法拉第效应

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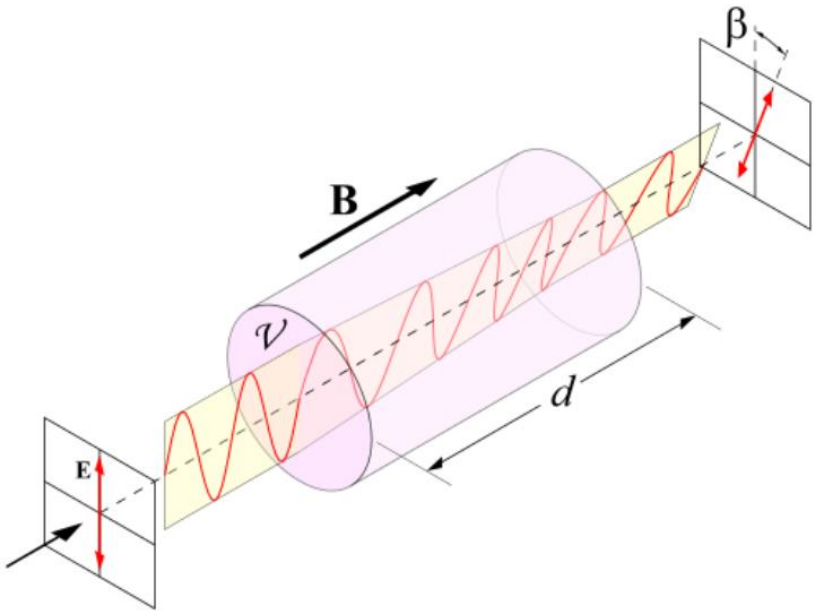
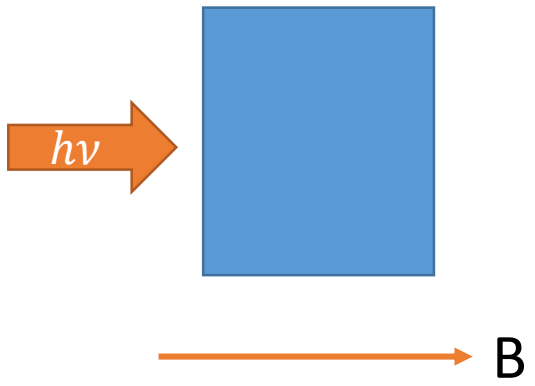
法拉第效应



