usepackage[hidelinks,colorlinks]{hyperref}

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\newcommand{\Rev}[1]{{\color{blue}{#1}\normalcolor}} % Revision

\newcommand{\Com}[1]{{\color{red}{#1}\normalcolor}} %Comment

\begin{document}

\title{PHYS2041/2941/7141 Lab Report 2}

\author{Samuel Allpass s4803050}

\affiliation{School of Mathematics and Physics, University of Queensland, Brisbane, QLD 4072, Australia}

\begin{abstract}

This investigation aimed at quantitatively evaluating the Bragg effect for both a microwave and electron diffraction experiments in the aim of better understanding the effect and its applications. It was calculated that the polystyrene lattice within the microwave diffraction setup yielded $d\_{100}$ and $d\_{110}$ values of (1.6$\pm$0.1)mm and (1.5$\pm$0.6)mm. Despite the values differing significantly from the true plane spacing's of 39mm and 27.5mm and violating the expected 1:$\sqrt{2}$ ratio, the microwave diffraction effectively outlined methods of locating the $d\_{100}$ plane for some unknown sample. Alternatively, the electron diffraction conducted on a graphite powder sample calculated values for $d\_{100}$ and $d\_{110}$ of $(4.1\pm0.2)\*10^{-11}$ and $(2.32\pm0.09)\*10^{-11}$, correlating closely to the expected theoretically accepted magnitude and ratio of 1:$\sqrt{3}$. The experiments identified the vast application of such Bragg interactions into the field of crystallography, such as the classification and energy estimation of poly-crystalline samples, protein and biological structure study and geology.

\end{abstract}

\maketitle

\section{Introduction}

As light passes through a crystal lattice, it is reflected along atomic planes much like visible light on a mirror. Taking advantage of this phenomena, Bragg's law can be employed in order to analyse crystal lattice plane distances, a technique found extremely useful in all crystallography fields. Progress in quantum mechanics outlined that the same effect is encountered for matter particles, where Braggs law is satisfied by the de Broglie wavelength of the particle. Utilising Bragg's law, the investigation aimed at quantifying the inter atomic plane distances 100 and 110 for a known lattice using a microwave diffraction setup, and for an unknown graphite powder crystal using an electron diffraction tube.

\section{Theory}

With the discovery of the particle-wave duality of light demonstrated through experiments such as Young's double slit experiment, the field of optics was now equipped with properties applicable to the analysis of crystal atomic structures \cite{youngs\_double\_slit}. Crystallography, the study of crystal atomic lattices, employs the technique of reducing crystal structures into repetitive patterns of atoms named unit cells, basic of which provided in figure 1.

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Unit cells.png}

\end{center}

\caption{Depiction of basic crystal unit cells \cite{askiitians\_crystal\_lattices}}

\end{figure}

Further, a crystal can be described as the summation of unit cells separated by some inter-atomic spacing, usually denoted as a. As demonstrated in figure 1, such a summation leads to multiple atomic planes, lattice cross-sections of identical structure separated by some planer distance d. Such planes are described using a three dimensional (i,j,k) vector normal to the plane, the corresponding components of which being 0 or Miller's indices, 1 or 2 \cite{libretexts\_surface\_science}. The 1,0,0, 1,1,0 and 1,1,1 planes, often denoted without commas, are given as an example in figure 2.

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/100 and 110 planes.png}

\end{center}

\caption{100, 110 and 111 planes of an atomic lattice with displayed $d\_{i,j,k}$ values \cite{springer\_chapter}}

\end{figure}

With the structure of crystals well defined, Australian father and son, W.H. and W.L. Bragg, observed and quantified a method of calculating these plane distances. The Nobel prize winning Bragg law, first published in 1913, reasons that for a fixed X-ray wavelength ($\lambda$) directed at a crystal lattice, the inter-planer distance d can be related to the angle of incident at which constructive interference occurs by the equation:

\[

2dsin\theta = n\lambda

\]

Where n is an integer corresponding to the diffraction order, as such, for known n, $\theta$ and $\lambda$, the inter-atomic plane distance d could be calculated. To understand how Bragg's condition is satisfied in such a case, a geometrical 2D interpretation was produced in figure 3.

