X光系列实验

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目录

1、 普朗克常数的测定

2、 德拜相

3、 劳厄相

普朗克常数的测定

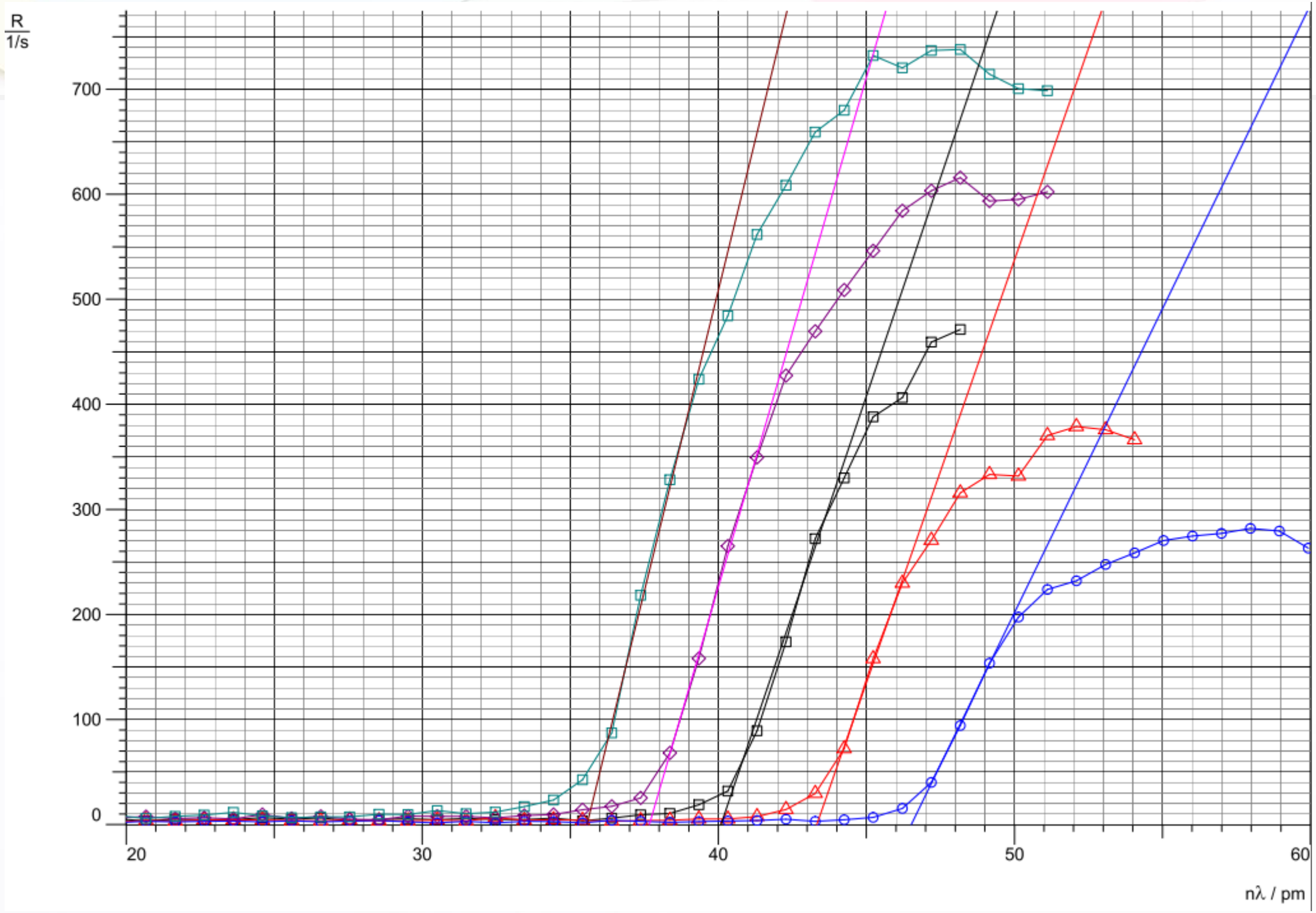
普朗克常数的测定

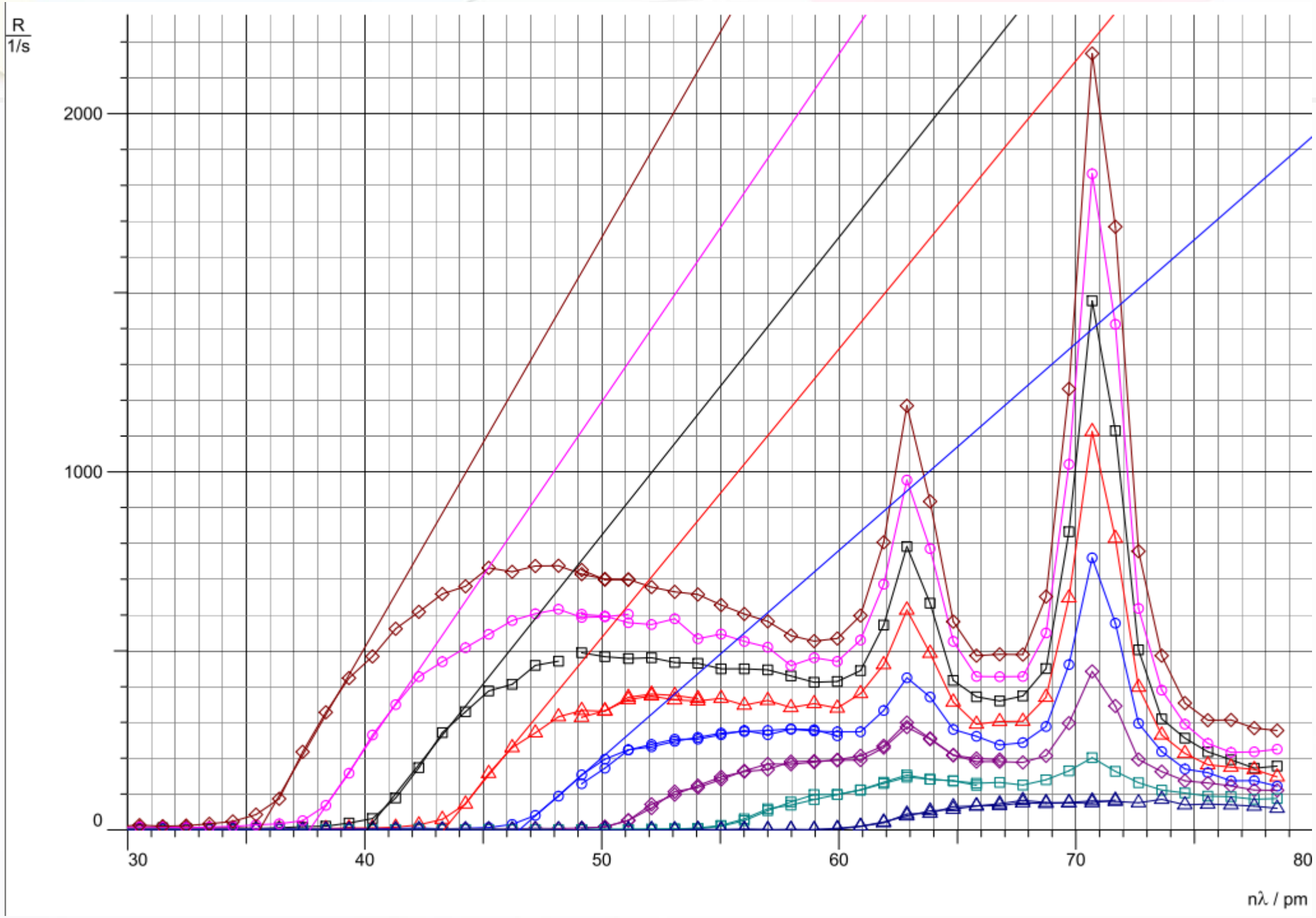
- Daune-Hunt关系

$$\lambda_{min} \sim \frac{1}{U}$$

- 电子动能全部转化为X光光子能量

$$E = eU = hf_{max} = \frac{hc}{\lambda_{min}} \Rightarrow \lambda_{min} = \frac{hc}{e} \cdot \frac{1}{U}$$