磁 ⟷ 光

实验原理

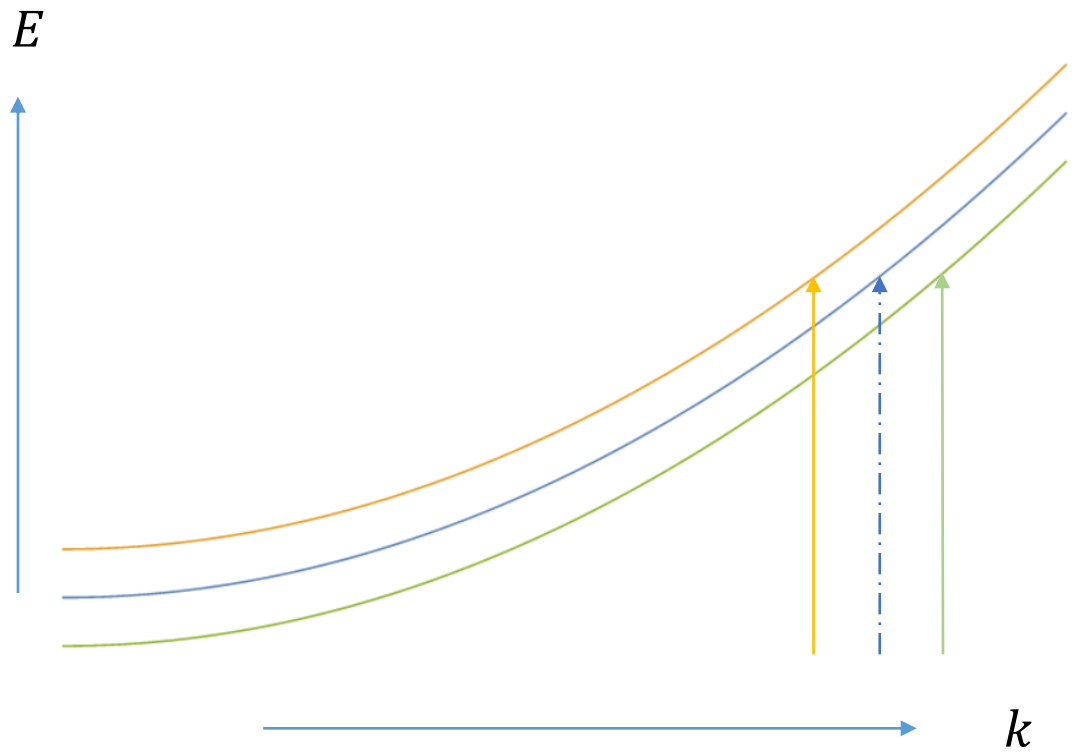
磁场 → 晶体手征对称性被破坏 → 左右旋光折射率不同



线偏光 → 左旋光 θ / 右旋光 $\theta + \Delta\theta$ → 线偏光转过$\Delta\theta/2$

实验原理

磁场 → 塞曼分裂 → 选择性吸收

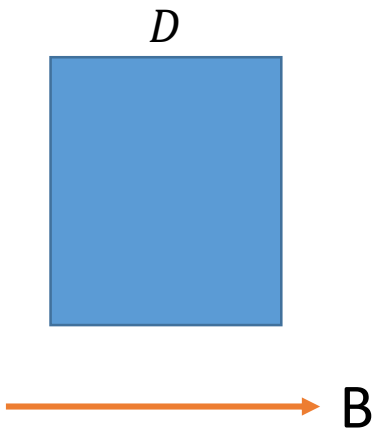


$$n_L(\omega) = n\left(\omega - \frac{eB_0}{2m}\right) = n(\omega) - \frac{eB}{2m}\cdot\frac{\mathrm{d}n}{\mathrm{d}\omega}$$

$$n_R(\omega) = n\left(\omega + \frac{eB_0}{2m}\right) = n(\omega) + \frac{eB}{2m}\cdot\frac{\mathrm{d}n}{\mathrm{d}\omega}$$

B：磁场强度
m：电子有效质量
e：电子电荷

实验原理



$$\Delta\varphi = \frac{\Delta\theta}{2} = \frac{\omega D}{2c(n_R - n_L)} = -\frac{D}{2}\frac{Be}{mc}\lambda\frac{\mathrm{d}n}{\mathrm{d}\lambda} = V(\lambda)DB$$

$$V(\lambda) = -\frac{e}{2mc}\lambda\frac{\mathrm{d}n}{\mathrm{d}\lambda}$$

D：晶体厚度
B：磁场强度
m：电子有效质量
e：电子电荷
c：光速

实验设计

- 偏振偏转检验 $\Delta\varphi = \frac{\Delta\theta}{2} = -\frac{e}{2mc}\lambda\frac{\mathrm{d}n}{\mathrm{d}\lambda}DB$