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Braggs law.png}

\end{center}

\caption{2D geometry of Braggs law for given d and $\lambda$ \cite{researchgate\_braggs\_law}}

\end{figure}

Given the wavelength of X-rays are comparable to the inter atomic distances of a crystal lattice, it was proposed that the rays would interact with the planes much like visible light does with a mirror \cite{serc\_braggs\_law}. Figure 3 highlights the ray path on which constructive interference occurs, some integer n of the wavelength ($n\lambda$). Additionally, for each ascending order of diffraction, such that the X-ray passes through to the next layer, an extra distance of $2dsin\theta$ is traveled, and thus Bragg's condition outlines this trend.

It became relevant to recognise that for the cubic lattice, the inter planar distances could be recognised as the magnitude of the Miller components, such that:

\[

d\_{i,j,k} = \sqrt{i^2 + j^2 + k^2}\quad thus\quad \frac{d\_{100}}{d\_{110}} = \frac{\sqrt{1^2}}{\sqrt{1^2 + 1^2}} = \frac{1}{\sqrt{2}}

\]

Importantly, the incident X-rays must be both in phase and plane waves. Plane waves entail that a physical property of an electromagnetic wave must remain constant with respect to a plane perpendicular to the direction of motion \cite{nde\_ed\_plane\_waves}. As such, the constructive interference observed in the Bragg condition is only satisfied for plane waves. Further, this fact promoted that the wave generator used in the experiment first be assessed on how well it produced plane waves.

Further to this optical interpretation, in 1924 Louis de Broglie proposed that all matter share lights wave-particle duality \cite{libretexts\_university\_physics}. As such, investigations into how effectively Bragg's law could be utilised with matter as a substitute for X-rays. In order to quantify this relationship, the de Broglie relation is first employed:

\[

\lambda = \frac{h}{p}

\]

Where $\lambda$ is the de Broglie wavelength of the particle, h is Plank's constant and p is the momentum of the particle. For the given experiment, it was understood that the potential difference through which that particle travels, and its momentum are directly proportional. Given it is also known that the energy of an electron is achieved by solving:

\[

E = \frac{P^2}{2m} = eV

\]

We derive to be true:

\[

\lambda = \frac{h}{\sqrt{2eVm}}

\]

Where m is the mass of the electron. We can further derive for practical applications that:

\[

\lambda = \frac{6.626\*10^{-34}}{\sqrt{2\*1.6\*10^{-19}\*9.1\*10^{-31}}}\*\frac{1}{\sqrt{V}}

\]

\[

\lambda[Angstroms] = \frac{3.88\*10^{-10}\*10^{10}}{\sqrt{V}} = \sqrt{\frac{151.3}{V[volts]}}

\]

It was therefore justified that a voltage source on the kV order of magnitude would be used as to result in wavelengths of on the order of 0.1 Angstroms, comparable to that of X-ray wavelengths. For the purpose of this investigation, it was concluded that an electron diffraction tube of powdered graphite would be used to simulate electrons passing through a crystal lattice. Graphite unit cells consist of a hexagonal arrangement of carbon atoms as displayed in figure 4a.

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Graphite unit cells.png}

\includegraphics[width=1\columnwidth]{Images/Powder rings over mixed cells.png}

\end{center}

\caption{(a) Hexagonal unit cell of graphite and (b) 100 and 110 planes of graphite. (c) Formation of powder plane rings as the uniformity of graphite unit cells is decreased \cite{electron6}.}

\end{figure}

Despite this, the experiment was to investigate powdered graphite. In contrast to treating graphite as a repetitive arrangement of hexagonal unit cells, powdered graphite more accurately represents that of naturally forming graphite, such that the although the unit cells represent perfect crystals, the orientation of the cells is not uniform. A completely uniform crystal would form a grid of diffracted electron spots, each corresponding to to a particular diffraction order. However, as arrangement of the unit cells become less symmetrical, powder rings form as displayed in figure 4(c), with each ring representing an atom plane.