R
1/s
700
600
500
400
300
200
100
0
20
30
40
50
60
nλ / pm

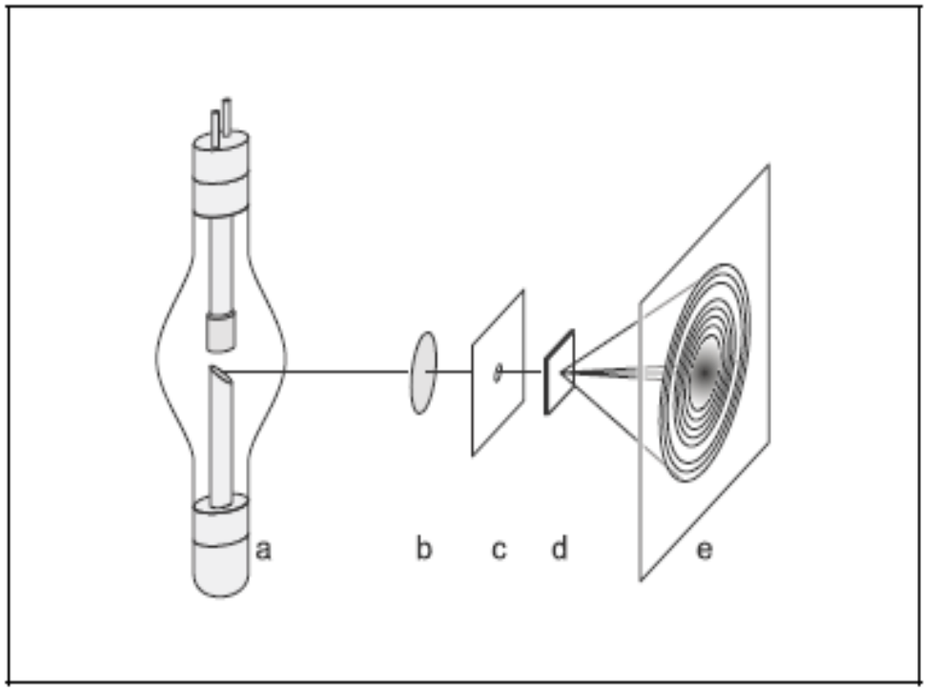

R
1/s
2000
1000
0
30
40
50
60
70
80
nλ / pm

U/kV	$\lambda_{\min}$/pm	λ^*/pm	$\lambda_{理论}$/pm
34	35.6	36.7	36.5
32	37.7	38.8	38.7
30	40.1	41.2	41.3
28	43.3	44.4	44.3
26	46.5	47.7	47.7
h/*10^-34J·s	6.49	6.55	6.63