$$\Delta\varphi \propto B$$

1. 光强不变

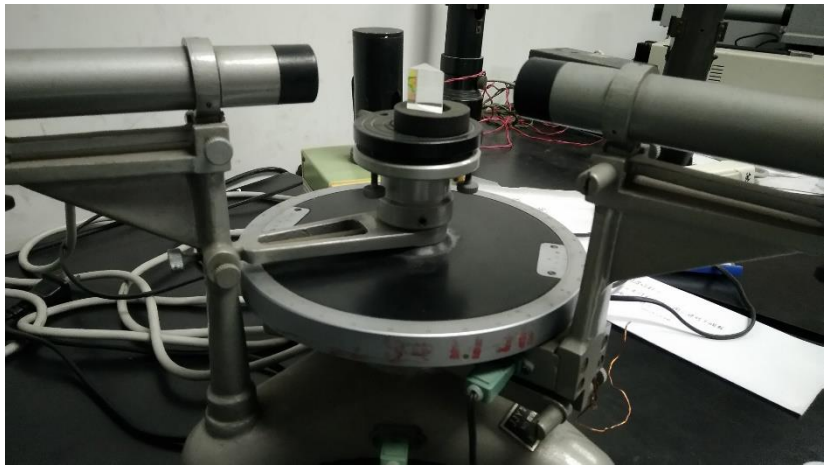
2. 偏转角与磁场成正比

实验设计

- 定量常数检验

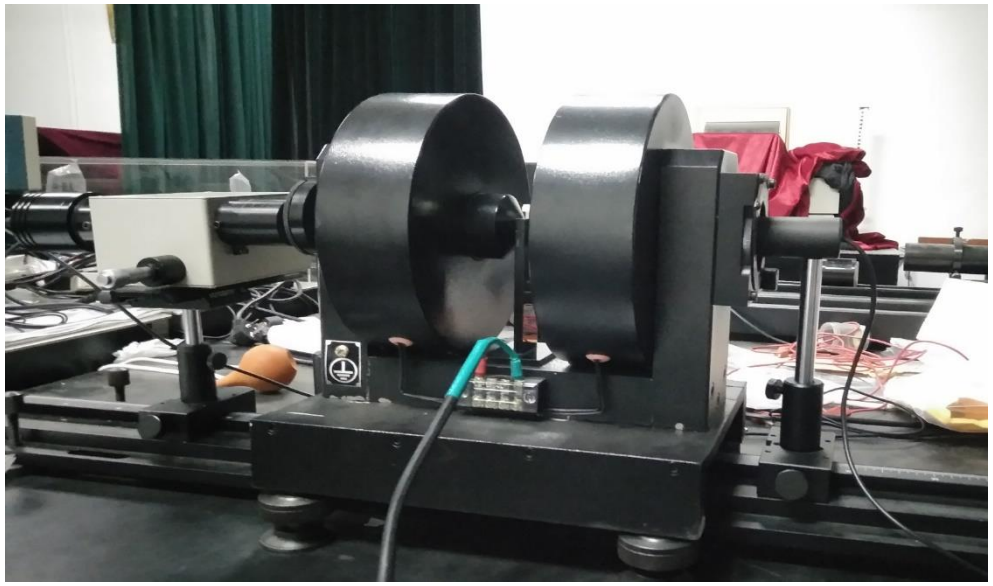
$$\Delta\varphi = \frac{\Delta\theta}{2} = -\frac{e}{2mc}\lambda\frac{\mathrm{d}n}{\mathrm{d}\lambda}DB$$

