五、实验数据处理

1.计算光栅常数d，并计算不确定度u(d)

(1)原始数据记录表格

测量级次 / 测量次数	−1级		+1级		$2\theta_1=\frac{1}{2}[(\alpha_1-\beta_1)-(\alpha_2-\beta_2)]$
	α_1	β_1	α_2	β_2	
1	156.47°	336.5°	136.37°	316.3°	20.250°
2	219.05°	39.04°	198.42°	18.42°	20.375°
3	290.59°	110.55°	270.37°	90.33°	20.367°
4	353.24°	173.23°	333.01°	153.0°	20.383°
5	52.05°	232.08°	31.45°	211.46°	20.350°

−2级		+2级		$2\theta_2=\frac{1}{2}[(\alpha_1-\beta_1)-(\alpha_2-\beta_2)]$
α_1	β_1	α_2	β_2	
62.35°	242.29°	21.1°	201.12°	41.35°

(2)计算光栅常数d

$$\overline{2\theta_1}=\frac{\sum_{k=1}^{5}2\theta_1}{5}=20.345^\circ$$

$$\overline{\theta_1}=\frac{1}{2}\,\overline{2\theta_1}=0.1775rad$$

$$\overline{\theta_2}=\frac{1}{2}\,\overline{2\theta_2}=0.3608rad$$

由 $d\sin\theta=k\lambda$,取 $k=1$ 得 $d=\dfrac{\lambda}{\sin\theta_1}$

又钠黄光 $\lambda=589.3mm$

$$\therefore\ d=\frac{\lambda}{\sin\theta_1}=3.337\mu m$$

取 $k=2$得 $d'=\dfrac{2\lambda}{\sin\theta_2}=3.338\mu m$

(3)计算不确定度u(d)

1. ±1级d的不确定度

$$u_a(\overline{2\theta})=\sqrt{\frac{\sum_{i=1}^{5}(2\theta_i-\overline{2\theta_1})^2}{5\times4}}=0.000426rad$$

$$u_b(\overline{2\theta})=\frac{1}{\sqrt{3}}=0.000168rad$$

$$\text{不确定度合成为 } u(\overline{2\theta}) = \sqrt{u_a^2(\overline{2\theta}) + u_b^2(\overline{2\theta})} = 0.000457rad$$

$$u(\overline{\theta_1}) = \frac{1}{2}\ u(\overline{2\theta_1}) = 2.287\times10^{-4}rad$$

$$\text{由 } d = \frac{\lambda}{\sin\theta_1} \text{有 } \ln d = \ln\lambda - \ln\sin\theta_1$$

$$\text{相对不确定度 } \frac{u(d)}{d} = \sqrt{\left[\frac{\partial \ln\sin\theta_1}{\partial\theta_1}\ u(\theta_1)\right]^2} = \sqrt{\left[\frac{u(\theta_1)}{\tan\theta_1}\right]^2} = 1.275\times10^{-3}rad$$

$$\therefore\ u(d) = d\ \frac{u(d)}{d} = 0.00425\mu m$$

2. ±2级d的不确定度

$$\text{由 } d' = \frac{\lambda}{\sin\theta_2} \text{有 } \ln d' = \ln\lambda - \ln\sin\theta_2$$

$$\text{而 } u(2\theta_2) = u_b(2\theta_2) = \frac{1'}{\sqrt{3}} = 0.00962^\circ = 0.000168rad$$

$$\therefore u(\theta_2) = \frac{1}{2}\ u(2\theta_2) = 0.00481^\circ = 8.395\times10^{-5}rad$$

$$\therefore \text{相对不确定度 } \frac{u(d')}{d'} = \sqrt{\left[\frac{\partial \ln\sin\theta_2}{\partial\theta_2}\ u(\theta_2)\right]^2} = \sqrt{\left[\frac{u(\theta_2)}{\tan\tan_2}\right]^2} = 2.225\times10^{-4}$$

$$\therefore\ u(d') = d'\ \frac{u(d')}{d'} = 0.0007428\mu m$$

(4)测量结果加权平均求d最佳值

测量结果：

$$d \pm u(d) = (3.337 \pm 0.004)\mu m$$

$$d' \pm u(d') = (3.338 \pm 0.001)\mu m$$

$$\overline{d} = \frac{\frac{d}{u^2(d)} + \frac{d'}{u^2(d')}}{\frac{1}{u^2(d)} + \frac{1}{u^2(d')}} = 3.338\mu m$$

$$u^2(\overline{d}) = \frac{1}{\frac{1}{u^2(d)} + \frac{1}{u^2(d')}} = 5.354\times10^{-7}\mu m^2$$

$$\therefore\ u(\overline{d}) = 7.3\times10^{-4}\mu m$$

$$\therefore \text{光栅常数d的最终表达式为 } \overline{d} \pm u(\overline{d}) = (3.338 \pm 0.001)\mu m$$

