SCHOOL OF PHYSICS – LEVEL 200 PHYSICS LABORATORY REPORT SLIP

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PARTICULARS								
Name : TAN WEI LIANG								
Matric no. : 22302889								
Group : W2								
Expt. Code : 2OS2								
Expt. Title : DIFFRACTION GRATING SPECTROMETER								
Lecturer in charge : DR. SITI AZRAH MOHAMAD SAMSURI								
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REPORT SUBMISSION FORM

Name	:	TAN WEi LIANG
Partner's Name	:	TAN SHUENN PYNG
Group	:	W2
Experiment Code	:	2OS6
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Lecturer's/Examiner's Name	:	DR. SITI AZRAH MOHAMAD SAMSURI
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DIFFRACTION GRATING SPECTROMETER

By

TAN WEI LIANG

21 December 2024

Second Year Laboratory Report

DIFFRACTION GRATING SPECTROMETER

ABSTRACT

The title of this experiment is **DIFFRACTION GRATING SPECTROMETER**. In this experiment, the focus was on analyzing the bright-line emission spectra of Mercury, Helium, Cadmium, Hydrogen, and Sodium vapor light sources using a diffraction grating spectrometer. Light emitted by these vapor sources was diffracted through a grating, and the angles of the resulting spectral lines were measured. The calculated wavelengths corresponded closely to the known values for each element, validating the quantized nature of atomic electronic transitions. Mercury showed characteristic lines at 431.48 nm (purple), 541.97 nm (green), and 572.40 nm (yellow). Helium exhibited spectral lines at 452.09 nm (blue), 501.32 nm (cyan), and 580.58 nm (yellow). Cadmium showed distinct lines at 468.09 nm (blue), 480.85 nm (light blue), and 510.57 nm (green). Hydrogen exhibited lines at 431.88 nm (blue), 462.25 nm (cyan), and 661.52 nm (red). Finally, for Sodium, a prominent line was observed at a calculated wavelength of 580.20 nm (orange). Minor discrepancies between the calculated and theoretical values were attributed to experimental limitations, including apparatus alignment, angular measurement errors, and challenges in observing faint spectral lines.

ACKNOWLEDGEMENTS

First and foremost, I express my sincere appreciation to DR. SITI AZRAH MOHAMAD SAMSURI, our distinguished lecturer and examiner, for the invaluable guidance and unwavering support extended throughout our scientific exploration. I extend my sincere gratitude to my experiment partner, TAN SHUENN PYNG. His invaluable cooperation and dedication throughout both experiments were instrumental to the success of this project. I appreciate his commitment, expertise, and teamwork, which made these scientific endeavours both productive and enjoyable.

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INTRODUCTION

The purpose of this experiment is to determine the wavelengths of the colors in the emission spectra of sodium, mercury, helium, cadmium, and hydrogen vapor. An emission spectrum is produced when light emitted from an excited gas passes through a diffraction grating. Unlike a continuous spectrum produced by a solid incandescent source, the light emitted from an electric discharge in a rarefied gas of a single element consists of discrete wavelengths, forming a bright-line spectrum. Each line in the emission spectrum corresponds to a unique electronic transition within the atoms of the element, making the pattern of colors characteristic of that element. The light is separated into its spectral components by passing it through a narrow slit and then dispersing it with a diffraction grating. These separated colors, visible as bright lines, provide insight into the atomic structure and energy levels of the element. The focus of this experiment is to analyze and measure the angular positions of these bright lines to calculate their corresponding wavelengths, which will be compared to the known emission lines of sodium, mercury, helium, cadmium, and hydrogen.

THEORY

An incandescent source, such as a hot solid metal filament, produces a continuous spectrum of wavelengths. In contrast, light emitted by an electric discharge in a rarefied gas of a single element contains a limited number of discrete wavelengths, known as an emission or ”bright line” spectrum. The pattern of colors in an emission spectrum is characteristic of the element. These individual colors appear in the form of bright lines because the light, which is separated into the spectrum, usually passes through a narrow slit illuminated by the light source [1].

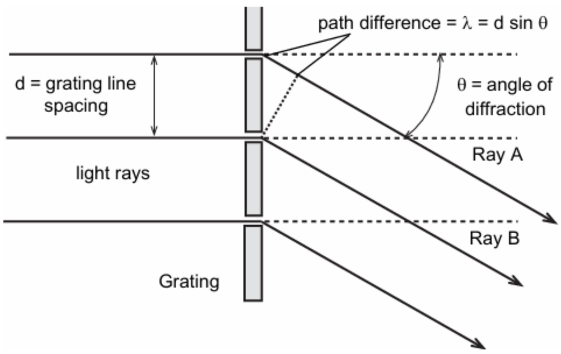


Figure 1: Ray diagram for first order diffraction pattern

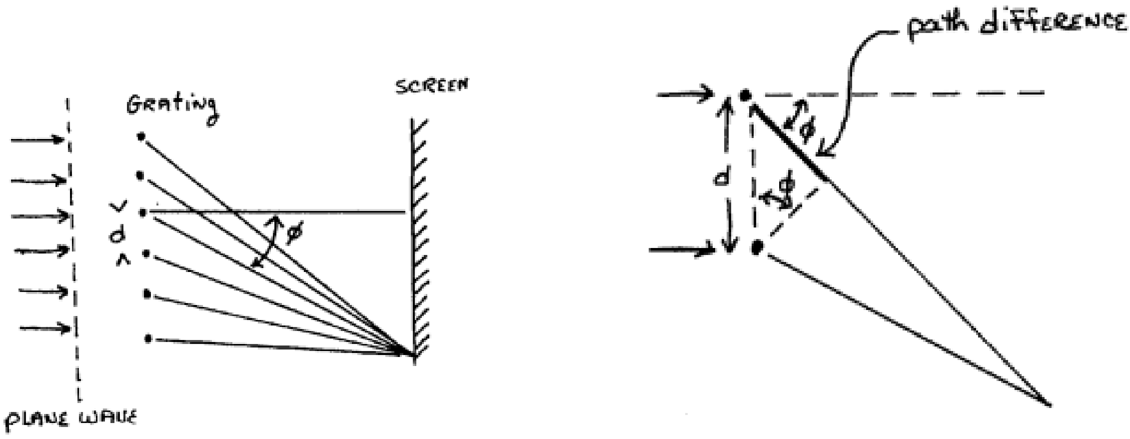
A diffraction grating is a transparent material on which a large number of equally spaced parallel lines have been ruled. The distance between these lines is called the grating line spacing, denoted by d. When light strikes the grating, it is diffracted by these parallel lines. The diffracted light passes through the grating at all angles relative to the original light path. If the diffracted light rays from adjacent lines are in phase, an image of the light source is formed. This happens when the difference in path length between the light rays equals an integral multiple of the wavelength of the light.

The diffraction angle θ, at which light rays are diffracted by the grating, depends on the grating line spacing d and the wavelength λ of the light. The relationship is described by the diffraction equation:

$$\lambda = d \sin\theta$$

This equation allows for the determination of the wavelength λ when the diffraction angle

θ and the grating spacing d are known. In the **Figure 1**, the path difference for Ray A is one wavelength longer than the path difference for Ray B, illustrating the principle of constructive interference at the diffraction grating.



(a) Scattering From Many Grating Lines

(b) Scattering From Two Grating Lines

Figure 2: Scattering diagrams showing the interaction of light waves with a diffraction grating.