德拜相

德拜相

一、实验装置



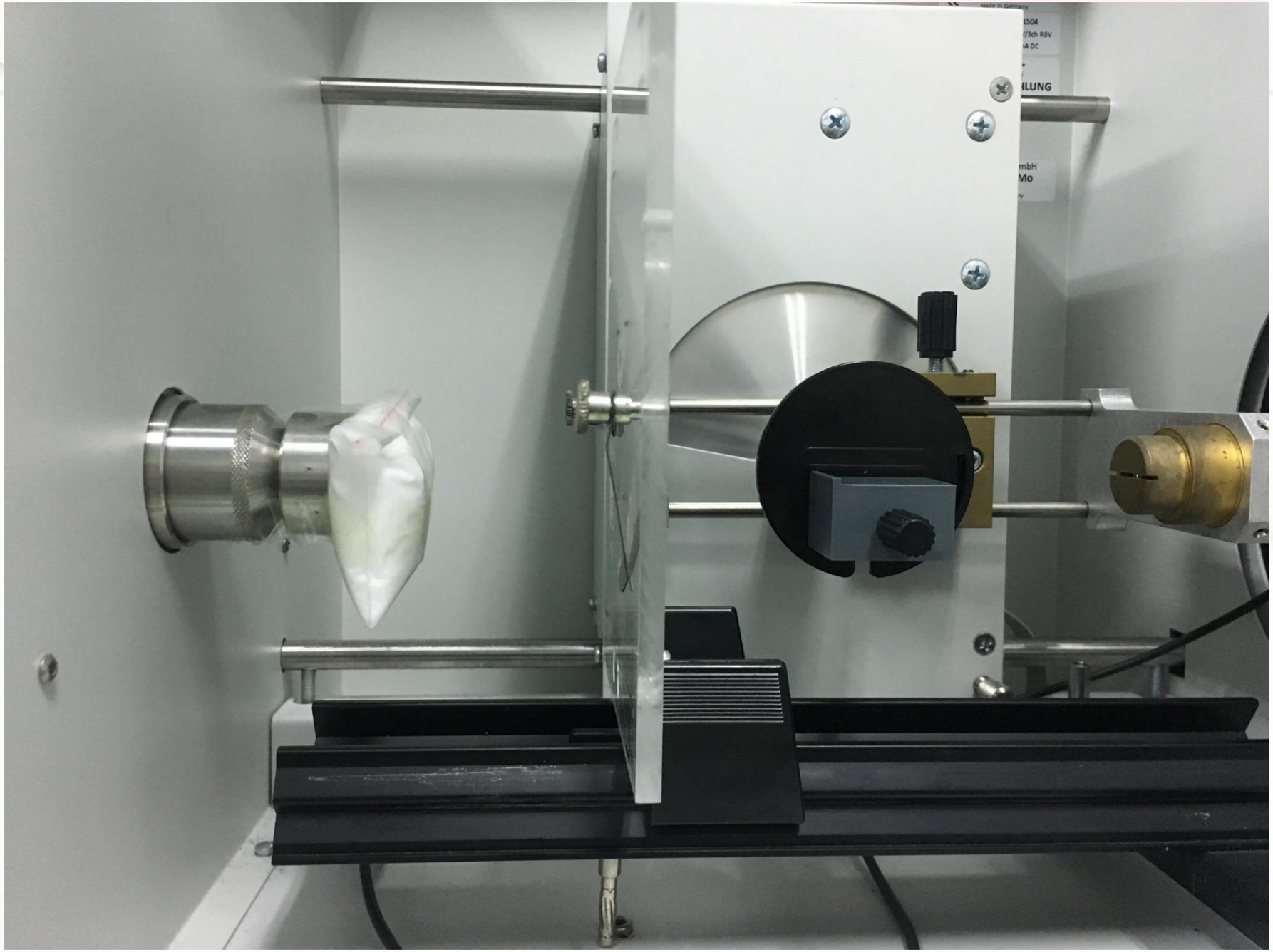
a. X射线管

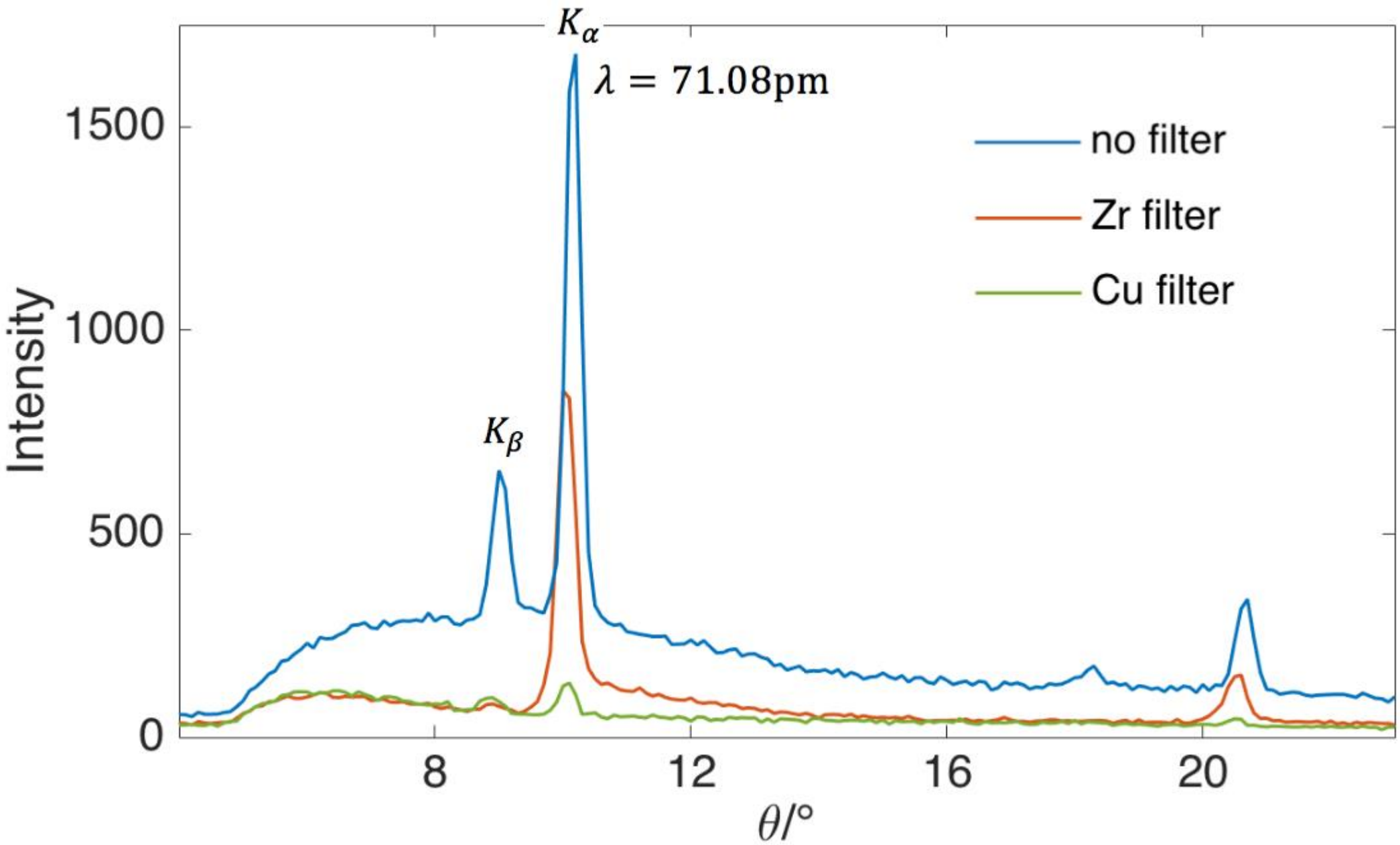
b. Zr滤片

c. 小孔准直器

d. 微米量级Nacl粉末：多晶

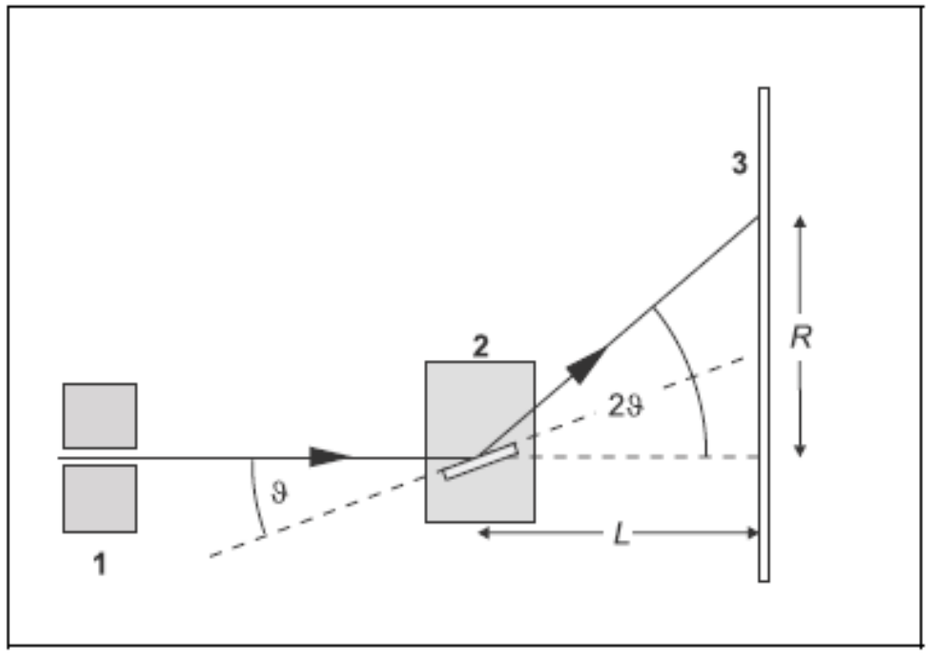
e. 成像胶片


Made in Germany
1504
/Sch R0V
A DC
ILUNG
mbH
Mo


K_α
$\lambda = 71.08\text{pm}$
K_β
no filter
Zr filter
Cu filter
Intensity
1500
1000
500
0
8
12
16
20
$\theta/°$

德拜相

一、实验原理



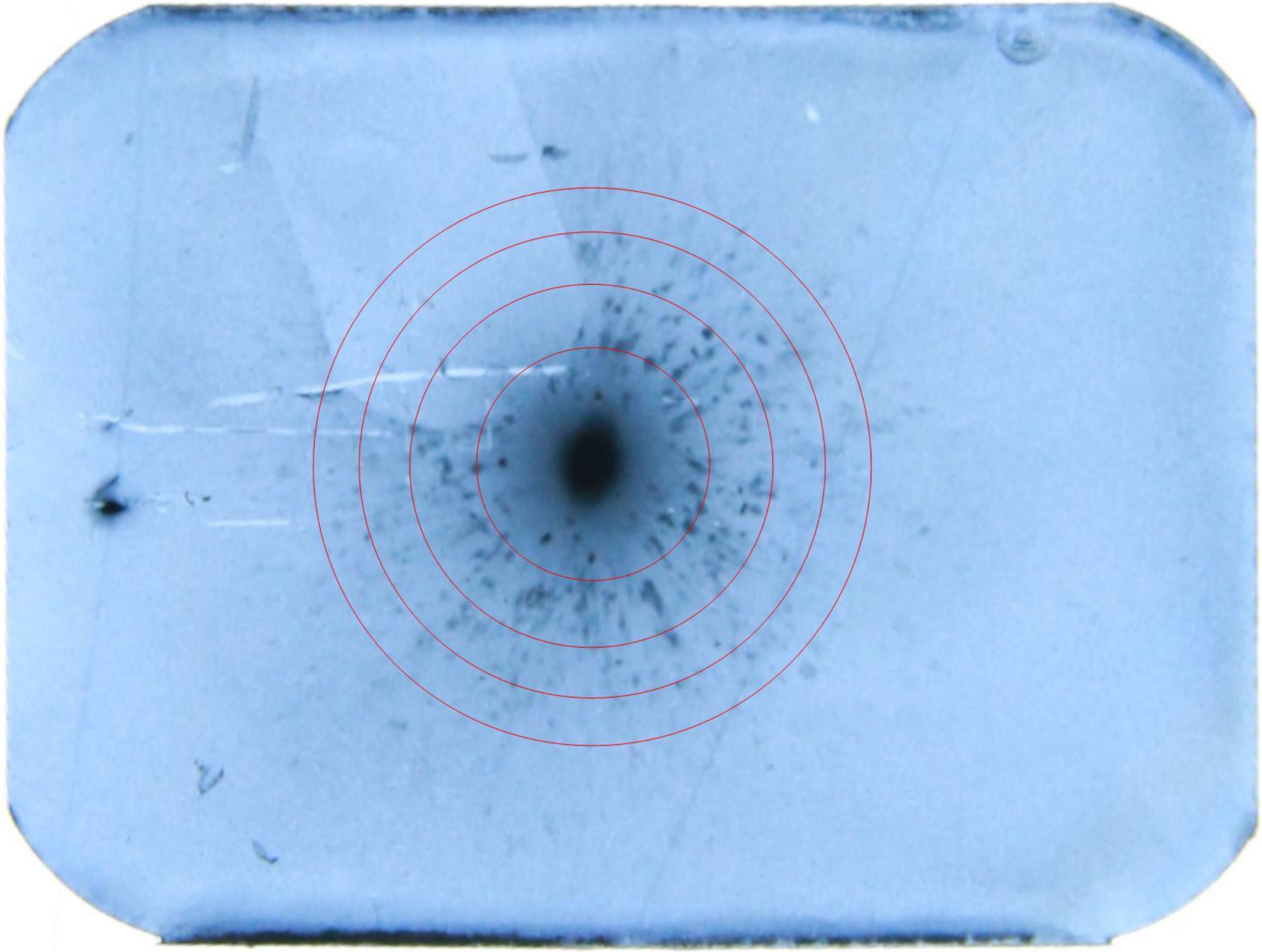
- 几何关系：$2\theta = arctan\frac{R}{L}$
- 布拉格公式：$2dsin\theta = n\lambda$ ⇒ $d = \frac{n\lambda}{2sin\theta}$
- 晶面间距：$d = \frac{a_0}{\sqrt{h^2+k^2+l^2}} = \frac{a_0}{\sqrt{Z}}$

