PHYS2941 Lab report 1

By Samuel Allpass

Theory:

Exercise 1: Using Bohr’s postulates and classical mechanics, show that the total energy of an electron En, with angular momentum n¯h, is proportional to −1/n2 . Derive the full expression including relevant constants.

Exercise 2: Draw a diagram showing the optical paths taken by light of different wavelengths through the spectrometer. Remember that there are collimating lenses in each arm. Explain how and why different wavelengths are dispersed at different angles.

Exercise 3: Explain why a plot of 1/ √ −E, where E are the energies of sodium, against the principle quantum number n is useful. What quantities can be extracted from such a plot?

\documentclass[twocolumn,aps,floatfix,showpacs,prl]{revtex4-2}

\setcounter{secnumdepth}{3}

\usepackage{amsmath}

\usepackage{amssymb}

\usepackage{esint}

\usepackage{graphicx}

\usepackage{bbold}

\usepackage[normalem]{ulem}

\usepackage{setspace}

\usepackage{breakurl}

\usepackage{seqsplit}

\usepackage[hidelinks,colorlinks]{hyperref}

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

\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}

\usepackage{breakurl}

\usepackage{seqsplit}

\usepackage[hidelinks,colorlinks]{hyperref}

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

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

\hypersetup{linkcolor=black}

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

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

\begin{document}

\title{PHYS2041/2941/7141 Lab Report 1}

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\begin{abstract}

The abstract should be no longer than around 150 words or about 900 characters. Keep in mind that the abstract and the introduction should read differently, that is one reason for the abstract to be short. Briefly state what topic was explored in the experiment. State what experiments were done in this investigation, state the final results along side the theoretical value with a reference. The lab report should be no longer than 8 pages, including references. All additional material, such as figures or tables of raw data, or lengthly derivations, should go into appendices, which go beyond the 8 page limit. Now the rest of this text will be copied to show what 150 words or about 900 characters looks like. The abstract should be no longer than around 150 words or about 900 characters. Keep in mind that the abstract and the introduction should read differently.

\end{abstract}

\maketitle

\section{Introduction}

\section{Theory}

Atomic spectroscopy forever changed our understanding of quantum mechanics, posing a new method of determining specific elements within a sample. After Sir Isaac Newton first demonstrated that light from the sun could be separated into a continuous spectrum of colour through an apparatus such as a glass prism or lens in 1666. Demonstrated in figure 1, as a single ray of light passes through varying mediums, it is refracted. This refraction was quantised by Dutch Astronomer Willebrord Snell in 1621 given by Snell's Law \cite{snellsLawBritannica}:

\[

n\_1 sin(\theta\_1) = n\_2 sin(\theta\_2)

\]

Where n and $\theta$ are the refractive indices and angle to the normal of the medium change respectively for mediums 1 and 2.

\begin{figure}[H]

\centering

\includegraphics{Snellslawdiagram.png}

\caption{Diagram depicting refraction of light from medium 1 to 2. Highlights elements in order to solve Snell's law \cite{buRefraction}.}

\label{fig:1}

\end{figure}

Interestingly, the refractive index itself, n, depends on the wavelength of the light ray. As a result, each wavelength of light is refracted a different amount given the mediums and angles of incident remain the same. For white light, this accounts for the continuous spectrum observed by Newton in 1666 and is depicted in figure 2.

\begin{figure}[H]

\centering

\includegraphics[scale=0.75]{refractionofdifferentwavelengths.jpg}

\caption{Diagram depicting refraction of varying wavelengths of light through a prism \cite{buRefraction}.}

\label{fig:2}

\end{figure}

Physicists began using this technique to isolate the wavelengths of light emitted by atoms with electrons in excited states through the use of a spectroscope \cite{timeline\_atomic\_spectroscopy}. As constructed in figure 3, a simple spectroscope consists of two scopes placed around a central prism, which as previously discussed has the purpose of separating some mixed light into into its superimposed components. The first scope consists of a thin slit through which the source light emits. The wave-like nature of light causes the lights to disperse in different directions down the scope as if it were a point source. To rectify this, a collimating lens is positioned in the scope to adjust all the light rays into parallel, such that they all have the same angle of incident compared to the normal of the prism. After passing through the prism, the refracted light is then transferred through another focusing lens to center all the now refracted wavelengths to a single focal point, which is adjusted to exactly reach the observer.

\begin{figure}[H]

\centering

\includegraphics[scale=0.75]{Spectroscopediagram.png}

\caption{Diagram depicting optical paths of different wavelengths of light through spectroscope.}

\label{fig:3}

\end{figure}

In 1859, German phsicist Gustav Kirchoff and Chemist Robert Wilhelm Bunsen realised that the spectral lines emitted from each element were unique, such that the light carried the equivalent energy to the energy difference of the two orbitals it jumped between. After two centuries of appending to the periodic table with this breakthrough, Swedish physicist Johannes Rydberg simplified the Balmer series for hydrogen found just three year prior by the Swiss physicist Johann Balmer in 1885. The Balmer-Rydberg series quantised the frequencies of visible light lines resulting from the atomic spectroscopy of the simplest element hydrogen.