As observed in figure 4b, it was hypothesised that the two innermost rings should reflect the first order constructive interference from the 100 and 110 graphite lattice planes, which should be further related by:

\[

d\_{100}^2+(\frac{a}{2})^2 = a^2 \:(1)\quad and \quad d\_{110} = \frac{a}{2}\:(2)

\]

Thus substituting (2) into (1):

\[

d\_{100}^2 + d\_{100}^2 = 4d\_{110}^2 \quad and\: further\quad \frac{d\_{100}}{d\_{110}} = \sqrt{3}

\]

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Apparatus diagram for proof.png}

\end{center}

\caption{Geometric diagram of the electron diffraction apparatus}

\end{figure}

Given the apparatus attains the geometric structure outlined in figure 5, the relationship between the radius observed on the screen, and the inter plane distance d was derived as followed.

\[

2dsin\theta = n\lambda

\]

We observe that $\alpha = 2\theta$. Additionally, given $\alpha$ is sufficiently small for the small angle approximation of sine:

\[

2d\_{i,j,k}\theta = d\_{i,j,k}\alpha = d\_{i,j,k}sin^{-1}(\frac{r\_{i,j,k}}{R}) = d\_{i,j,k}\frac{r\_{i,j,k}}{R} = n\lambda

\]

\[

r\_{i,j,k} = \frac{2R}{d\_{i,j,k}}n\lambda

\]

From this derivation it became apparent that for a given diffraction order and apparatus radius, the relationship between the radius of the constructive ring and the de Broglie wavelength could be linearised. As such, it was hypothesised that the gradient of such an equation could be used to find the inter-plane distance.

\section{Method}

\subsection{Uncertainties}

In order to minimise the uncertainty in the final conclusions drawn, it was observed that the two experiments each contained multiple sources of error. For the microwave diffraction system, it was first noticed that both the angle of the goniometer and the relative position of the lattice had associated uncertainties. Although the goniometer itself was incremented to 1 degree, indicating a device uncertainty of $\pm$0.5 degree, the group collectively justified that human measuring conditions only allowed for measurements accurate to $\pm$1 degree of uncertainty. Additionally, it was reasoned that the uncertainty in the relative angle of the lattice would roughly correlate with that of the goniometer's, however, given the investigation studies the trend between the angle and diffraction order rather than the angle itself, it was justified that the angle uncertainty would result negligible. Finally, the voltmeter used posed uncertainty of 0.005V which prove a potential limitation when determining the angle values at which constructive interference voltage peaks occurred. Despite this, when conducted, the extremely small fluctuations in voltage as well as extra measurements taken around suspected peaks provided reasoning that the construction peak angles could be estimated within reason.

The electron diffraction experiment similarly found three sources of uncertainty. Initial setup of the system informed the uncertainty of the voltage source, such that the analogue dial was only accurate to 0.2kV. Due to the large distances between each increment, such that we could be certain it was above or below a half increment, the group testified that the source could be accurately placed to an uncertainty of $\pm$0.1kV. Additionally, in accordance with the apparatus manual, the radius of the sphere was given to be 130$\pm$5mm. Finally, limitations in the caliper measuring capabilities were identified. Given the difficulties associated with measuring the diffraction radius with calipers over a spherical surface, it was concluded that the inner and outer radius of a given diffraction ring would be recorded to calculate and average value with appropriate uncertainty. Additionally, it was noted that the uncertainty of the caliper was negligible when compared to the uncertainty in the average.

\subsection{Apparatus}

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Microwave diffraction apparatus.png}

\end{center}

\caption{Microwave diffraction experiment labeled apparatus}

\end{figure}

As outlined in figure 6, the microwave diffraction apparatus consisted of a microwave transmitter and receiver pair (1 and 3 respectively), situated on rotating arms of length 60cm, between which was placed a polystyrene atomic lattice simulator (2). The lattice employed a 5x5x4 metal ball array to simulate that of a crystal lattice, with the transmitter producing a 10.5GHz frequency plane microwave. As a result of the plane wave output, it was essential that all experiments conducted maintained that the transmitter and receiver cones be parallel and a total 120cm apart. The lattice was situated atop a goniometer (4) with the rotating arm fixed to the microwave receiver. To finalise the setup, plugged into the receivers banana lead terminals was a voltmeter (5).