一、实验原理

光强由几何结构因子决定，$I \propto |S|^2$，

$$S = \left[f_1 + f_1 e^{i\pi(h+k+l)}\right]\left[1 + e^{i\pi(h+k)} + e^{i\pi(h+l)} + e^{i\pi(k+l)}\right]$$

$$= \begin{cases} 4(f_1 - f_2) & h, k, l\ all\ odd \\ 4(f_1 + f_2) & h, k, l\ all\ even \\ 0 & otherwise \end{cases}$$



R/mm	$\theta/°$	计算z^2		h	k	l
3.8	5.96	2.7	4	2	0	0
5.9	9.08	6.27	8	2	2	0
7.6	11.4	9.82	12	2	2	2
9.1	13.38	13.47	16	4	0	0

劳厄相

劳厄相

一、实验原理

- 连续X射线照射不动的$(NaCl)$单晶体
- 劳厄提出了X射线在晶体中发生衍射的理论
- 测定晶体的取向
- 观测晶体对称性
- 晶体是否为单晶
- 观测晶体完整性

一、实验原理

晶面指数 $(h\,k\,l)$

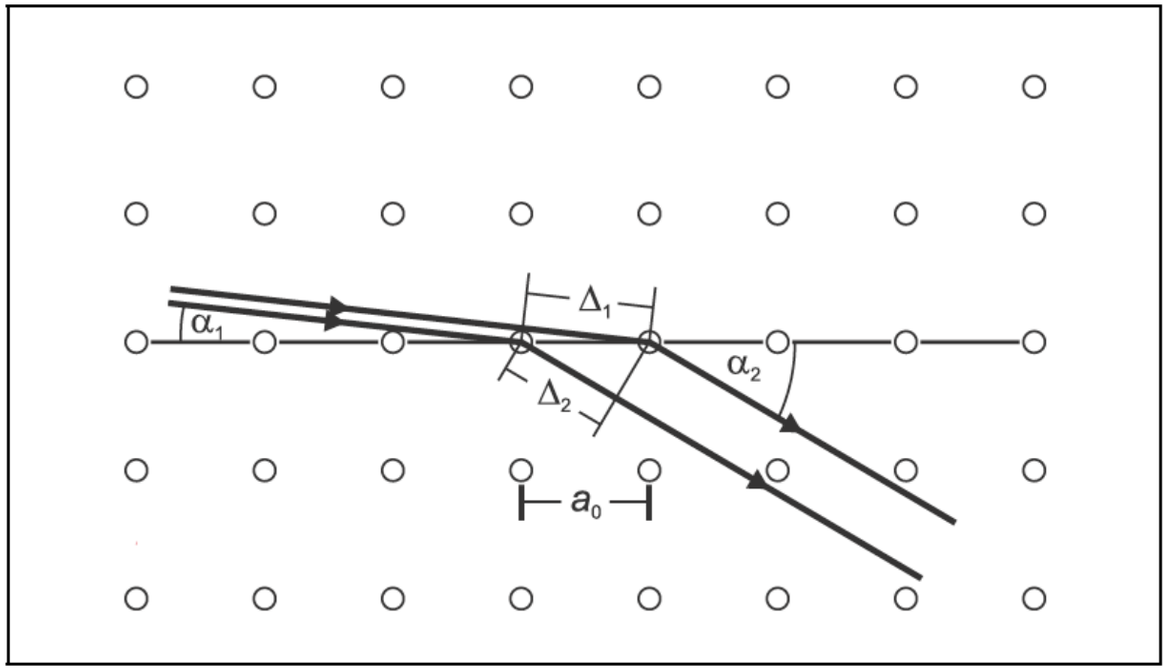
- 确定某平面在直角坐标系3个轴上的截点$(a\,b\,c)$，并以晶格常数为单位测得相应的截距。
- 取截距的倒数，约分为整数比。
- 将此结果以“$(h\,k\,l)$”表示，即为此平面的晶面指数。
- $[h\,k\,l]$代表晶体方向的矢量。

劳厄相

一、实验原理

劳厄方程 $\Delta = \Delta_1 - \Delta_2 = a_0 \cdot \cos\alpha_1 - a_0 \cdot \cos\alpha_2 = h \cdot \lambda$

产生相干散射的条件是光程差为波长的整数倍

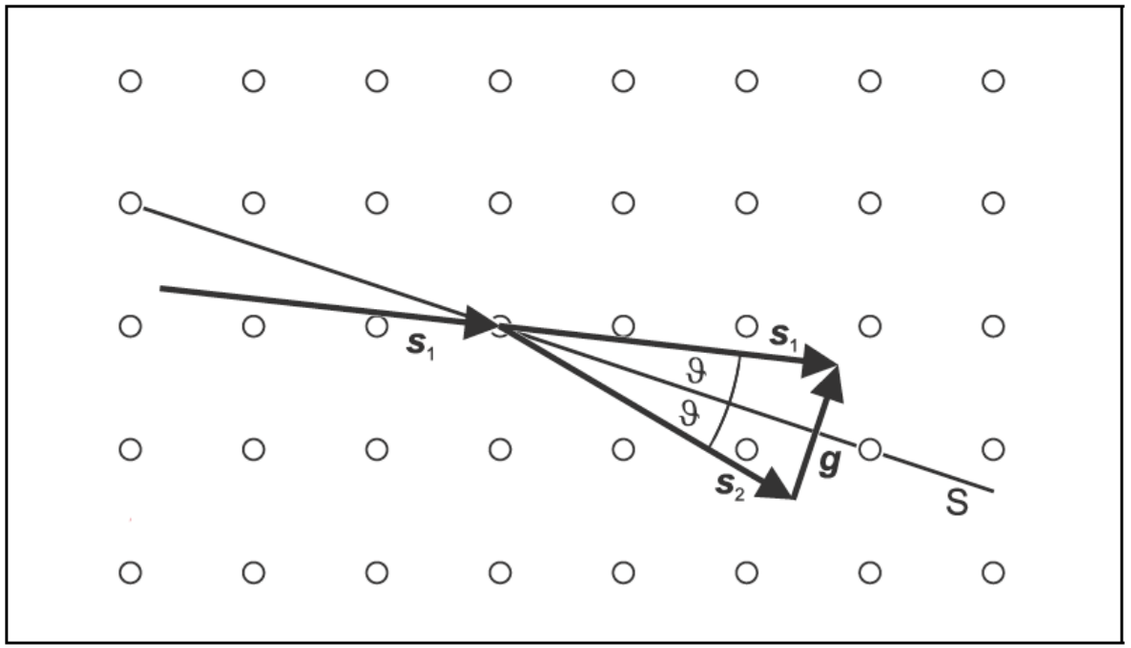


考虑三维空间：

$$\begin{cases} a_0 \cdot \cos\alpha_1 - a_0 \cdot \cos\alpha_2 = h \cdot \lambda \\ a_0 \cdot \cos\beta_1 - a_0 \cdot \cos\beta_2 = k \cdot \lambda \\ a_0 \cdot \cos\gamma_1 - a_0 \cdot \cos\gamma_2 = l \cdot \lambda \end{cases}$$