\[

\nu = Rc \left( \frac{1}{m^2} - \frac{1}{n^2} \right)

\]

Where R is the Rydberg constant, c is the speed of light and n is the excited energy level of the valence shell electron above the lower energy level m to which it reduced. Further to this postulate, Niels Bohr proposed the Nobel Prize winning theory of the Bohr model, such that the atom is comprised of a central mass nucleus of protons and neutrons orbited by electrons that can only occupy quantised energy levels. The Bohr model stood to validate the Balmer-Rydberg series for the simple case of the hydrogen atom. More specifically, the model highlighted four governing principles \cite{quantumChemFSU}; electrons occupy particular stable regions of space around the nucleus called "stationary" orbits, each stationary orbit has its own associated energy, the process of an electron jumping from an excited state to lower energy orbital will release a photon, and finally the energy of such a photon will follow:

\[

\Delta E\_{\text{light}} = E\_F - E\_I

\]

Where ${E\_F}$ and ${E\_I}$ are the energies of the final and initial orbitals that the electron occupied respectively. The model details that in the same way that force decreases by an inverse squared ratio, so to does the energy of each orbital, formally we can prove using classical mechanics:

\*Insert Proof\*

\[

E\_n = -R\_H{\frac{1}{n^2}}

\]

Or equivalently:

\[

{\frac{1}{\sqrt{-E}}} = {\frac{1}{\sqrt{R\_H}}}n

\]

\section{Method}

\subsection{Uncertainties}

State all aspects of the experimental process that may have introduced uncertainty to the data. How will this add in uncertainty, how did you attempt to mitigate it, what actual plus or minus $(\pm)$ value did you assign to the experimental data to account for all of this. It is generally worth googling the equipment you are using to see the manufacture's values for uncertainty, do you think when you are conducing the experiment, you will have the same value for uncertainty?

\subsection{Apparatus}

Include a clear image/drawing/diagram that has each component labeled of the experimental setup. Explain what each component is. Any setup notes can be mentioned here.

\subsection{Procedure}

Start your procedure with an introduction sentence that explains what the following procedure will result in. The method should be clear, explicit and concise enough that a peer who has not read the lab sheet for your particular experiment could easily replicate the experiment just from reading your method. Often times, when you write a method, it makes complete sense at the time since you have completed the experiment. It is a good idea to re-read the method a day or two after first writing to check if it still makes sense. So be sure you do not start this component of the report the day it is due. Any mention of measurement/data must have the uncertainty value with it, in addition a justification of the measurement. For example, "The component was displaced in $5\pm1$cm increments between trials, for a total displacement of $50\pm1$cm, this increment size was chosen as to ensure a data spread to show the required effect was visible".

\section{Results}

This is where you include any plots or refined data tables that you acquired from data in the method. Note, raw data is never required to include anywhere in a lab report. Once you have data, you will want to analyse it to find useful values. This may include using an equation from your theory section with data acquired in the experiment. If this is the case, be sure to show either here or in the appendix an example calculation of each equation that is used. When doing a sample calculation, you must show how you propagated your errors. For plots, these should have a brief explanation of what the plot is in addition to an explanation of the process taken from raw data to refined plot.

\begin{table}[tbp]%note, the [h] makes sure the table goes where you want it

\begin{tabular}{ |c|c| }

\hline

Time [s]& Displacement [m]\\

%$[s]$ & $[m]$\\

\hline

0.42 $\pm$ 0.02 & 0.80$\pm$0.03\\

0.47 $\pm$ 0.02 & 1.00$\pm$0.03\\

0.51 $\pm$ 0.02 & 1.20$\pm$0.03\\

0.54 $\pm$ 0.02 & 1.40$\pm$0.03\\

0.59 $\pm$ 0.02 & 1.60$\pm$0.03\\

\hline

\end{tabular}

\caption{Time taken for mass to drop at each distance. [NOTE: this is RAW DATA and should not be included in the report; this is here for demonstration only.] }

\label{Table:time}

\end{table}

\subsection{Linearising Data}

In a lab experiment, you will plot some value against another, this will often show some relationship. This is almost always easier to view/see on a plot rather than a table, see Table \ref{Table:time} versus Fig.~\ref{Fig:time}. These figures/tables show data from the first year experiment "Measuring $g$ from free-fall time of a ball", which you should all be familiar with.