The diagrams in Figure 2 illustrate the scattering of light waves from a diffraction grating. Subfigure 2a shows the scattering pattern generated by many grating lines, while Subfigure 2b focuses on the scattering from two grating lines, highlighting the path difference responsible for constructive or destructive interference. These figures provide a foundational understanding of how light interacts with a grating to produce its characteristic diffraction pattern [2].

METHODOLOGY

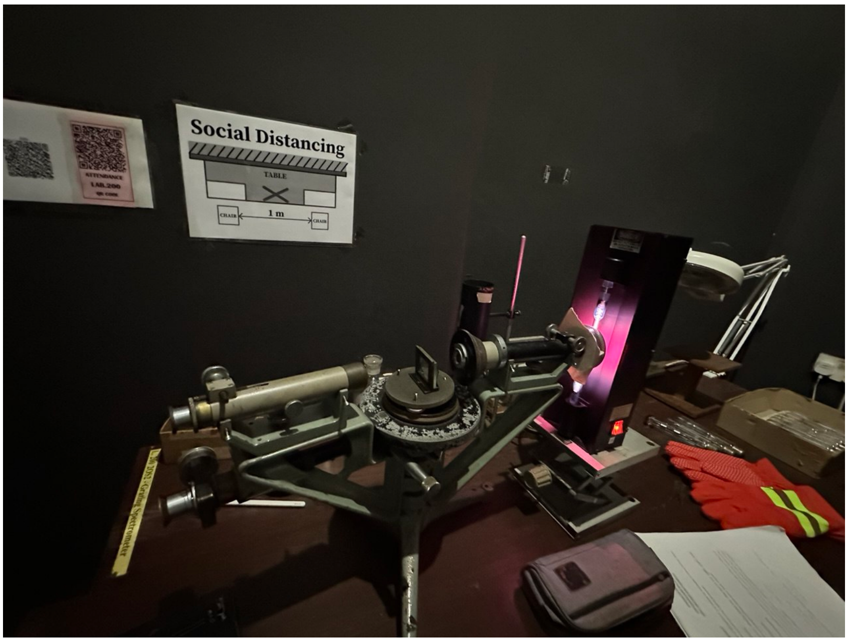


Figure 3: Experimental setup for the diffraction grating spectrometer. The setup includes the spectrometer (center), a light source (right) emitting the spectrum, and a telescope for observing and measuring diffraction angles. The diffraction grating is positioned between the collimator and the telescope to disperse the light into spectral lines.

The experiment involves using a diffraction grating spectrometer to measure the wavelengths of sodium, mercury, helium, cadmium, and hydrogen. The spectrometer is calibrated by first adjusting the telescope to focus on parallel rays and aligning the collimator for parallel light emission. A diffraction grating is then placed perpendicular to the axis of the collimator on the spectrometer table, ensuring proper alignment. The sodium lamp is switched on, and the telescope crosshairs are set on the central image to establish a zero-angle reference. The grating table is leveled, and the angles of diffraction maxima (θ) on both sides of the light spectrum are measured using the Vernier scale. The measured angles are used in the grating equation:

$$m\lambda = d \sin\theta,$$

where d is the grating spacing, calculated as

$$d = \frac{1}{N},$$

with N being the number of lines per millimeter on the grating. m is the order of the diffraction maxima, and λ is the wavelength. The procedure is repeated for mercury, helium, cadmium, and hydrogen discharge lamps. Data analysis includes computing the standard deviation of the wavelengths, comparing experimental wavelengths to standard values, and performing error analysis [3].

DATA ANALYSIS

All data, calculation and programming python code of the experments are attached in the Appendices.

Table 1 presents the spectral line data for various elements, including mercury (Hg), helium (He), cadmium (Cd), hydrogen (H_2), and sodium (Na).

Element	**Color**	m	θ_L (deg)	θ_R (deg)	θ_L (rad)	θ_R (rad)	$\bar{\theta}$ (rad)
Hg	White	0	11°11'30"	11°24'30"	0.195331	0.199113	0.197222
Hg	Purple	1	25°54'30"	26°13'0"	0.452186	0.457567	0.454876
Hg	Green	1	29°47'30"	30°8'30"	0.519963	0.526071	0.523017
Hg	Yellow	1	30°52'50"	31°14'0"	0.538967	0.545125	0.542046
Hg	Purple	2	41°40'50"	42°6'0"	0.727463	0.734784	0.731123
Hg	Green	2	50°39'0"	50°56'30"	0.884009	0.889100	0.886555
Hg	Yellow	2	53°19'0"	53°44'30"	0.930551	0.937969	0.934260
He	Orange	0	11°9'10"	11°22'40"	0.194653	0.198580	0.196616
He	Blue	1	26°36'0"	26°54'0"	0.464258	0.469494	0.466876
He	Cyan	1	28°20'0"	28°38'20"	0.494510	0.499843	0.497176
He	Yellow	1	31°10'30"	31°27'30"	0.544106	0.549051	0.546579
Cd	Cyan	0	11°17'30"	11°32'0"	0.197077	0.201295	0.199186
Cd	Blue	1	27°17'0"	27°38'10"	0.476184	0.482341	0.479263
Cd	Light Blue	1	27°45'0"	28°4'10"	0.484329	0.489904	0.487117
Cd	Green	1	28°47'10"	29°8'10"	0.502412	0.508521	0.505467
H2	Reddish Pink	0	11°7'20"	11°22'10"	0.194119	0.198434	0.196277
H2	Blue	1	25°52'0"	26°10'40"	0.451458	0.456888	0.454173
H2	Cyan	1	26°40'50"	27°29'40"	0.465664	0.479869	0.472766
H2	Red	1	33°39'20"	34°49'40"	0.587400	0.607859	0.597630
Na	Orange	0	11°8'40"	11°23'10"	0.194507	0.198725	0.196616
Na	Orange	1	31°11'0"	31°25'20"	0.544252	0.548421	0.546337

Table 1: Spectral Line Data for Various Elements with $\bar{\theta}$ in Radians.

The data in **Table** 1 highlight clear trends in the diffraction angles $\bar{\theta}$ across multiple spectral lines for various elements. These angles increase with both the diffraction order (m) and the wavelength of the spectral line, which is consistent with the diffraction grating equation:

$$d \sin\theta = m\lambda.$$

For mercury (Hg), the yellow spectral line at first-order diffraction ($m = 1$) has a $\bar{\theta}$ value of 0.542046 rad, while at second-order diffraction ($m = 2$), the angle increases to 0.934260 rad. This demonstrates that higher diffraction orders result in larger angular deviations. For helium (He), the angular measurements of the blue, cyan, and yellow lines show a systematic increase in $\bar{\theta}$ with increasing wavelength.

Similar trends are observed for cadmium (Cd), where the first-order blue and green lines exhibit increasing values of $\bar{\theta}$ at 0.479263 rad and 0.505467 rad, respectively. For hydrogen (H_2), the red line has the largest angle among the observed spectral lines, with $\bar{\theta} = 0.597630$ rad, reflecting its longer wavelength compared to the blue and cyan lines. The sodium (Na) spectral data further support these observations. The first-order orange line exhibits a $\bar{\theta}$ value of 0.546337 rad, which is consistent with its longer wavelength.

Overall, the results validate the relationship between the diffraction angle and the wavelength of light. The consistency across elements and spectral lines demonstrates the reliability of the experimental setup and highlights the effectiveness of diffraction gratings for precise wavelength determination.