劳厄相

一、实验原理



$$\boldsymbol{s_1} - \boldsymbol{s_2} = \boldsymbol{g}$$
$$|\boldsymbol{g}| = 2|\boldsymbol{s}|sin\theta$$

$$\boldsymbol{s_1} = (\cos\alpha_1,\ \cos\beta_1,\ \cos\gamma_1)$$
$$\boldsymbol{s_2} = (\cos\alpha_2,\ \cos\beta_2,\ \cos\gamma_2)$$

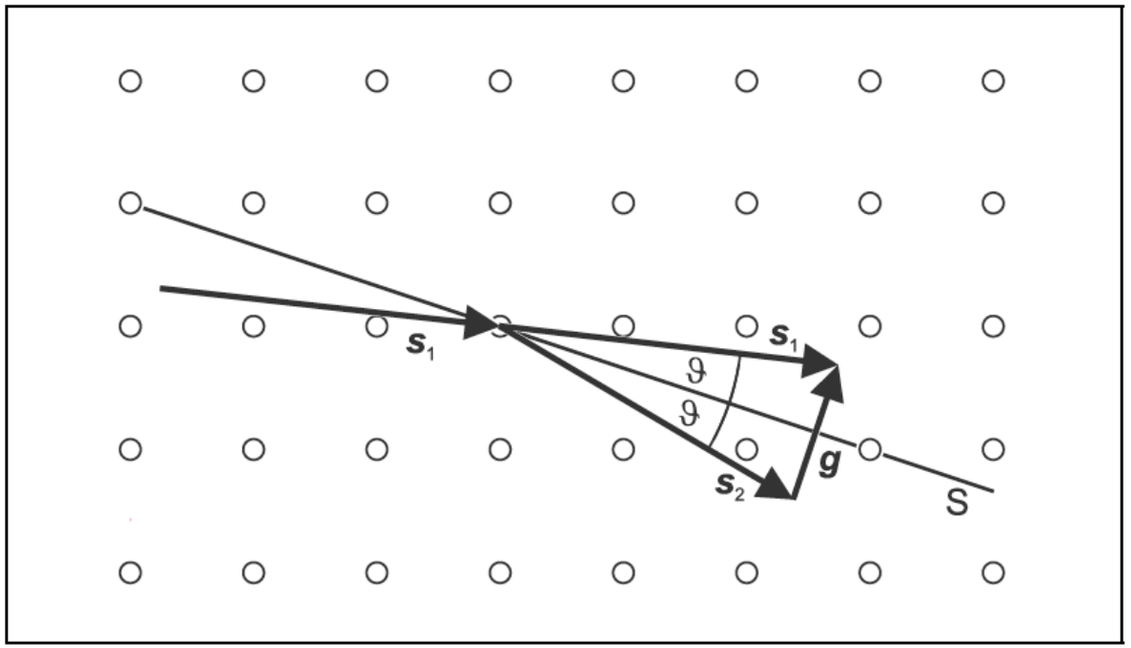
$$\begin{cases} a_0 \cdot \cos\alpha_1 - a_0 \cdot \cos\alpha_2 = h \cdot \lambda \\ a_0 \cdot \cos\beta_1 - a_0 \cdot \cos\beta_2 = k \cdot \lambda \\ a_0 \cdot \cos\gamma_1 - a_0 \cdot \cos\gamma_2 = l \cdot \lambda \end{cases}$$

引入倒格矢$\boldsymbol{G} = [h, k, l] \cdot \frac{1}{a_0}$

$$\boldsymbol{s_1} - \boldsymbol{s_2} = \boldsymbol{g} = \lambda \cdot \boldsymbol{G}$$

劳厄相

一、实验原理



$$\boldsymbol{s_1} - \boldsymbol{s_2} = \boldsymbol{g}$$

$$|\boldsymbol{g}| = 2|\boldsymbol{s}|sin\theta$$

$$\boldsymbol{s_1} - \boldsymbol{s_2} = \boldsymbol{g} = \lambda \cdot \boldsymbol{G}$$

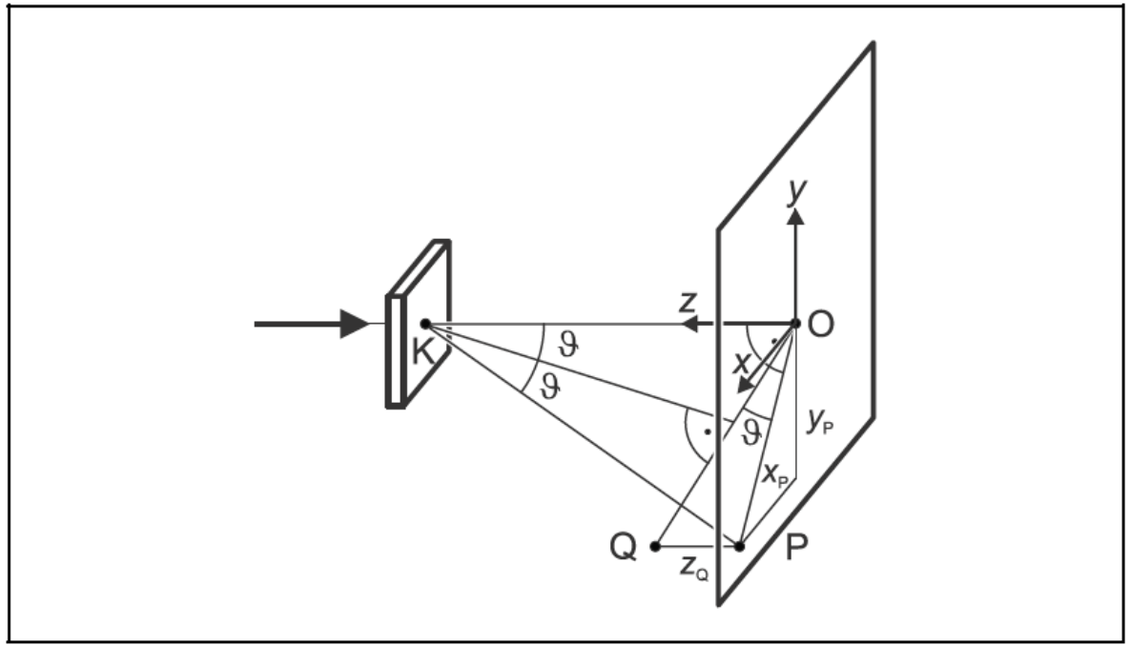
$$|\boldsymbol{g}| = 2|\boldsymbol{s}|sin\theta = 2sin\theta$$

$$\boldsymbol{G} = [h, k, l] \cdot \frac{1}{a_0}$$

$$\lambda = \frac{2\sin\theta}{|G|} = 2\sin\theta\frac{a_0}{\sqrt{h^2 + k^2 + l^2}}$$