\begin{figure}[bp]

\begin{center}

\includegraphics[width=.9\columnwidth]{tut11.png}

\end{center}

\caption{Fall time at increasing initial displacement.}

\label{Fig:time}

\end{figure}

When it comes to plots, Fig~\ref{Fig:time} is a good example of how they should be presented. Data points clearly within the x and y bounds, error bars, x and y labels, legend, figure number with caption and most importantly, a fitted trend line. From theory, we might know the above data should take the form

\begin{equation}

s=\frac{1}{2} a t^2, \label{eq:1}

\end{equation}

where $s$ is displacement, $t$ is time and $a$ is gravitational acceleration. Then using MATLAB's cftool(x,y) tool (see Fig. \ref{Fig:fit}), we can fit an equation of the form shown in Eq.~\eqref{eq:1}, with an uncertainty value for the coefficient $a$,

\begin{equation}

s=\frac{1}{2} (9.3\pm0.3) t^2 \label{eq:2}

\end{equation}

\begin{figure\*}[tbp]

\begin{center}

\includegraphics[width=15cm]{tut10.png}

\end{center}

\caption{MATLAB curve fitting tool, top red box is input custom equation, bottom red box gives values with uncertainties for the coefficients. }

\label{Fig:fit}

\end{figure\*}

Since this is a simple equation to fit, we can immediately find the value of interest from this fit, that being $a=9.3\pm0.3$. However, extracting values is not always so simple/accurate. To aid in this process, if we know from theory that the data follows some trend, we can attempt to linearise it. This often makes extracting values of interest easier. We can see if we manipulate Eq.~\eqref{eq:1} to look like

\begin{equation}

a=\frac{2 s}{t^2}, \label{eq:3}

\end{equation}

then a plot of displacement multiplied by 2 over time squared will give a constant equal to the gravitational acceleration. The linearised data can be seen in Table~\ref{Table:lin}. Then, from the linear regression shown in Fig.~\ref{Fig:lin}, we get

\begin{table}[bp]

\begin{tabular}{ |c|c| }

\hline

time$^2$& Displacement$\cdot$2\\

$[s^2]$ & $[m]$\\

\hline

0.18$\pm0.01$&1.60$\pm0.06$\\

0.22$\pm0.01$& 2.00$\pm0.06$\\

0.26$\pm0.01$&2.40$\pm0.06$\\

0.29$\pm0.02$&2.80$\pm0.06$\\

0.35$\pm0.02$&3.20$\pm0.06$\\

\hline

\end{tabular}

\caption{Linearised data. [RAW DATA.] }

\label{Table:lin}

\end{table}

\begin{equation}

y=(9.7\pm0.3) x -(0.108\pm0.006). \label{eq:4}

\end{equation}

Note how the value for gravitational acceleration from the linear trend is $a=(9.7\pm0.3)$, while the quadratic fit was $a=(9.3\pm0.3)$. Which one looks like a better value to you?

\begin{figure}[tbp]

\begin{center}

\includegraphics[width=.9\columnwidth]{tut14.png}

\end{center}

\caption{Linearised relation between displacement and time. }

\label{Fig:lin}

\end{figure}

\subsection{Significant figures}

Significant figures are a profoundly important concept to understand when writing a lab report. Take the first entry in Table~\ref{Table:time}, $0.42\pm0.02$. The actual recorded time may have been $0.415689$ seconds, but our measurement devise only has an precision of $\pm0.02$ seconds. This means that any digits in our actual time after the precision of our uncertainty are not significant, which means $0.415689$ goes to $0.042$, where we round based on the uncertainty. Another important use of this is from computations. The linear regression script used to generate Fig.~\ref{Fig:lin} resulted in

\begin{align}

&m=9.6471, \Delta m= 0.30215,\\

&c= -0.10824, \Delta c=0.006482.

\end{align}

We can see that the uncertainly values have far too many digits, these need to be rounded to one significant figure, then the $m$ and $c$ will be rounded to match

\begin{align}

&m=9.6, \Delta m= 0.3,\\

&c= -0.108 , \Delta c=0.007.

\end{align}

Another important concept to consider is keeping consistent in scientific notation. The power of the scientific notation should match, and stay consistent when mentioning this value throughout the report. As such, writing $(1.54 10^4) \pm( 5 10^2)$

is not appropriate. This should instead be written as

$(1.54\pm0.05) \times 10^4$.

\section{Discussion}

In your discussion, you will thoroughly analyse each component of your experiment. Explain what your results are, how do they compare to theory. If the experimental results do not line up with theory, explain why this happened/ what could be done differently to improve the results. This should be a long portion of your report.

\section{Conclusion}

Brief summary of the experiment, state the final results again. Make a link to the big picture, what are the implication/applications of this experiment.

Example citation: \cite{Arrazola\_2020}

%\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{PHYS2941LABREPORT1REF}

~

\newpage

\appendix

\section{What to include in Appendices}

The appendices should start from page No. 11 and should be referred to from the main text. Do not include raw data anywhere in the report, not even in the appendices. In an appendix, you can show an example calculation of each type you used in your report. In addition, you need to show an example error propagation calculation for each calculation type. Make sure you explain the steps in enough detail that the marker can understand; you can assume the marker knows how to do simple calculations.

\end{document}