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Electron diffraction apparatus.png}

\end{center}

\caption{Electron diffraction experiment labeled apparatus}

\end{figure}

In similar fashion to the apparatus displayed in figure 5, the electron diffraction employs a cathode ray tube to accelerate electrons through a poly-crystalline layer of graphite (3). The cathode ray tube uses high a high voltage node G3 to accelerate the electrons, with the remaining G1, G2 and G4 nodes focusing the electron beam into the graphite layer. The voltage for such nodes was provided by the displayed voltage source with analogue voltage display and shifting dial represented by 1 and 2 respectively. The apparatus displayed the electron diffraction rings onto the circular fluorescent screen (4) which could then be measured using the observed caliper.

\subsection{Procedure}

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Plane wave approximation.png}

\end{center}

\caption{Voltage intensity against angle measurements without lattice for plane wave approximation analysis}

\end{figure}

In order to validate the results of the microwave diffraction experiment, it was first evaluated how successfully the microwave transmitter produced a plane wave. This was achieved by maintaining the setup outlined in figure 6 without the polystyrene lattice. By then recording the voltmeter readings as the goniometer was rotated from 0 to 90 degrees with increments of 10 degrees. It was understood that the resulting uninterrupted microwaves would form a constructive interference pattern indicated by a squared cosine wave. Figure 7 clearly outlines that the receiver voltage only followed such a pattern for the first 45 degrees, as such it was concluded that the experiment would only investigate voltages between 0 and 45 degrees.

Recording the angle at which constructive interference voltage peaks occurred in the microwave diffraction experiment for both the 100 and 110 planes was accurately achieved by first initialising the setup in the same method as the plane wave approximation. However, in separating the parallel receiver and transmitter horns, the lattice was placed with side perpendicular to the horns, such that the orientation was that of a 100 plane. In this position, it was hypothesised that measuring the multimeter voltage across varying angles would allow the construction of an intensity-angle graph with distinct construction peaks for each diffraction order. It was determined that voltage measurements taken every two degrees, with one degree increments added surrounding voltage peaks, would ensure an accurate representation of the diffraction orders. Further, given Braggs law relates to the grazing angle, the angle at which the microwaves encounter the plane from its normal, the complement of the goniometer measurement would be investigated as the angle. Throughout the series of measurements, it was to be ensured that the transmitter-receiver horns remain parallel and 120cm apart.

In order to collect relevant information from the experiment to outline an experimental trend between the radius of the diffraction ring and the wavelength of the electron as previously identified, the follow procedure was conducted. Firstly the voltage supply was connected to the electron diffraction tube and switched on as outlined in figure 7. The voltage modifying dial was adjusted such that the analogue voltmeter read 0kV. Adjustments of the dial revealed that diffraction rings precise and observable enough for measurement only appeared at 2kV. As such, the procedure increased the voltage from 2-5kV's with increments of 0.2kV. At each kV value, the calipers observed in figure 7 were employed to measure the smallest and largest radii for each diffraction order on the fluorescent screen. Following such process, each diffraction order, for each voltage, would have a corresponding inner and outer radius, for which the average could then further be calculated. The predefined nature of the setup, such that the diffraction tube apparatus was unalterable, ensured that all variables remained constant for each voltage, with only the voltage itself being adjustable.

\section{Results}

After conducting the methodology previously outlined, results raw goniometer angle and voltage measurements for the microwave diffraction experiment were compiled into figure 9. As previously justified, the voltage carried an uncertainty of 0.005V.

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Raw microwave diffraction data.png}

\end{center}

\caption{Goniometer angle vs voltage/intensity for microwave diffraction of 100 plane}

\end{figure}

As previously explained, the intensity peaks observed on figure 9 theoretically indicate the constructive interference of different diffraction orders. Given the goniometer angle is the conjugate of the grazing angle (90 - $\theta$), it was deduced that the peaks at 45, 36 and 26 degrees were indicative of the first, second and third diffraction orders respectively. Thus figure 10 was constructed with appropriate grazing angle uncertainties. All lab members justified that the apparent voltage increase before 20 goniometer degrees, over 70 degrees grazing angle, were unexpected results due to environmental factors, specifically, reflection of the microwaves against the metal power point holders identified in figure 6.