劳厄相

一、实验原理



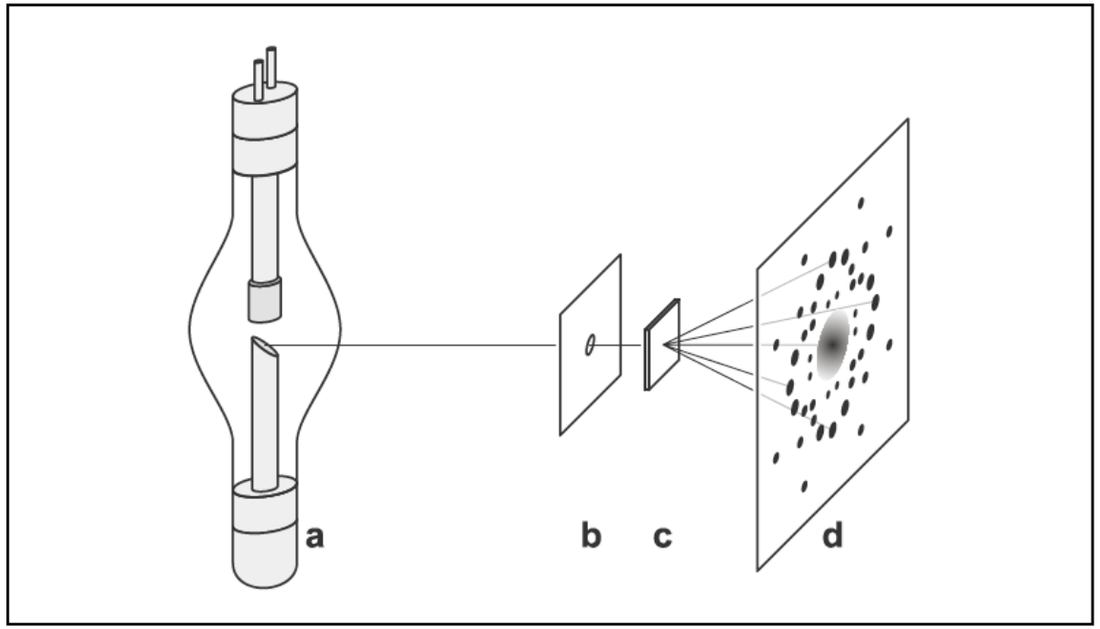
几何关系 $\begin{cases} \tan 2\theta = \dfrac{OP}{OK} \\ \tan\theta = \dfrac{z_Q}{OP} \end{cases}$

代入 $\begin{cases} OK = L \\ OP = \sqrt{{x_P}^2 + {y_P}^2} \end{cases}$

得到 $z_Q = \sqrt{{x_P}^2 + {y_P}^2 + L^2} - L$

$$\boldsymbol{G} = [h,k,l]\cdot\frac{1}{a_0},\quad \boldsymbol{OQ}\ //\ \boldsymbol{G} \Longrightarrow x_P:\ y_P:\ z_Q = h:k:l$$

二、实验过程



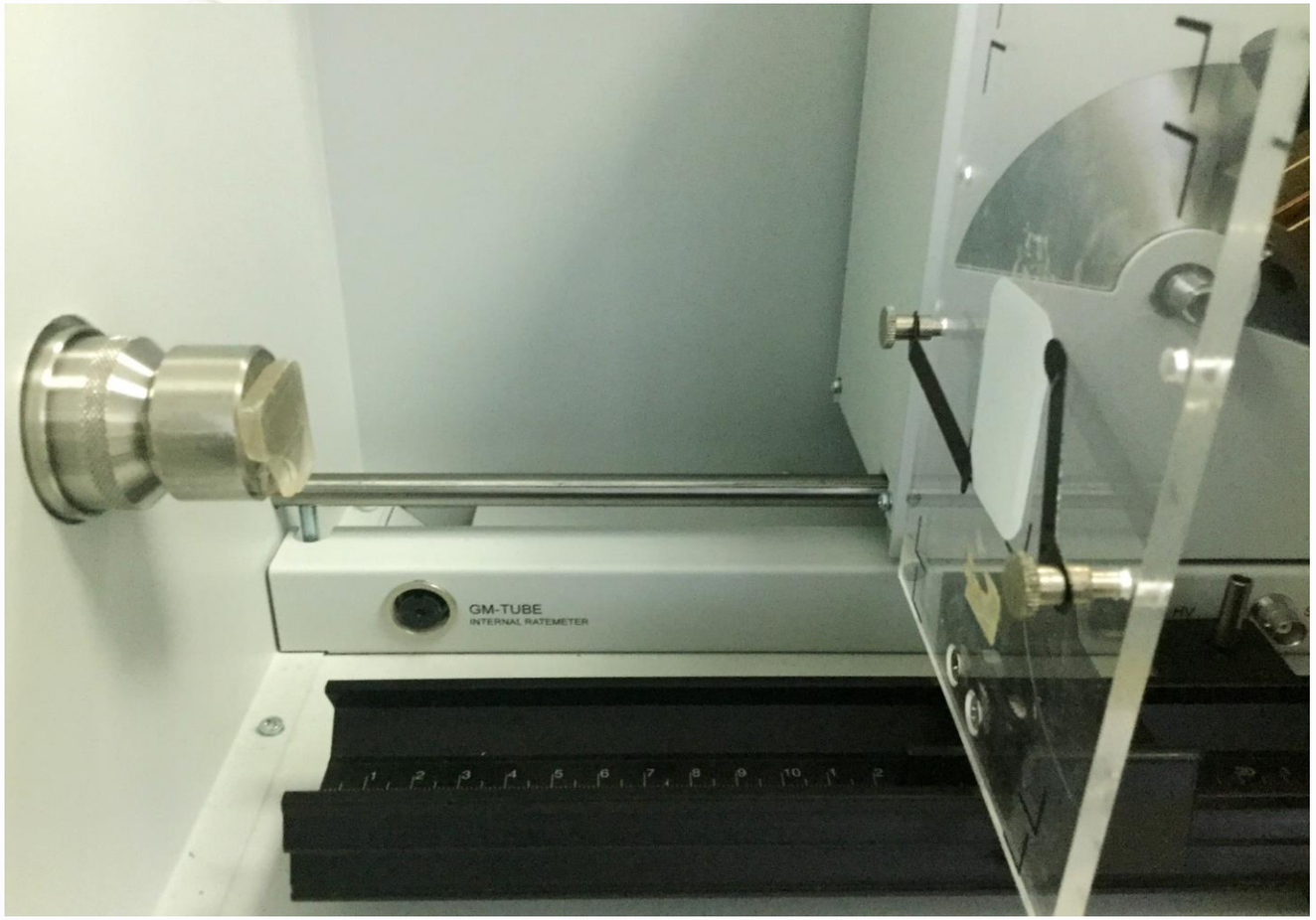
a. X射线管（连续光源）

b. 小孔准直器

c. NaCl晶体 (单晶)