Mercury

Table 2 presents the angular measurements, calculated diffraction angles and wavelengths for mercury's spectral lines.

Color	m	θ_L (deg)	θ_R (deg)	θ_L (rad)	θ_R (rad)	$\bar{\theta}$ (rad)	θ (rad)	λ (nm)
White	0	11°11'30"	11°24'30"	0.195331	0.199113	0.197222	0.000000	0
Purple	1	25°54'30"	26°13'0"	0.452186	0.457567	0.454877	0.257655	431.4845
Green	1	29°47'30"	30°8'30"	0.519963	0.526071	0.523017	0.325795	542.4718
Yellow	1	30°52'50"	31°14'0"	0.538967	0.545125	0.542046	0.344824	572.3992
Purple	2	41°40'50"	42°6'0"	0.727463	0.734784	0.731124	0.533902	862.7308
Green	2	50°39'0"	50°56'30"	0.883801	0.888333	0.886067	0.688845	1076.3605
Yellow	2	53°19'0"	53°44'30"	0.930109	0.937297	0.933703	0.736481	1137.3867

Table 2: Spectral Line Data for Mercury (Hg).

Based on **Table** 2 the angular measurements and corresponding diffraction angles for various spectral lines observed in mercury light. The angles θ_L and θ_R were recorded symmetrically on both sides of the light spectrum. These angles were converted into radians, and the average diffraction angle $\bar{\theta}$ was calculated to determine the diffraction angle θ for each spectral line.

The angles θ provided in **Table** 2 are calculated relative to the zeroth-order diffraction peak ($m = 0$), which serves as the reference point for all subsequent diffraction angles. The zeroth-order peak represents the central position where no diffraction occurs, corresponding to $\theta = 0$. The angles θ_L and θ_R measured for higher orders ($m = 1$ and $m = 2$) are absolute deviations from this reference point. By averaging these values, the mean diffraction angle $\bar{\theta}$ accurately represents the position of the spectral lines relative to the zeroth order.

The results show that the diffraction angle θ increases with increasing wavelength λ, which is consistent with the diffraction grating equation $d \sin\theta = m\lambda$. For instance, at $m = 1$, the diffraction angles for the purple, green and yellow lines are **0.257655 rad**, **0.325795 rad** and **0.344824 rad**, corresponding to wavelengths of **431.4845 nm**, **542.4718 nm** and **572.3992 nm**, respectively. For higher orders, such as $m = 2$, the angles increase further, as seen for the purple, green and yellow lines. This trend validates the theoretical expectation that longer wavelengths result in greater diffraction angles.

Table 3 compares the wavelengths calculated from the diffraction measurements with the theoretical (real) values of mercury's spectral lines, along with their percentage difference.

Color	m	**Calculated Wavelength (nm)**	**Real Wavelength (nm)**	**Percentage Difference (%)**
Purple	1	431.4845	435.8328	1.00
Green	1	541.9718	546.0735	0.75
Yellow	1	572.3992	567.7105	0.83

Table 3: Mercury spectrum data with calculated and real wavelengths, and their percentage differences.[4][5]

Based on **Table** 3, a comparison between the calculated wavelengths obtained from the diffraction measurements and the theoretical (real) values of mercury's spectral lines, along with their percentage differences. For purple light, the calculated wavelength is **431.4845 nm**, which is within 1.00% of the real value 435.8328 nm. For green light, the calculated wavelength is **541.9718 nm**, with a minor deviation of 0.75% from the theoretical value 546.0735 nm. Similarly, for yellow light, the calculated wavelength of **572.3992 nm** shows a small difference of 0.83% compared to the real value 567.7105 nm.

Helium

Table 4 presents the angular measurements, calculated diffraction angles, and wavelengths for helium's spectral lines.

Color	m	θ_L (deg)	θ_R (deg)	θ_L (rad)	θ_R (rad)	$\bar{\theta}$ (rad)	θ (rad)	λ (nm)
Orange	0	11°9'10"	11°22'40"	0.194653	0.198580	0.196616	0.0000	0.0000
Blue	1	26°36'0"	26°54'0"	0.464258	0.469494	0.466876	0.2703	452.0885
Cyan	1	28°20'0"	28°38'20"	0.494510	0.499843	0.497176	0.3006	501.3204
Yellow	1	31°10'30"	31°27'30"	0.544106	0.549051	0.546579	0.3500	580.5810

Table 4: Spectral Line Data for Helium (He).

Based on **Table** 4, at $m = 1$, the diffraction angles for blue, cyan, and yellow light are **0.2703 rad**, **0.3006 rad**, and **0.3500 rad**, corresponding to wavelengths of **452.0885 nm**, **501.3204 nm**, and **580.5810 nm**, respectively. These values confirm that longer wavelengths result in larger diffraction angles, as expected.

Table 5 compares the wavelengths calculated from the diffraction measurements with the theoretical (real) values of helium's spectral lines, along with their percentage differences.

Color	**m**	**Calculated Wavelength (nm)**	**Real Wavelength (nm)**	**Percentage Difference (%)**
Blue	1	452.0885	447.1479	1.10
Cyan	1	501.3204	501.5678	0.05
Yellow	1	580.5810	587.5615	1.19

Table 5: Helium spectrum data with calculated and real wavelengths, and their percentage differences.[6][7]

Based on **Table** 5, the calculated wavelengths closely match the real (theoretical) values, with small percentage differences observed. For blue light, the calculated wavelength of **452.0885 nm** deviates by 1.10% from the real value 447.1479 nm. For cyan light, the calculated wavelength of **501.3204 nm** shows excellent agreement with the theoretical value 501.5678 nm, with a negligible percentage difference of 0.05%. Similarly, the yellow light has a calculated wavelength of **580.5810 nm**, which deviates by 1.19% from the real value 587.5615 nm.

Cadmium

Table 6 presents the angular measurements, calculated diffraction angles, and wavelengths for cadmium's spectral lines.

Color	m	θ_L (deg)	θ_R (deg)	θ_L (rad)	θ_R (rad)	$\bar{\theta}$ (rad)	θ (rad)	λ (nm)
Cyan	0	11°17'30"	11°32'0"	0.197077	0.201295	0.199186	0.0000	0.0000
Blue	1	27°17'0"	27°38'10"	0.476184	0.482341	0.479263	0.2801	468.0873
Light Blue	1	27°45'0"	28°4'10"	0.484329	0.489904	0.487117	0.2879	480.8539
Green	1	28°47'10"	29°8'10"	0.502412	0.508521	0.505467	0.3063	510.5651

Table 6: Spectral Line Data for Cadmium (Cd).

Based on **Table 6**, at $m = 1$, the diffraction angles for blue, light blue, and green spectral lines are **0.2801 rad**, **0.2879 rad**, and **0.3063 rad**, corresponding to wavelengths of **468.0873 nm**, **480.8539 nm**, and **510.5651 nm**, respectively. This observation aligns with the theoretical relationship where the diffraction angle increases with increasing wavelength.

Table 7 compares the wavelengths calculated from the diffraction measurements with the theoretical (real) values of cadmium's spectral lines, along with their percentage differences.