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Grazing angle vs n for 100.png}

\end{center}

\caption{Grazing angle against diffraction order for 100 plane given by equation $\theta$ = (9.0$\pm$0.6)n + (36$\pm$1)}

\end{figure}

This same process was conducted for the 110 plane as outlined in the method with results presented in figure 11 and further the grazing angle against diffraction order in figure 12.

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Raw microwave diffraction data for 110.png}

\end{center}

\caption{Raw angle vs voltage/intensity for microwave diffraction of 100 plane}

\end{figure}

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Grazing angle vs n for 110.png}

\end{center}

\caption{Grazing angle against diffraction order for 110 plane given by equation $\theta$ = (9.5$\pm$0.4)n + (31$\pm$1)}

\end{figure}

After the collation of such data, it was apparent that the regressions formed in figures 10 and 12 theoretically represent the relationship previously linearised assuming the small angle approximation for sine.

\[

\theta = \frac{\lambda}{2d}n

\]

And as such:

\[

m = \frac{\lambda}{2d}\quad or \: alternatively \quad d= \frac{\lambda}{2m} = \frac{\frac{c}{f}}{2m}

\]

With appropriate uncertainty given by:

\[

\Delta d = d\sqrt{(\frac{\Delta m}{m})^2}

\]

Conducting this translation, it was calculated that the inter planar distances for the 100 and 110 planes were (0.0016$\pm$0.0001)m and (0.0015$\pm$0.0006)m respectively. This differs considerably from the practically measured 0.035m and 0.0276mm for d100 and d110 respectively.

Direction our attention to the electron diffraction experiment, raw voltage and diameter measurements as outlined in the methodology were processed as follows.

As derived previously, the de Broglie wavelength of the electrons at a particular voltage is given by:

\[

\lambda [Angstroms] = \sqrt{\frac{151.3}{V [volts]}}

\]

Further, the radii for each diffraction ring for a given voltage could be processed as follows:

\[

r\_{i,j,k} = \frac{max.r\_{i,j,k} + min.r\_{i,j,k}}{2}

\]

with corresponding uncertainty:

\[

\Delta r\_{i,j,k} = r\_{i,j,k}\sqrt{(\frac{\Delta max.r\_{i,j,k}}{max.r\_{i,j,k}})^2+(\frac{\Delta min.r\_{i,j,k}}{min.r\_{i,j,k}})^2}

\]

As such, figures 13 and 14 were constructed for the 100 and 110 planes respectively.

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Electron diffraction graph for n = 1.png}

\end{center}

\caption{Wavelength-radius graph for innermost diffraction ring following regression $r\_{100} = (0.64\pm0.01)\lambda + (-0.007\pm0.002)$}

\end{figure}

\begin{figure}[H]

\begin{center}

\includegraphics[width=1\columnwidth]{Images/Electron diffraction graph for n = 2.png}

\end{center}

\caption{Wavelength-radius graph for outermost diffraction ring following regression $r\_{110} = (1.12\pm0.01)\lambda + (-0.012\pm0.003)$}

\end{figure}

Following these findings, as previously outlined, the gradient of such functions would correspond to:

\[

m = \frac{2Rn}{d\_{i,j,k}} \quad and\: so\: follows\quad d\_{i,j,k} = \frac{2Rn}{m}

\]

Importantly, the gradient wavelength must be converted from angstroms to meters and the diffraction order for the inner and outer rings are 1 and 2 respectively. Additionally follows the uncertainty:

\[

\Delta d\_{i,j,k} = d\_{i,j,k}\sqrt{(\frac{\Delta m}{m})^2+(\frac{\Delta R}{R})^2}

\]

Following this method, it was calculated that the graphite sample had 100 and 110 atom plane spacing's of $(4.1\pm0.2)\*10^{-11}$ and $(2.32\pm0.09)\*10^{-11}$ meters respectively.