d. 成像胶片

二、实验过程

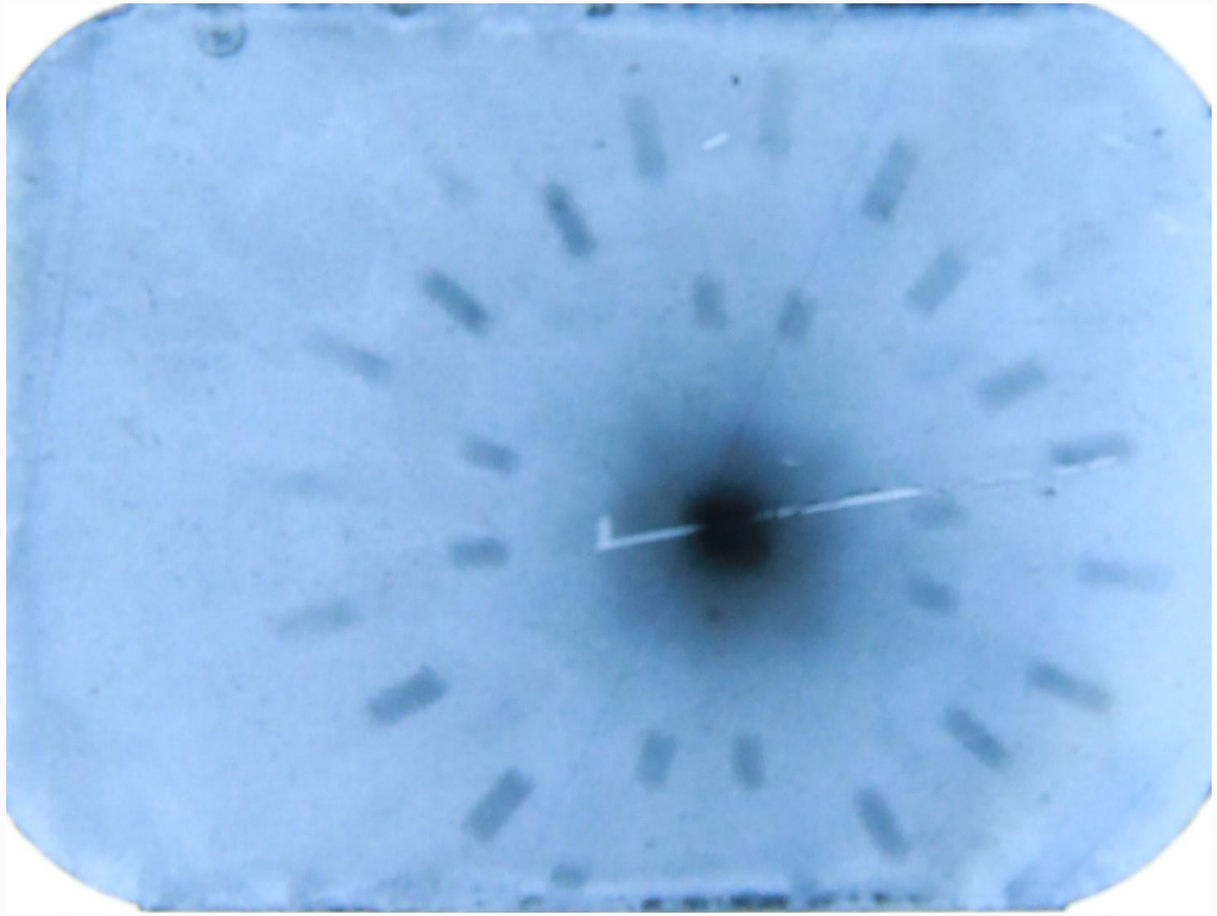


劳厄相

二、实验过程

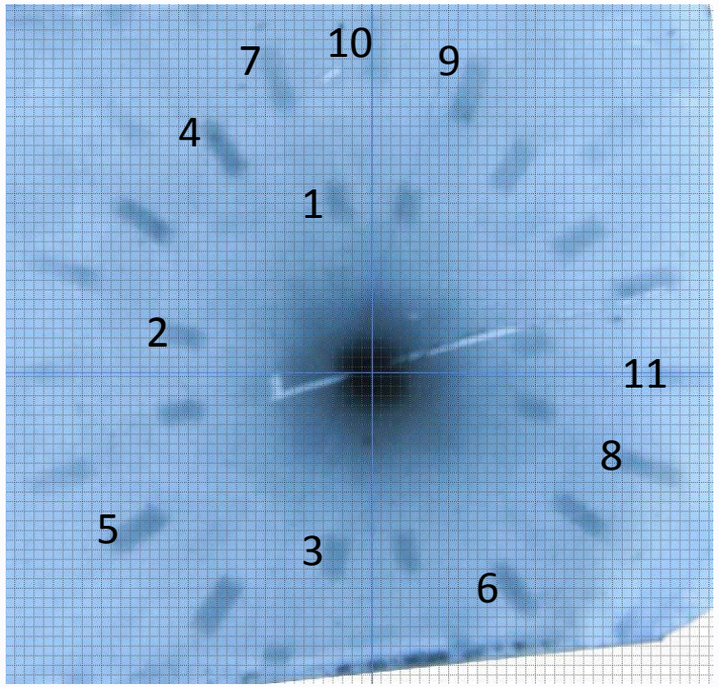
时间：1.5h

L：18.0mm



三、数据分析

- 计算z_Q，得到坐标

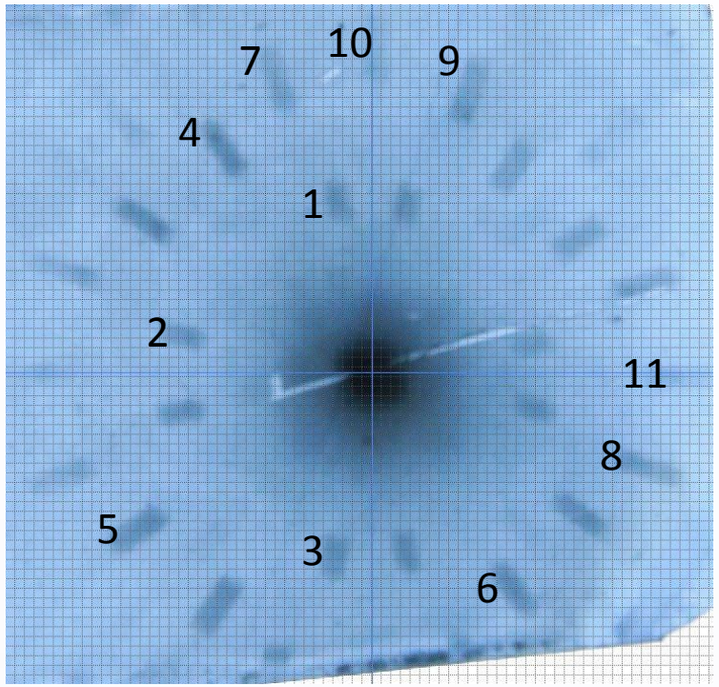


$$z_Q = \sqrt{{x_P}^2 + {y_P}^2 + L^2} - L$$

序号	x_P/mm	y_P/mm	z_Q/mm
1	1.52	7.58	1.59
2	8.17	1.60	1.83
3	1.68	8.08	1.8
4	6.52	9.85	3.53
5	10.27	6.82	3.82
6	6.19	9.51	3.28
7	4.17	12.88	4.52
8	12.04	4.21	4.06
9	4.25	12.42	4.28
10	0.04	14.19	4.92
11	13.47	0.21	4.48

三、数据分析

- 根据比例估算$(h\ k\ l)$

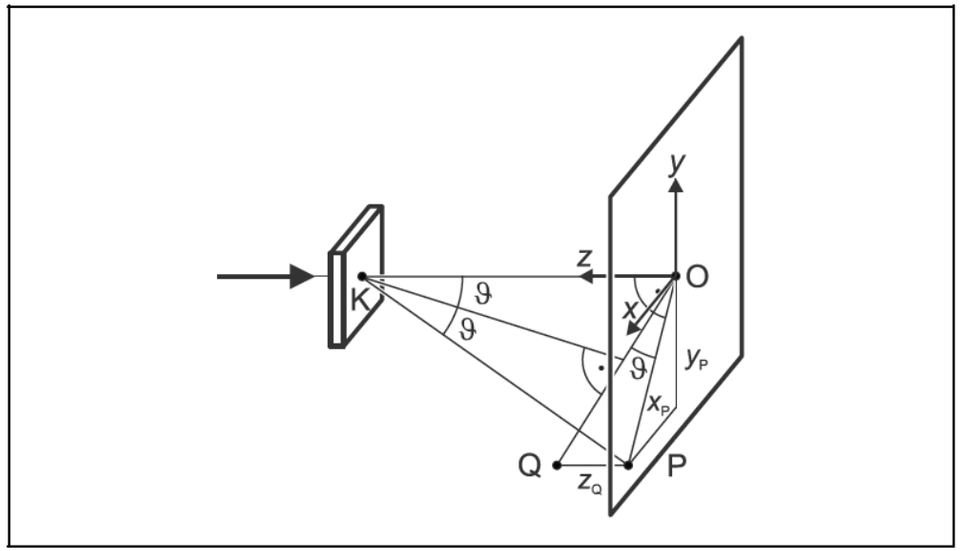


x_P： y_P： $z_Q = h:k:l$

序号	x_P/mm	y_P/mm	z_Q/mm	h	k	l
1	1.52	7.58	1.59	1	5	1
2	8.17	1.60	1.83	5	1	1
3	1.68	8.08	1.80	1	5	1
4	6.52	9.85	3.53	4	6	2
5	10.27	6.82	3.82	6	4	2
6	6.19	9.51	3.28	4	6	2
7	4.17	12.88	4.52	2	6	2
8	12.04	4.21	4.06	6	2	2
9	4.25	12.42	4.28	2	6	2
10	0.04	14.19	4.92	0	3	1
11	13.47	0.21	4.48	3	0	1