Color	**m**	**Calculated Wavelength (nm)**	**Real Wavelength (nm)**	**Percentage Difference (%)**
Blue	1	468.0873	467.8149	0.06
Light Blue	1	480.8539	479.9912	0.18
Green	1	510.5651	508.5822	0.39

Table 7: Cadmium spectrum data with calculated and real wavelengths, and their percentage differences.[8][9]

Based on **Table 7**, the calculated wavelengths closely match the real (theoretical) values of cadmium's spectral lines, with small percentage differences observed. For blue light, the calculated wavelength of **468.0873 nm** deviates by only 0.06% from the real value 467.8149 nm. Similarly, for light blue light, the calculated wavelength of **480.8539 nm** has a small difference of 0.18% compared to the real value 479.9912 nm. The green light shows a calculated wavelength of **510.5651 nm**, with a deviation of 0.39% from the real value 508.5822 nm.

Hydrogen

Table 8 presents the angular measurements, calculated diffraction angles, and wavelengths for hydrogen's spectral lines.

Color	m	θ_L (deg)	θ_R (deg)	θ_L (rad)	θ_R (rad)	$\bar{\theta}$ (rad)	θ (rad)	λ (nm)
Reddish Pink	0	11°7'20"	11°22'10"	0.194119	0.198434	0.196277	0.0000	0.0000
Blue	1	25°52'0"	26°10'40"	0.451458	0.456888	0.454173	0.2579	431.8801
Cyan	1	26°40'50"	27°29'40"	0.465664	0.479869	0.472766	0.2765	462.2460
Red	1	33°39'20"	34°49'40"	0.587400	0.607859	0.597630	0.4014	661.5247

Table 8: Spectral Line Data for Hydrogen (H_2).

Based on **Table** 8, at $m = 1$, the diffraction angles for blue, cyan, and red spectral lines are **0.2579 rad**, **0.2765 rad**, and **0.4014 rad**, corresponding to wavelengths of **431.8801 nm**, **462.2460 nm**, and **661.5247 nm**, respectively. These results clearly show that longer wavelengths correspond to larger diffraction angles, which is consistent with theoretical predictions.

Table 9 compares the calculated wavelengths with the theoretical (real) values of hydrogen's spectral lines and their percentage differences.

Color	**m**	**Calculated Wavelength (nm)**	**Real Wavelength (nm)**	**Percentage Difference (%)**
Blue	1	431.8801	434.0462	0.50
Cyan	1	462.2460	486.1362	4.91
Red	1	661.5247	656.2852	0.80

Table 9: Hydrogen spectrum data with calculated and real wavelengths, and their percentage differences.[10][11]

Based on **Table** 9, the calculated wavelengths are compared with the theoretical values for hydrogen's spectral lines. The results show that the blue light has a calculated wavelength of **431.8801 nm**, which deviates by 0.50% from the real value of 434.0462 nm. For cyan light, the calculated wavelength is **462.2460 nm**, with a larger percentage difference of 4.91% compared to the theoretical value 486.1362 nm. The red light has a calculated wavelength of **661.5247 nm**, showing a small deviation of 0.80% from the real value 656.2852 nm.

Sodium

Table 10 presents the angular measurements, calculated diffraction angles, and wavelengths for sodium's spectral lines.

Color	m	θ_L (deg)	θ_R (deg)	θ_L (rad)	θ_R (rad)	$\bar{\theta}$ (rad)	θ (rad)	λ (nm)
Orange	0	11°8'40"	11°23'10"	0.194507	0.198725	0.196616	0.00000	0.0000
Orange	1	31°11'0"	31°25'20"	0.544252	0.548421	0.546337	0.34972	580.1954

Table 10: Spectral Line Data for Sodium (Na).

Based on **Table** 10, at $m = 1$, the diffraction angle for the orange line is **0.34972 rad**, corresponding to a calculated wavelength of **580.1954 nm**. This observation confirms the relationship where longer wavelengths are associated with larger diffraction angles.

Table 11 compares the calculated wavelength with the theoretical (real) value of sodium's spectral line and the percentage difference.

Color	**m**	**Calculated Wavelength (nm)**	**Real Wavelength (nm)**	**Percentage Difference (%)**
Orange	1	580.1954	588.995	1.49

Table 11: Sodium spectrum data with calculated and real wavelengths, and their percentage differences.[12][13]

Based on **Table** 11, the calculated wavelength for the orange line is **580.1954 nm**, which deviates by 1.49% from the real wavelength of 588.995 nm. This small discrepancy can be attributed to minor uncertainties in the angular measurements, instrumental resolution, or imperfections in the diffraction grating. Despite the minor difference, the experimental results closely align with the theoretical value, validating the diffraction grating method as an accurate tool for measuring spectral line wavelengths.

DISCUSSION

In this experiment, a diffraction grating spectrometer was employed to measure the wavelengths of light emitted by sodium, mercury, helium, cadmium, and hydrogen. The grating equation, $\lambda = m\lambda$, was utilized to calculate the wavelengths, where θ is the diffraction angle, d is the grating spacing, and m represents the diffraction order. This equation provided the foundation for analyzing the diffraction patterns observed.

In the case of **mercury** (*Hg*), the first-order spectral lines for purple, green, and yellow light were measured. The calculated wavelengths were 431.4845 nm, 541.9718 nm, and 572.3992 nm, compared to their respective theoretical values of 435.8328 nm, 546.0735 nm, and 567.7105 nm. The percentage differences were 1.00%, 0.75%, and 0.83%, respectively. These results confirm the experiment's precision, with minor discrepancies arising from small angular reading errors.

For **helium** (*He*), the blue, cyan, and yellow spectral lines were analyzed. The calculated wavelengths were 452.0885 nm, 501.3204 nm, and 580.5810 nm, compared to their theoretical values of 447.1479 nm, 501.5678 nm, and 587.5615 nm. The percentage differences were 1.10%, 0.05%, and 1.19%, respectively. The cyan line showed an exceptional agreement with the theoretical value, confirming the diffraction grating's reliability, while minor deviations for the other lines reflected systematic measurement uncertainties.

For **cadmium** (*Cd*), the blue, light blue, and green lines were observed at $m = 1$. The calculated wavelengths were 468.0873 nm, 480.8539 nm, and 510.5651 nm, compared to their theoretical values of 467.8149 nm, 479.9912 nm, and 508.5822 nm. The corresponding percentage differences were 0.06%, 0.18%, and 0.39%, indicating high precision in the measurements.

For **hydrogen** (H_2), the blue, cyan, and red spectral lines were analyzed. The calculated wavelengths were 431.8801 nm, 462.2460 nm, and 661.5247 nm, with theoretical values of 434.0462 nm, 486.1362 nm, and 656.2852 nm, respectively. The percentage differences were 0.50% for the blue line, 4.91% for the cyan line, and 0.80% for the red line. The larger deviation for the cyan line likely resulted from difficulties in observing faint spectral lines and alignment errors.

For **sodium** (Na), the measured orange spectral line at $m = 1$ produced a calculated wavelength of 580.1954 nm, compared to the theoretical value of 588.995 nm, yielding a percentage difference of 1.49%. This small deviation reflects the method's accuracy, with slight errors attributed to alignment issues and instrumental resolution.

Various sources of error were identified during the experiment. Instrumental factors included potential imperfections or damage to the diffraction grating, which could affect the uniformity of line spacing and introduce inaccuracies in measured angles. The presence of dust on the diffraction grating's lens may have caused unwanted reflections of light, interfering with the clarity and precision of the diffraction pattern. Misalignment of the collimator and telescope also posed a risk to angle measurements, impacting the accuracy of the calculated wavelengths. The inability to adjust the focus of the spectrometer to the actual position of the spectral lines could have further affected the accuracy of the angular readings, leading to minor discrepancies between the calculated and theoretical wavelengths. The low intensity of the light sources contributed to the dimness of the observed spectral lines, making it difficult to clearly identify the boundaries of the light spectrum. This limitation could have introduced errors in measuring the diffraction angles. Environmental influences, such as temperature fluctuations and air currents, altered the refractive index, potentially affecting the diffraction patterns. Human limitations, particularly the eye's reduced sensitivity to dim spectral lines in the red and violet regions, further complicated precise observations.