2.计算氢原子的里德伯常数$R_H + u(R_H)$;并通过加权平均获得R_H的最佳值$\overline{R_H} \pm u(\overline{R_H})$

巴耳末系:

$$\frac{1}{\lambda} = R_H\ \left(\frac{1}{2^2} - \frac{1}{n^2}\right)(n = 3, 4, 5, 6\dots)$$

当 $n = 3$ 时，光谱颜色为红光; 当 $n = 5$ 时，光谱颜色为蓝光; 当 $n = 6$ 时，光谱颜色为紫光;

以下将分别计算红光，蓝光，紫光对应的R_H:

(1)红光

测量级次 / 测量次数	−1级		+1级		$2\theta_\gamma=\frac{1}{2}[(\alpha_1-\beta_1)-(\alpha_2-\beta_2)]$
	α_1	β_1	α_2	β_2	
1	53.15°	233.19°	30.33°	210.34°	22.725°
2	117.55°	297.59°	95.17°	275.16°	22.675°
3	183.11°	3.12°	160.29°	340.31°	22.692°
4	249.01°	69.0°	226.19°	46.18°	22.700°
5	311.31°	131.29°	288.49°	108.47°	22.700°

1.

$$\overline{2\theta_\gamma}=\frac{\sum_{k=1}^{5}2\theta_\gamma}{5}=0.3962rad$$

$$\text{由 } d\sin\theta=\lambda \text{ 得 } \lambda_\gamma=d\sin\theta_\gamma=d\sin\frac{\overline{2\theta_\gamma}}{2}=656.904nm$$

$$\text{在巴耳末系中对应n取3，有 } \frac{1}{\lambda_\gamma}=R_{H_1}\left(\frac{1}{2^2}-\frac{1}{3^2}\right)$$

$$\therefore\ R_{H_1}=\frac{1}{\lambda_\gamma}\left(\frac{1}{2^2}-\frac{1}{3^2}\right)=1.096051\times10^7m^{-1}$$

2. 不确定度的计算

$$u_a(\overline{2\theta_\gamma})=\sqrt{\frac{\sum_{i=1}^{5}(2\theta_{\gamma_i}-\overline{2\theta_\gamma])^2}}{5\times4}}=1.4101\times10^{-4}rad$$

$$u_b(\overline{2\theta})=\frac{1}{\sqrt{3}}=9.6225\times10^{-3}=1.679\times10^{-4}rad$$

$$\therefore \text{不确定度合成为 } u(\overline{2\theta_\gamma})=\sqrt{u_a^2(\overline{2\theta_\gamma})+u_b^2(\overline{2\theta_\gamma})}=2.1929\times10^{-4}rad$$

$$u(\overline{\theta_\gamma})=\frac{1}{2}\,u(\overline{2\theta_\gamma})=1.0965\times10^{-4}rad$$

$$\therefore\theta_\gamma\pm u(\theta_\gamma)=(0.1981\pm0.0001)rad$$

$$\text{而 } R_{H_1}=\frac{1}{\lambda_\gamma}\left(\frac{1}{2^2}-\frac{1}{3^2}\right)=\frac{7.2}{d\sin\theta_\gamma}$$

$$\therefore\ln R_{H_1}=\ln7.2-\ln d-\ln d\sin\theta_\gamma$$

$$\therefore\frac{u(R_{H_1})}{R_{H_1}}=\sqrt{\left[\frac{\partial\ln d}{\partial d}\,u(d)\right]^2+\left[\frac{\partial\ln\sin\theta_\gamma}{\partial\theta_\gamma}\,u(\theta_\gamma)\right]^2}=\sqrt{\left[\frac{u(d)}{d}\right]^2+\left[\frac{u(\theta_\gamma)}{\tan\theta_\gamma}\right]^2}=5.8863\times10^{-4}$$

$$\therefore\ u(R_{H_1})=R_{H_1}\,\frac{u(R_{H_1})}{R_{H_1}}=6.45167818\times10^3$$

$$R_{H_1}\pm u(R_{H_1})=(1.0961\pm0.0006)\times10^7m^{-1}$$

测量级次 / 测量次数	-1级		$+1$级		$2\theta_b=\frac{1}{2}\left[(\alpha_1-\beta_1)-(\alpha_2-\beta_2)\right]$
	α_1	β_1	α_2	β_2	
1	50.18°	230.2°	33.31°	213.33°	16.783°
2	114.57°	295.0°	98.1°	278.12°	16.792°
3	180.15°	0.14°	163.28°	343.29°	16.767°
4	246.04°	66.02°	229.18°	49.16°	16.767°
5	308.32°	128.31°	291.48°	111.42°	16.775°