三、数据分析

- 计算x_0、y_0，分析误差



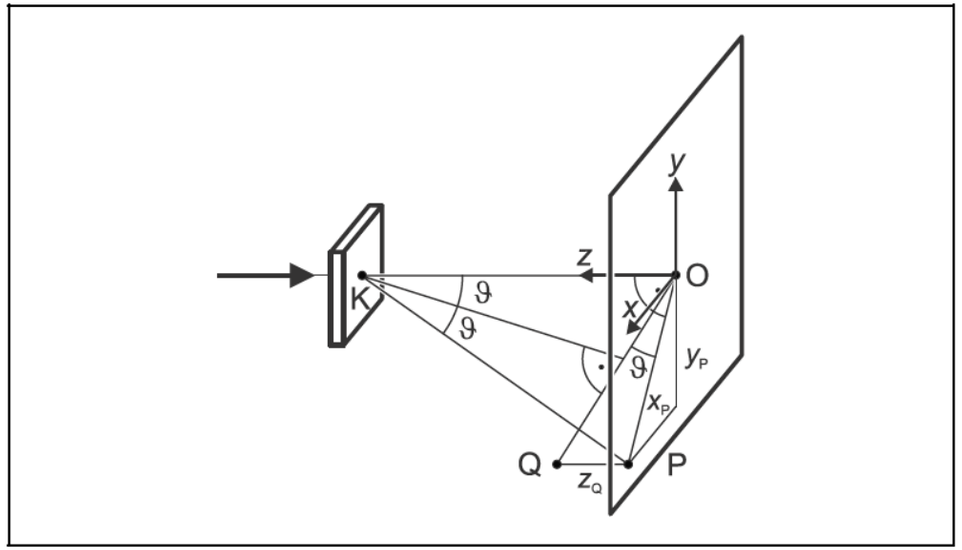
$$x_0 = L\tan\left(2\arctan\left(\frac{l}{\sqrt{h^2+k^2}}\right)\right)\frac{h}{\sqrt{h^2+k^2}}$$

$$y_0 = k\cdot\frac{x_0}{h}$$

序号	x_P	y_P	x_0	y_0	$\Delta x/x_0$	$\Delta y/y_0$
1	1.52	7.58	1.44	7.20	5.6%	5.3%
2	8.17	1.60	7.20	1.44	13.5%	11.1%
3	1.68	8.08	1.44	7.20	16.7%	12.2%
4	6.52	9.85	6.00	9.00	8.7%	9.4%
5	10.27	6.82	9.00	6.00	14.1%	13.7%
6	6.19	9.51	6.00	9.00	3.2%	5.7%
7	4.17	12.88	4.00	12.00	4.3%	7.3%
8	12.04	4.21	12.00	4.00	0.3%	5.3%
9	4.25	12.42	4.00	12.00	6.3%	3.5%
10	0.04	14.19	0.00	13.50	/	5.1%
11	13.47	0.21	13.50	0.00	-0.2%	/

三、数据分析

- 修正后



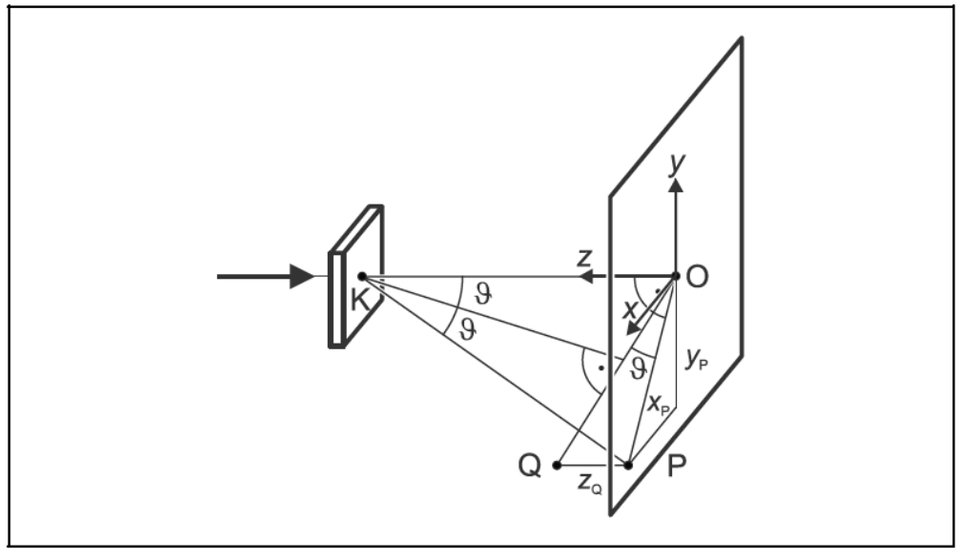
$$x_0 = L\tan\left(2\arctan\left(\frac{l}{\sqrt{h^2+k^2}}\right)\right)\frac{h}{\sqrt{h^2+k^2}}$$

$$y_0 = k\cdot\frac{x_0}{h}$$

序号	x_P	y_P	x_0	y_0	$\Delta x/x_0$	$\Delta y/y_0$
1	1.52	7.58	1.52	7.6	0.0%	-0.3%
2	8.17	1.60	7.6	1.52	7.5%	5.3%
3	1.68	8.08	1.52	7.6	10.5%	6.3%
4	6.52	9.85	6.33	9.5	3.0%	3.7%
5	10.27	6.82	9.5	6.33	8.1%	7.7%
6	6.19	9.51	6.33	9.6	-2.2%	-0.9%
7	4.17	12.88	4.22	12.67	-1.2%	1.7%
8	12.04	4.21	12.67	4.22	-5.0%	-0.2%
9	4.25	12.42	4.22	12.67	0.7%	-2.0%
10	0.04	14.19	0	14.25	/	-0.4%
11	13.47	0.21	14.25	0	-5.5%	/

三、数据分析

- 计算衍射角θ与波长λ



$$\theta = arctan(\frac{z_Q}{\sqrt{{x_P}^2 + {y_P}^2}}) = arctan(\frac{l}{\sqrt{h^2 + k^2}})$$

$$\lambda = 2\sin\theta \frac{a_0}{\sqrt{h^2 + k^2 + l^2}}$$

序号	h	k	l	$\theta/°$	λ/pm
1	1	5	1	11.1	41.8
2	5	1	1	11.1	41.8
3	1	5	1	11.1	41.8
4	4	6	2	15.5	40.3
5	6	4	2	15.5	40.3
6	4	6	2	15.5	40.3
7	2	6	2	17.5	51.1
8	6	2	2	17.5	51.1
9	2	6	2	17.5	51.1
10	0	6	2	18.4	54.5
11	6	0	2	18.4	54.5

实验结论

实验结论

成像方法	光源	使用滤光片	样品
德拜	单色光	是	多晶粉末
劳厄	连续光	否	单晶

实验结论

- 用连续光源照射$NaCl$单晶晶体，得到对称分布的劳厄斑。通过相片上劳厄斑的坐标计算，得到衍射强度较大的晶面的晶面参数，计算得到衍射角θ与波长λ, 验证晶体内部结构的有序性。

建议：

- 使用可精确测量间距L的相片架，提高准确度。

谢 谢 ！