To address these challenges, several improvements were adopted. Cleaning the dust on diffraction grating glass by using alcohol and cotton swab. Regular calibration of the spectrometer using light sources with known wavelengths ensured systematic errors were identified and corrected. Experiments were conducted in controlled environments to minimize external disturbances like temperature variations and air currents. Sensitive detection equipment, such as photomultiplier tubes or CCDs (Charge-coupled Device), enhanced the visibility of dim spectral lines, compensating for human limitations. Increasing the number of slits in the diffraction grating was another effective strategy, as it sharpened the diffraction maxima and improved the resolution and precision of wavelength measurements.

CONCLUSION

For the Mercury spectrum, the wavelengths are 431.48 nm for purple, 541.97 nm for green, and 572.40 nm for yellow.

For the Helium spectrum, the wavelengths are 452.09 nm for blue, 501.32 nm for cyan, and 580.58 nm for yellow.

For the Cadmium spectrum, the wavelengths are 468.09 nm for blue, 480.85 nm for light blue, and 510.57 nm for green.

For the Hydrogen spectrum, the wavelengths are 431.88 nm for blue, 462.25 nm for cyan, and 661.52 nm for red.

For the Sodium spectrum, the wavelengths are 580.20 nm for orange.

REFERENCES

[1] P. Scientific. *Educational Spectrophotometer System Manual*. https://cdn.pasco.com/product_document/Educational-Spectrophotometer-System-Manual-OS-8539.pdf. Accessed: November 3, 2024. 2017.

[2] S. Cortland. *Physics Laboratory Manual: Experiment 1*. https://web.cortland.edu/wheeler/phy150/Laboratory/Laboratory1.pdf. Accessed: November 3, 2024. Nov. 2024.

[3] Universiti Sains Malaysia (USM). *2OS2 Diffraction Grating Spectrometer Manual*. [Accessed: Dec. 8, 2024]. Dec. 2024.

[4] U. contributions. *Second order spectra vs. first order*. https://physics.stackexchange.com/questions/284394/second-order-spectra-vs-first-order. Accessed: 2024-12-15.

[5] N. I. of Standards and T. (NIST). *Atomic Spectra Database - Mercury Wavelengths*. https://physics.nist.gov/PhysRefData/Handbook/Tables/mercurytable2.htm. Accessed: 2024-12-15.

[6] S. P. Library. *Helium emission and absorption spectra*. https://www.sciencephoto.com/media/673903/view/helium-emission-and-absorption-spectra. Accessed: 2024-12-15.

[7] N. I. of Standards and T. (NIST). *Atomic Spectra Database - Helium Wavelengths*. https://physics.nist.gov/PhysRefData/Handbook/Tables/heliumtable2.htm. Accessed: 2024-12-15.

[8] S. P. Library. *Emission Spectrum of Cadmium*. https://www.sciencephoto.com/media/1674/view/emission-spectrum-of-cadmium. Accessed: 2024-12-15.

[9] N. I. of Standards and T. (NIST). *Atomic Spectra Database - Cadmium Wavelengths*. https://physics.nist.gov/PhysRefData/Handbook/Tables/cadmiumtable2_a.htm. Accessed: 2024-12-15.

[10] U. of Texas at Austin. *Hydrogen Atom Line Spectra*. https://ch301.cm.utexas.edu/section2.php?target=atomic/H-atom/line-spectra.html. Accessed: 2024-12-15.

[11] N. I. of Standards and T. (NIST). *Atomic Spectra Database - Hydrogen Wavelengths*. https://physics.nist.gov/PhysRefData/Handbook/Tables/hydrogentable2.htm. Accessed: 2024-12-15.

[12] L. Gallery. *Sodium Vapor Emission Spectrum*. https://www.lighting-gallery.net/gallery/displayimage.php?album=3248&pos=46&pid=110444. Accessed: 2024-12-15.

[13] N. I. of Standards and T. (NIST). *Atomic Spectra Database - Sodium Wavelengths*. https://physics.nist.gov/PhysRefData/Handbook/Tables/sodiumtable2.htm. Accessed: 2024-12-15.

APPENDICES

Data

```python
import math
import pandas as pd

# Function to convert degrees, minutes, and seconds to radians
def dms_to_radians(degrees, minutes, seconds):
    total_degrees = degrees + minutes / 60 + seconds / 3600
    return math.radians(total_degrees)

# Data for the table
data = [
    ["Hg", "White", 0, (11, 11, 30), (11, 24, 30)],
    ["Hg", "Purple", 1, (25, 54, 30), (26, 13, 0)],
    ["Hg", "Green", 1, (29, 47, 30), (30, 8, 30)],
    ["Hg", "Yellow", 1, (30, 52, 50), (31, 14, 0)],
    ["Hg", "Purple", 2, (41, 40, 50), (42, 6, 0)],
    ["Hg", "Green", 2, (50, 39, 0), (50, 56, 30)],
    ["Hg", "Yellow", 2, (53, 19, 0), (53, 44, 30)],
    ["He", "Orange", 0, (11, 9, 10), (11, 22, 40)],
    ["He", "Blue", 1, (26, 36, 0), (26, 54, 0)],
    ["He", "Cyan", 1, (28, 20, 0), (28, 38, 20)],
    ["He", "Yellow", 1, (31, 10, 30), (31, 27, 30)],
    ["Cd", "Cyan", 0, (11, 17, 30), (11, 32, 0)],
    ["Cd", "Blue", 1, (27, 17, 0), (27, 38, 10)],
    ["Cd", "Light Blue", 1, (27, 45, 0), (28, 4, 10)],
    ["Cd", "Green", 1, (28, 47, 10), (29, 8, 10)],
    ["H2", "Reddish Pink", 0, (11, 7, 20), (11, 22, 10)],
    ["H2", "Blue", 1, (25, 52, 0), (26, 10, 40)],
    ["H2", "Cyan", 1, (26, 40, 50), (27, 29, 40)],
    ["H2", "Red", 1, (33, 39, 20), (34, 49, 40)],
    ["Na", "Orange", 0, (11, 8, 40), (11, 23, 10)],
    ["Na", "Orange", 1, (31, 11, 0), (31, 25, 20)],
]

# Process the data
processed_data = []
for element, color, m, theta_L, theta_R in data:
    theta_L_rad = dms_to_radians(*theta_L)
    theta_R_rad = dms_to_radians(*theta_R)
```

```
        delta_theta_rad = (theta_L_rad + theta_R_rad) / 2
        processed_data.append([element, color, m, theta_L, theta_R, theta_L_rad, theta_R_rad, delta_theta_rad])

# Create a DataFrame
columns = [
    "Element", "Color", "m", "Theta_L (deg)", "Theta_R (deg)", "Theta_L (rad)", "Theta_R (rad)", "Delta Theta (rad)"
]
df = pd.DataFrame(processed_data, columns=columns)

# Display the DataFrame
print(df)
```