(2)蓝光(深绿)

1.

$$\overline{2\theta_b}=\frac{\sum_{k=1}^{5}2\theta_b}{5}=0.29281rad$$

$$\text{由 } d\sin\theta=\lambda \text{ 得 } \lambda_b=d\sin\theta_b=d\sin\frac{\overline{2\theta_b}}{2}=486.973\mu m$$

$$\text{在巴耳末系中对应n取4，有 } \frac{1}{\lambda_b}=R_{H_2}\left(\frac{1}{2^2}-\frac{1}{4^2}\right)$$

$$\therefore\ R_{H_2}=\frac{1}{\lambda_b}\left(\frac{1}{2^2}-\frac{1}{4^2}\right)=1.0952\times10^7m^{-1}$$

2. 不确定度的计算

$$u_a(\overline{2\theta_b})=\sqrt{\frac{\sum_{i=1}^{5}(2\theta_{b_i}-\overline{2\theta_{\gamma]})^2}}{5\times4}}=8.48078\times10^{-5}rad$$

$$u_b(\overline{2\theta})=\frac{1}{\sqrt{3}}=9.6225\times10^{-3}=1.679\times10^{-4}rad$$

$$\therefore \text{不确定度合成为 } u(\overline{2\theta_b})=\sqrt{u_a^2(\overline{2\theta_b})+u_b^2(\overline{2\theta_b})}=1.88143\times10^{-4}rad$$

$$u(\overline{\theta_b})=\frac{1}{2}\ u(\overline{2\theta_b})=9.40713\times10^{-5}rad$$

$$\therefore \theta_b\pm u(\theta_b)=(0.14640\pm0.00009)$$

$$\text{而 } R_{H_2}=\frac{1}{\lambda_b}\left(\frac{1}{2^2}-\frac{1}{4^2}\right)=\frac{5.333}{d\sin\theta_b}$$

$$\therefore \ln R_{H_2}=\ln5.333-\ln d-\ln d\sin\theta_b$$

$$\therefore \frac{u(R_{H_2})}{R_{H_2}}=\sqrt{\left[\frac{\partial\ln d}{\partial d}\ u(d)\right]^2+\left[\frac{\partial\ln\sin\theta_b}{\partial\theta_b}\ u(\theta_b)\right]^2}=\sqrt{\left[\frac{u(d)}{d}\right]^2+\left[\frac{u(\theta_b)}{\tan\theta_b}\right]^2}=6.7456\times10^{-4}$$

$$\therefore\ u(R_{H_2})=R_{H_2}\ \frac{u(R_{H_2})}{R_{H_2}}=7.3877809\times10^3m^{-1}$$

$$R_{H_2}\pm u(R_{H_2})=(1.0952\pm0.0007)\times10^7m^{-1}$$

测量级次 / 测量次数	−1级		+1级		$2\theta_p=\frac{1}{2}\left[(\alpha_1-\beta_1)-(\alpha_2-\beta_2)\right]$
	α_1	β_1	α_2	β_2	
1	49.22°	229.25°	34.28°	214.29°	14.917°
2	114.0°	294.04°	99.04°	279.08°	14.933°
3	179.2°	359.2°	164.23°	344.23°	14.950°
4	245.09°	65.05°	230.12°	50.1°	14.933°
5	307.39°	127.37°	292.42°	112.39°	14.958°

(3)紫光(青)

1.

$$\overline{2\theta_p}=\frac{\sum_{k=1}^{5}2\theta_p}{5}=0.13036rad$$

$$\text{由 } d\sin\theta=\lambda \text{ 得 } \lambda_p=d\sin\theta_p=d\sin\frac{\overline{2\theta_p}}{2}=433.93306nm$$

$$\text{在巴耳末系中对应n取5，有 } \frac{1}{\lambda_p}=R_{H_3}\left(\frac{1}{2^2}-\frac{1}{5^2}\right)$$

$$\therefore\ R_{H_3}=\frac{1}{\lambda_p}\left(\frac{1}{2^2}-\frac{1}{5^2}\right)=1.097382\times10^7m^{-1}$$