\section{Discussion}

When comparing the experimentally calculated values for the distance between the 100 and 110 lattice planes using the microwave diffraction experiment outlined, a large discrepancy from the measured values was apparent. The microwave diffraction experiment calculated $d\_{100}$ and $d\_{110}$ values of (1.6$\pm$0.1)mm and (1.5$\pm$0.6)mm respectively, whilst the lattice truly comprised of roughly 38mm and 27.5mm spaced 100 and 110 planes. Additionally, the experimental results also violated the geometric relationship between the 100 and 110 planes, with $d\_{100}\*\sqrt{2} = 0.002$.

The findings indicated clear issues within the methodology. Given the emphasis placed on discussing how accurately the microwave generator approximated a plane wave, such that goniometer angle values were restricted to within 50 degrees, it became evident to the team that one larger sources of error was present. It was reasoned that the metallic wire casings around the experimental setup likely resulted in the reflection and scattering of microwaves, in turn causing unexpected voltage peaks at particular grazing angles. Although the conducted microwave diffraction experiment proved ineffective at calculating any accurate inter planar distance, it was recommended that similar experimental procedure undertaken in a far less reflective environment would likely host the recording of more accurate data. Whilst seemingly a failed result, the experiment identified that in the case of a sample with unknown plane orientation, despite the increase in complexity, the 100 plane could be identified by orienting the sample until the maximum transmission of microwaves is encountered. Further, the experiment also demonstrated that while other plane families, such as (101), can be examined, as the inter-planar distance decreases, the diffraction patterns become harder to resolve, making accurate measurement more challenging.

For the electron diffraction experiment, the particle-like interaction between the traveling electrons and the atomic lattice, in combination with the wave-like interference between multiple electrons, resulted in diffraction rings, with the innermost and second rings corresponding to the 100 and 110 planes first order diffraction's respectively. It was observed that the d100 and d110 of $(4.1\pm0.2)\*10^{-11}$ and $(2.32\pm0.09)\*10^{-11}$ respectively roughly correlate with theoretically accepted values with order of magnitude of $10^{-10}$. Despite slightly deviating from the expected magnitude, the results demonstrated the ratio predicted previously, such that $d\_{110}\*\sqrt{3} = 0.4 \approx d\_{100}$, further supporting standing theory that graphite unit cells are hexagonal in structure. These observations evidently validated the method, specifically informing that the process of taking the average of the radii thickness resulted in extremely accurate values and well reasoned uncertainties.

\section{Conclusion}

The aim of the experiment was to experimentally calculate the inter-planar 100 and 110 distances for a microwave diffraction experiment and an electron diffraction experiment. Analysis determined that the microwave system fell victim to the reflective nature of the experimental environment, as such, predicting $d\_{100}$ and $d\_{110}$ values of (1.6$\pm$0.1)mm and (1.5$\pm$0.6)mm respectively, despite the lattice actually comprised of roughly 38mm and 27.5mm spaced 100 and 110 planes. However, the experiment identified clear practicality for crystallography, such that for a sample with unknown atomic plane orientation, the 100 plane could be located from the position at which light transmission is maximised. Further the electron diffraction experiment proved extremely successful in calculating $d\_{100}$ and $d\_{110}$ of $(4.1\pm0.2)\*10^{-11}$ and $(2.32\pm0.09)\*10^{-11}$ respectively, roughly the same magnitude as that theoretically accepted. The findings further supported the hexagonal crystal structure of graphite, such that the $d\_{100}$ and $d\_{110}$ planes shared a ratio of $\sqrt{3}$:1. Finally, it was concluded that the Bragg diffraction of both experiments, given appropriate setup, methodology and environmental conditions could effectively calculate inter atomic plane distances, an attribute vital in the classification and energy estimation of poly-crystalline samples, protein and biological structure study and geology.

%\section{Bibliography}

%This is where you will give a list of all of your references. Note, you must also use in-text referencing throughout the entire report. This should be done when you use a statement, value, table or figure caption from a source. See below and example of a reference to Ref.~\cite{Ye:96}.

%\begin{thebibliography}{}

%\bibitem{Jun} J. Ye, J. Helmcke, J. L. Hall, B.P. Stoicheff,(1996) “Hyperfine structure and absolute frequency of the $^{87}$RB $5P\_{3/2}$ state,”, Optics Letters, 21(16), p.1280

%\end{thebibliography}

\bibliography{phys2941labreport2}

\end{document}