Output

```
Element          Color  m Theta_L (deg) Theta_R (deg)  Theta_L (rad)  \
0       Hg          White  0  (11, 11, 30)  (11, 24, 30)       0.195331
1       Hg         Purple  1  (25, 54, 30)   (26, 13, 0)       0.452186
2       Hg          Green  1  (29, 47, 30)   (30, 8, 30)       0.519963
3       Hg         Yellow  1  (30, 52, 50)   (31, 14, 0)       0.538967
4       Hg         Purple  2  (41, 40, 50)    (42, 6, 0)       0.727463
5       Hg          Green  2   (50, 39, 0)  (50, 56, 30)       0.884009
6       Hg         Yellow  2   (53, 19, 0)  (53, 44, 30)       0.930551
7       He         Orange  0   (11, 9, 10)  (11, 22, 40)       0.194653
8       He           Blue  1   (26, 36, 0)   (26, 54, 0)       0.464258
9       He           Cyan  1   (28, 20, 0)  (28, 38, 20)       0.494510
10      He         Yellow  1  (31, 10, 30)  (31, 27, 30)       0.544106
11      Cd           Cyan  0  (11, 17, 30)   (11, 32, 0)       0.197077
12      Cd           Blue  1   (27, 17, 0)  (27, 38, 10)       0.476184
13      Cd     Light Blue  1   (27, 45, 0)   (28, 4, 10)       0.484329
14      Cd          Green  1  (28, 47, 10)   (29, 8, 10)       0.502412
15      H2   Reddish Pink  0   (11, 7, 20)  (11, 22, 10)       0.194119
16      H2           Blue  1   (25, 52, 0)  (26, 10, 40)       0.451458
17      H2           Cyan  1  (26, 40, 50)  (27, 29, 40)       0.465664
18      H2            Red  1  (33, 39, 20)  (34, 49, 40)       0.587400
19      Na         Orange  0   (11, 8, 40)  (11, 23, 10)       0.194507
20      Na         Orange  1   (31, 11, 0)  (31, 25, 20)       0.544252

    Theta_R (rad)  Delta Theta (rad)
0        0.199113           0.197222
1        0.457567           0.454876
2        0.526071           0.523017
3        0.545125           0.542046
4        0.734784           0.731123
5        0.889100           0.886555
6        0.937969           0.934260
7        0.198580           0.196616
8        0.469494           0.466876
9        0.499843           0.497176
10       0.549051           0.546579
11       0.201295           0.199186
12       0.482341           0.479263
13       0.489904           0.487117
14       0.508521           0.505467
15       0.198434           0.196277
```

```
16        0.456888            0.454173
17        0.479869            0.472766
18        0.607859            0.597630
19        0.198725            0.196616
20        0.548421            0.546337
```

Mercury

```python
import math
import pandas as pd

# Data for the table
data = [
    ["White", 0, (11, 11, 30), (11, 24, 30), 0.195331, 0.199113, 0.197222],
    ["Purple", 1, (25, 54, 30), (26, 13, 0), 0.452186, 0.457567, 0.454877],
    ["Green", 1, (29, 47, 30), (30, 8, 30), 0.519963, 0.526071, 0.523017],
    ["Yellow", 1, (30, 52, 50), (31, 14, 0), 0.538967, 0.545125, 0.542046],
    ["Purple", 2, (41, 40, 50), (42, 6, 0), 0.727463, 0.734784, 0.731124],
    ["Green", 2, (50, 39, 0), (50, 56, 30), 0.883801, 0.888333, 0.886067],
    ["Yellow", 2, (53, 19, 0), (53, 44, 30), 0.930109, 0.937297, 0.933703],
]

# Create a DataFrame
columns = [
    "Color", "m", "Theta_L (deg)", "Theta_R (deg)", "Theta_L (rad)", "Theta_R (rad)", "Delta Theta (rad)"
]
df = pd.DataFrame(data, columns=columns)

# Extract Delta Theta for m = 0
delta_theta_m0 = df[df["m"] == 0]["Delta Theta (rad)"].iloc[0]

# Calculate theta for each color
df["Theta (rad)"] = df["Delta Theta (rad)"] - delta_theta_m0

# Grating spacing in nanometers
d_inch = 1 / 15000  # d in inches
d_meter = d_inch * 0.0254  # Convert d to meters
d_nm = d_meter * 1e9  # Convert d to nanometers

# Calculate d * sin(Theta) in nanometers
df["d sin(Theta) (nm)"] = (d_nm * df["Theta (rad)"].apply(math.sin)).round(4)

# Display the updated DataFrame
print(df)
```

Output

```
  Color   m Theta_L (deg) Theta_R (deg)  Theta_L (rad)  Theta_R (rad)  \
0   White  0  (11, 11, 30)  (11, 24, 30)       0.195331       0.199113
1  Purple  1  (25, 54, 30)   (26, 13, 0)       0.452186       0.457567
2   Green  1  (29, 47, 30)   (30, 8, 30)       0.519963       0.526071
3  Yellow  1  (30, 52, 50)   (31, 14, 0)       0.538967       0.545125
4  Purple  2  (41, 40, 50)    (42, 6, 0)       0.727463       0.734784
5   Green  2   (50, 39, 0)  (50, 56, 30)       0.883801       0.888333
6  Yellow  2   (53, 19, 0)  (53, 44, 30)       0.930109       0.937297

   Delta Theta (rad)  Theta (rad)  d sin(Theta) (nm)
0           0.197222     0.000000             0.0000
1           0.454877     0.257655           431.4845
2           0.523017     0.325795           541.9718
3           0.542046     0.344824           572.3992
4           0.731124     0.533902           861.7308
5           0.886067     0.688845          1076.3605
6           0.933703     0.736481          1137.3867
```

Mercury percentage difference

```
import pandas as pd

# Provided data for m = 1
data = {
    "Color": ["Purple", "Green", "Yellow"],
    "m": [1, 1, 1],
    "Calculated Wavelength (nm)": [431.4845, 541.9718, 572.3992],
}

# Add the real wavelength values provided by the user for m = 1
real_values = [435.8328, 546.0735, 567.7105]  # Replace with your actual values
data["Real Wavelength (nm)"] = real_values

# Create a DataFrame
df = pd.DataFrame(data)

# Calculate the percentage difference
df["Percentage Difference (%)"] = (
    abs(df["Calculated Wavelength (nm)"] - df["Real Wavelength (nm)"]) / df["Real Wavelength (nm)"] * 100
).round(2)

# Show only the required columns
result_df = df[["Color", "m", "Calculated Wavelength (nm)", "Real Wavelength (nm)", "Percentage Difference (%)"]]

# Display the result DataFrame
print(result_df)
```

Output

```
  Color   m  Calculated Wavelength (nm)  Real Wavelength (nm)  \
0  Purple  1                    431.4845             435.8328
1   Green  1                    541.9718             546.0735
2  Yellow  1                    572.3992             567.7105

   Percentage Difference (%)
0                      1.00
1                      0.75
2                      0.83
```