2. 不确定度的计算

$$u_a(\overline{2\theta_p})=\sqrt{\frac{\sum_{i=1}^{5}(2\theta_{p_i}-\overline{2\theta_\gamma]})^2}{5\times4}}=1.2680\times10^{-4}rad$$

$$u_b(\overline{2\theta})=\frac{1}{\sqrt{3}}=9.6225\times10^{-3}=1.679\times10^{-4}rad$$

$$\therefore \text{不确定度合成为 } u(\overline{2\theta_p})=\sqrt{u_a^2(\overline{2\theta_p})+u_b^2(\overline{2\theta_p})}=2.1043\times10^{-4}rad$$

$$u(\overline{\theta_p})=\frac{1}{2}\ u(\overline{2\theta_p})=1.0522\times10^{-4}rad$$

$$\therefore\theta_p\pm u(\theta_p)=(0.1304\pm0.0001)rad$$

$$\text{而 } R_{H_3}=\frac{1}{\lambda_p}\left(\frac{1}{2^2}-\frac{1}{5^2}\right)=\frac{1}{0.21}\ \frac{1}{d\sin\theta_p}$$

$$\therefore\ln R_{H_3}=\ln\frac{1}{0.21}-\ln d-\ln d\sin\theta_p$$

$$\therefore\frac{u(R_{H_3})}{R_{H_3}}=\sqrt{\left[\frac{\partial\ln d}{\partial d}\ u(d)\right]^2+\left[\frac{\partial\ln\sin\theta_p}{\partial\theta_p}\ u(\theta_p)\right]^2}=\sqrt{\left[\frac{u(d)}{d}\right]^2+\left[\frac{u(\theta_p)}{\tan\theta_p}\right]^2}=8.3194\times10^{-4}$$

$$\therefore\ u(R_{H_3})=R_{H_3}\ \frac{u(R_{H_3})}{R_{H_3}}=1.09738234\times10^7m^{-1}$$

$$R_{H_3}\pm u(R_{H_3})=((1.0974\pm0.0009)\times10^7)m^{-1}$$

3. 加权平均求R_H的最佳值

$$\overline{R_H}=\frac{\frac{R_{H_1}}{u^2R_{H_1}}+\frac{R_{H_2}}{u^2R_{H_2}}+\frac{R_{H_3}}{u^2R_{H_3}}}{\frac{1}{u^2R_{H_1}}+\frac{1}{u^2R_{H_2}}+\frac{1}{u^2R_{H_3}}}=1.0961\times10^7m^{-1}$$

$$u^2(\overline{R_H})=\frac{1}{\frac{1}{u^2R_{H_1}}+\frac{1}{u^2R_{H_2}}+\frac{1}{u^2R_{H_3}}}=m^{-1}$$

$$\therefore\ u(\overline{R_H})=4289.66027208m^{-1}$$

$$\therefore \text{最佳测量值 } \overline{R_H}\pm u(\overline{R_H})=(1.0961\pm0.0004)\times10^7m^{-1}$$

3.分别计算钠黄光k=1,2级的角散射率和分辨本领，并由此说明钠黄光双线能否被分开

(1)色分辨本领

$$\because\ N=\frac{D}{d}=659.05$$

$$\therefore\ R=\frac{\lambda}{\delta_\lambda}=kN=\begin{cases}659.05, & k=1\\ 1318.10, & k=2\end{cases}$$

(2)角色散率

由前面实验，$\overline{\theta_1}=0.1775°,\overline{\theta_1}=0.3608°$ 由公式$D_\theta=\frac{k}{ds\sin\theta}$,求解可得

$$k=1\ \text{时},\ D_{\theta_1}=\frac{1}{d\sin\overline{\theta_1}}=1.69619\times10^0rad/m$$

$$k=2\ \text{时},\ D_{\theta_2}=\frac{2}{d\sin\overline{\theta_2}}=1.69695\times10^0rad/m$$

(3)钠黄光双线

$$\theta_1=\arcsin\frac{\lambda_1}{d}=0.177°$$

$$\theta_2=\arcsin\frac{\lambda_2}{d}=0.178°$$

$$\Delta\theta=\theta_1-\theta_2=0.000°$$

根据谱线的半角宽度计算公式可得

$$\delta_\theta=\arcsin\frac{2\lambda N_0}{Nd}=0.000183°$$

$\because \Delta_\theta>\delta_\theta$

∴本实验可将钠黄光的双线分开。