Helium

```
import math
import pandas as pd

# Function to convert degrees, minutes, and seconds to radians
def dms_to_radians(degrees, minutes, seconds):
    total_degrees = degrees + minutes / 60 + seconds / 3600
    return math.radians(total_degrees)

# Data for the table
data = [
    ["Orange", 0, (11, 9, 10), (11, 22, 40)],
    ["Blue", 1, (26, 36, 0), (26, 54, 0)],
    ["Cyan", 1, (28, 20, 0), (28, 38, 20)],
    ["Yellow", 1, (31, 10, 30), (31, 27, 30)],
]

# Process the data
processed_data = []
for color, m, theta_L_dms, theta_R_dms in data:
    theta_L_rad = dms_to_radians(*theta_L_dms)
    theta_R_rad = dms_to_radians(*theta_R_dms)
    delta_theta_rad = (theta_L_rad + theta_R_rad) / 2
    processed_data.append([color, m, theta_L_dms, theta_R_dms, theta_L_rad,
  theta_R_rad, delta_theta_rad])

# Create a DataFrame
columns = [
    "Color", "m", "Theta_L (deg)", "Theta_R (deg)", "Theta_L (rad)", "Theta_R
   (rad)", "Delta Theta (rad)"
]
df = pd.DataFrame(processed_data, columns=columns)

# Extract Delta Theta for m = 0
delta_theta_m0 = df[df["m"] == 0]["Delta Theta (rad)"].iloc[0]

# Calculate theta for each color
df["Theta (rad)"] = df["Delta Theta (rad)"] - delta_theta_m0

# Grating spacing in nanometers
d_inch = 1 / 15000  # d in inches
```

```python
d_meter = d_inch * 0.0254  # Convert d to meters
d_nm = d_meter * 1e9  # Convert d to nanometers

# Calculate d * sin(Theta) in nanometers
df["d sin(Theta) (nm)"] = (d_nm * df["Theta (rad)"].apply(math.sin)).round(4)

# Display the updated DataFrame
print(df)
```

Output

```
Color  m Theta_L (deg) Theta_R (deg)  Theta_L (rad)  Theta_R (rad)  \
0  Orange  0   (11, 9, 10)  (11, 22, 40)       0.194653       0.198580
1    Blue  1   (26, 36, 0)   (26, 54, 0)       0.464258       0.469494
2    Cyan  1   (28, 20, 0)  (28, 38, 20)       0.494510       0.499843
3  Yellow  1  (31, 10, 30)  (31, 27, 30)       0.544106       0.549051

   Delta Theta (rad)  Theta (rad)  d sin(Theta) (nm)
0           0.196616     0.000000             0.0000
1           0.466876     0.270259           452.0885
2           0.497176     0.300560           501.3204
3           0.546579     0.349963           580.5810
```

Helium percentage difference

```python
import pandas as pd

# Provided data for m = 1
data = {
    "Color": ["Blue", "Cyan", "Yellow"],
    "m": [1, 1, 1],
    "Calculated Wavelength (nm)": [452.0885,501.3204,580.5810]
}

# Real wavelength values for m = 1
real_values = [447.1479,501.5678,587.5615]  # Replace with actual values

# Create a DataFrame
df = pd.DataFrame(data)

# Add real wavelength values
df["Real Wavelength (nm)"] = real_values

# Calculate the percentage difference
df["Percentage Difference (%)"] = (
    abs(df["Calculated Wavelength (nm)"] - df["Real Wavelength (nm)"]) / df["
  Real Wavelength (nm)"] * 100
).round(2)

# Display the DataFrame
print(df)
```

Output

```python
import pandas as pd

# Provided data for m = 1
data = {
    "Color": ["Blue", "Cyan", "Yellow"],
    "m": [1, 1, 1],
    "Calculated Wavelength (nm)": [452.0885,501.3204,580.5810]
}

# Real wavelength values for m = 1
real_values = [447.1479,501.5678,587.5615]  # Replace with actual values

# Create a DataFrame
df = pd.DataFrame(data)

# Add real wavelength values
df["Real Wavelength (nm)"] = real_values

# Calculate the percentage difference
df["Percentage Difference (%)"] = (
    abs(df["Calculated Wavelength (nm)"] - df["Real Wavelength (nm)"]) / df["Real Wavelength (nm)"] * 100
).round(2)

# Display the DataFrame
print(df)
```

Cadmium

```
import math
import pandas as pd

# Function to convert degrees, minutes, and seconds to radians
def dms_to_radians(degrees, minutes, seconds):
    total_degrees = degrees + minutes / 60 + seconds / 3600
    return math.radians(total_degrees)

# Data for the table
data = [
    ["Cyan", 0, (11, 17, 30), (11, 32, 0)],
    ["Blue", 1, (27, 17, 0), (27, 38, 10)],
    ["Light Blue", 1, (27, 45, 0), (28, 4, 10)],
    ["Green", 1, (28, 47, 10), (29, 8, 10)],
]

# Process the data
processed_data = []
for color, m, theta_L_dms, theta_R_dms in data:
    theta_L_rad = dms_to_radians(*theta_L_dms)
    theta_R_rad = dms_to_radians(*theta_R_dms)
    delta_theta_rad = (theta_L_rad + theta_R_rad) / 2
    processed_data.append([color, m, theta_L_dms, theta_R_dms, theta_L_rad,
  theta_R_rad, delta_theta_rad])

# Create a DataFrame
columns = [
    "Color", "m", "Theta_L (deg)", "Theta_R (deg)", "Theta_L (rad)", "Theta_R
  (rad)", "Delta Theta (rad)"
]
df = pd.DataFrame(processed_data, columns=columns)

# Extract Delta Theta for m = 0
delta_theta_m0 = df[df["m"] == 0]["Delta Theta (rad)"].iloc[0]

# Calculate theta for each color
df["Theta (rad)"] = df["Delta Theta (rad)"] - delta_theta_m0

# Grating spacing in nanometers
d_inch = 1 / 15000  # d in inches
```

```
d_meter = d_inch * 0.0254  # Convert d to meters
d_nm = d_meter * 1e9  # Convert d to nanometers

# Calculate d * sin(Theta) in nanometers
df["d sin(Theta) (nm)"] = (d_nm * df["Theta (rad)"].apply(math.sin)).round(4)

# Display the updated DataFrame
print(df)
```

Output

```
Color  m Theta_L (deg) Theta_R (deg)  Theta_L (rad)  Theta_R (rad)  \
0        Cyan  0  (11, 17, 30)   (11, 32, 0)       0.197077       0.201295
1        Blue  1   (27, 17, 0)  (27, 38, 10)       0.476184       0.482341
2  Light Blue  1   (27, 45, 0)   (28, 4, 10)       0.484329       0.489904
3       Green  1  (28, 47, 10)   (29, 8, 10)       0.502412       0.508521

   Delta Theta (rad)  Theta (rad)  d sin(Theta) (nm)
0           0.199186     0.000000             0.0000
1           0.479263     0.280077           468.0873
2           0.487117     0.287931           480.8539
3           0.505467     0.306281           510.5651
```

Cadmium percentage difference

```
import pandas as pd

# Provided data for m = 1
data = {
    "Color": ["Blue", "Light Blue", "Green"],
    "m": [1, 1, 1],
    "Calculated Wavelength (nm)": [468.0873, 480.8539, 510.5651]
}

# Real wavelength values for m = 1
real_values = [467.8149, 479.9912, 508.5822]  # Replace with actual real
  values

# Create a DataFrame
df = pd.DataFrame(data)

# Add real wavelength values
df["Real Wavelength (nm)"] = real_values

# Calculate the percentage difference
df["Percentage Difference (%)"] = (
    abs(df["Calculated Wavelength (nm)"] - df["Real Wavelength (nm)"]) / df["
  Real Wavelength (nm)"] * 100
).round(2)

# Display the result DataFrame
print(df)
```

Output

```
Color  m  Calculated Wavelength (nm)  Real Wavelength (nm)  \
0        Blue  1                    468.0873              467.8149
1  Light Blue  1                    480.8539              479.9912
2       Green  1                    510.5651              508.5822

   Percentage Difference (%)
0                       0.06
1                       0.18
2                       0.39
```

Hydrogen

```
import math
import pandas as pd

# Function to convert degrees, minutes, and seconds to radians
def dms_to_radians(degrees, minutes, seconds):
    total_degrees = degrees + minutes / 60 + seconds / 3600
    return math.radians(total_degrees)

# Data for the table
data = [
    ["Reddish Pink", 0, (11, 7, 20), (11, 22, 10)],
    ["Blue", 1, (25, 52, 0), (26, 10, 40)],
    ["Cyan", 1, (26, 40, 50), (27, 29, 40)],
    ["Red", 1, (33, 39, 20), (34, 49, 40)],
]

# Process the data
processed_data = []
for color, m, theta_L_dms, theta_R_dms in data:
    theta_L_rad = dms_to_radians(*theta_L_dms)
    theta_R_rad = dms_to_radians(*theta_R_dms)
    delta_theta_rad = (theta_L_rad + theta_R_rad) / 2
    processed_data.append([color, m, theta_L_dms, theta_R_dms, theta_L_rad, theta_R_rad, delta_theta_rad])

# Create a DataFrame
columns = [
    "Color", "m", "Theta_L (deg)", "Theta_R (deg)", "Theta_L (rad)", "Theta_R (rad)", "Delta Theta (rad)"
]
df = pd.DataFrame(processed_data, columns=columns)

# Extract Delta Theta for m = 0
delta_theta_m0 = df[df["m"] == 0]["Delta Theta (rad)"].iloc[0]

# Calculate theta for each color
df["Theta (rad)"] = df["Delta Theta (rad)"] - delta_theta_m0

# Grating spacing in nanometers
d_inch = 1 / 15000  # d in inches
```

```
d_meter = d_inch * 0.0254  # Convert d to meters
d_nm = d_meter * 1e9  # Convert d to nanometers

# Calculate d * sin(Theta) in nanometers
df["d sin(Theta) (nm)"] = (d_nm * df["Theta (rad)"].apply(math.sin)).round(4)

# Display the updated DataFrame
print(df)
```

Output

```
Color   m Theta_L (deg) Theta_R (deg)  Theta_L (rad)  Theta_R (rad)  \
0  Reddish Pink  0    (11, 7, 20)  (11, 22, 10)       0.194119       0.198434
1          Blue  1    (25, 52, 0)  (26, 10, 40)       0.451458       0.456888
2          Cyan  1   (26, 40, 50)  (27, 29, 40)       0.465664       0.479869
3           Red  1   (33, 39, 20)  (34, 49, 40)       0.587400       0.607859

   Delta Theta (rad)  Theta (rad)  d sin(Theta) (nm)
0           0.196277     0.000000             0.0000
1           0.454173     0.257897           431.8801
2           0.472766     0.276489           462.2460
3           0.597630     0.401353           661.5247
```

Hydrogen percentage difference

```python
import pandas as pd

# Provided data for m = 1
data = {
    "Color": ["Blue", "Cyan", "Red"],
    "m": [1, 1, 1],
    "Calculated Wavelength (nm)": [431.8801, 462.2460, 661.5247]
}

# Real wavelength values for m = 1
real_values = [434.0462, 486.1362, 656.2852]  # Replace with actual real values

# Create a DataFrame
df = pd.DataFrame(data)

# Add real wavelength values
df["Real Wavelength (nm)"] = real_values

# Calculate the percentage difference
df["Percentage Difference (%)"] = (
    abs(df["Calculated Wavelength (nm)"] - df["Real Wavelength (nm)"]) / df["Real Wavelength (nm)"] * 100
).round(2)

# Display the result DataFrame
print(df)
```

Output

```
Color  m  Calculated Wavelength (nm)  Real Wavelength (nm)  \
0  Blue  1                    431.8801              434.0462
1  Cyan  1                    462.2460              486.1362
2   Red  1                    661.5247              656.2852

   Percentage Difference (%)
0                       0.50
1                       4.91
2                       0.80
```

Sodium

```
import math
import pandas as pd

# Function to convert degrees, minutes, and seconds to radians
def dms_to_radians(degrees, minutes, seconds):
    total_degrees = degrees + minutes / 60 + seconds / 3600
    return math.radians(total_degrees)

# Data for the table
data = [
    ["Orange", 0, (11, 8, 40), (11, 23, 10)],
    ["Orange", 1, (31, 11, 0), (31, 25, 20)],
]

# Process the data
processed_data = []
for color, m, theta_L_dms, theta_R_dms in data:
    theta_L_rad = dms_to_radians(*theta_L_dms)
    theta_R_rad = dms_to_radians(*theta_R_dms)
    delta_theta_rad = (theta_L_rad + theta_R_rad) / 2
    processed_data.append([color, m, theta_L_dms, theta_R_dms, theta_L_rad, theta_R_rad, delta_theta_rad])

# Create a DataFrame
columns = [
    "Color", "m", "Theta_L (deg)", "Theta_R (deg)", "Theta_L (rad)", "Theta_R (rad)", "Delta Theta (rad)"
]
df = pd.DataFrame(processed_data, columns=columns)

# Extract Delta Theta for m = 0
delta_theta_m0 = df[df["m"] == 0]["Delta Theta (rad)"].iloc[0]

# Calculate theta for each color
df["Theta (rad)"] = df["Delta Theta (rad)"] - delta_theta_m0

# Grating spacing in nanometers
d_inch = 1 / 15000  # d in inches
d_meter = d_inch * 0.0254  # Convert d to meters
d_nm = d_meter * 1e9  # Convert d to nanometers
```

```

# Calculate d * sin(Theta) in nanometers
df["d sin(Theta) (nm)"] = (d_nm * df["Theta (rad)"].apply(math.sin)).round(4)

# Display the updated DataFrame
print(df)
```

Output

```
Color  m Theta_L (deg) Theta_R (deg)  Theta_L (rad)  Theta_R (rad)  \
0  Orange  0   (11, 8, 40)  (11, 23, 10)       0.194507       0.198725
1  Orange  1   (31, 11, 0)  (31, 25, 20)       0.544252       0.548421

   Delta Theta (rad)  Theta (rad)  d sin(Theta) (nm)
0           0.196616      0.00000             0.0000
1           0.546337      0.34972           580.1954
```

Sodium percentage difference

```
import pandas as pd

# Provided data for m = 1
data = {
    "Color": ["Orange"],
    "m": [1],
    "Calculated Wavelength (nm)": [580.1954]
}

# Real wavelength value for m = 1
real_values = [588.9950]  # Replace with actual real value

# Create a DataFrame
df = pd.DataFrame(data)

# Add real wavelength value
df["Real Wavelength (nm)"] = real_values

# Calculate the percentage difference
df["Percentage Difference (%)"] = (
    abs(df["Calculated Wavelength (nm)"] - df["Real Wavelength (nm)"]) / df["
  Real Wavelength (nm)"] * 100
).round(2)

# Display the result DataFrame
print(df)
```

Output

```
Color  m  Calculated Wavelength (nm)  Real Wavelength (nm)  \
0  Orange  1                    580.1954                588.995

   Percentage Difference (%)
0                       1.49
```