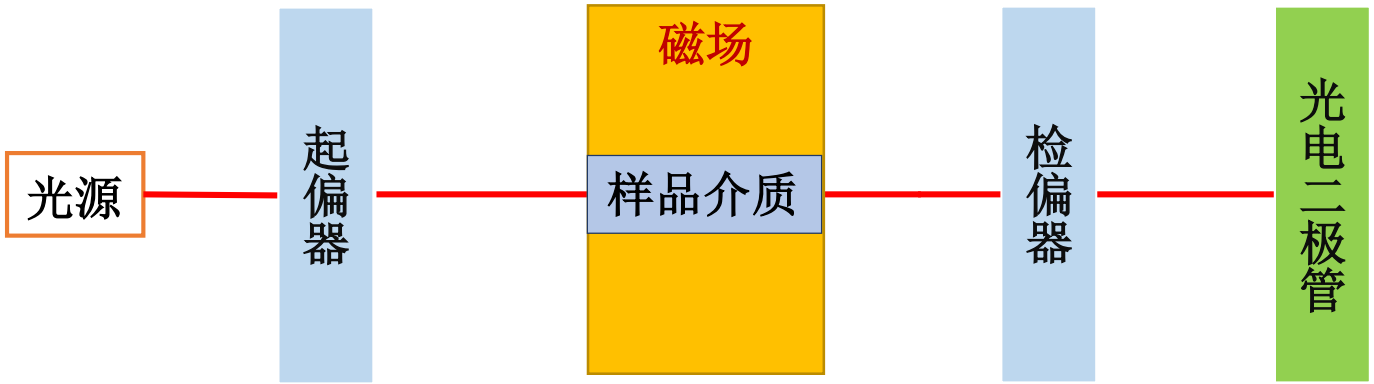
分光计 → 折射率@不同波长 —拟合→ $\lambda\frac{\mathrm{d}n}{\mathrm{d}\lambda}$



实验设计

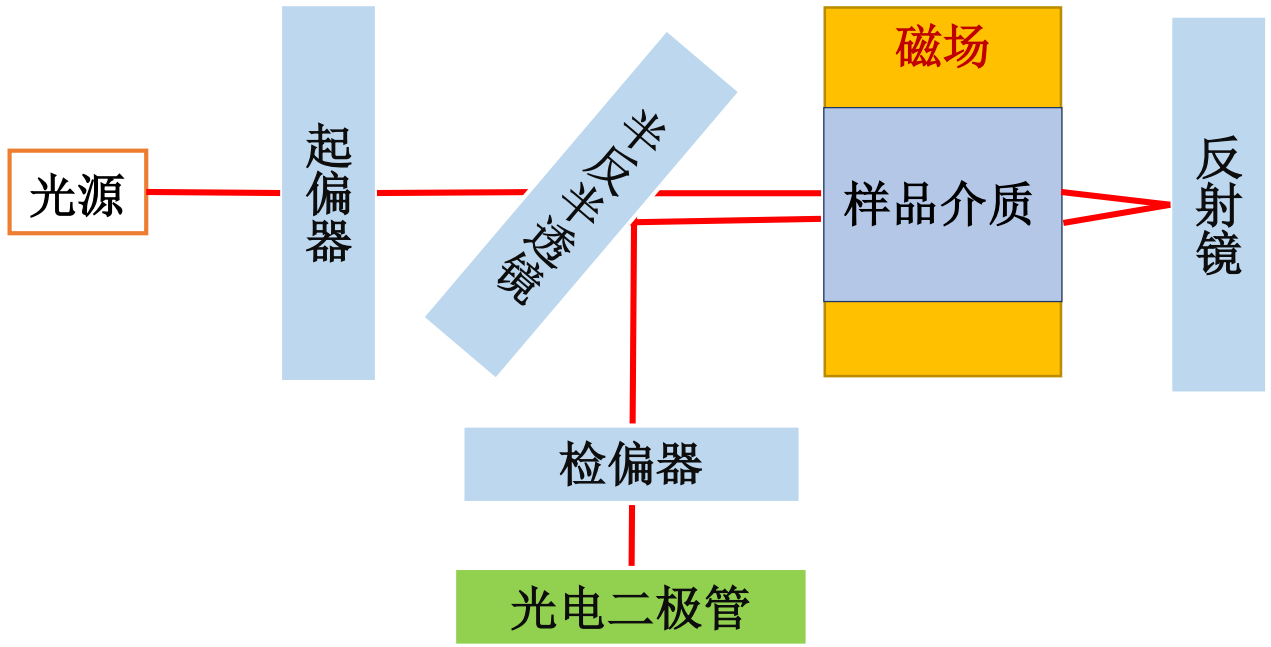
- 透射

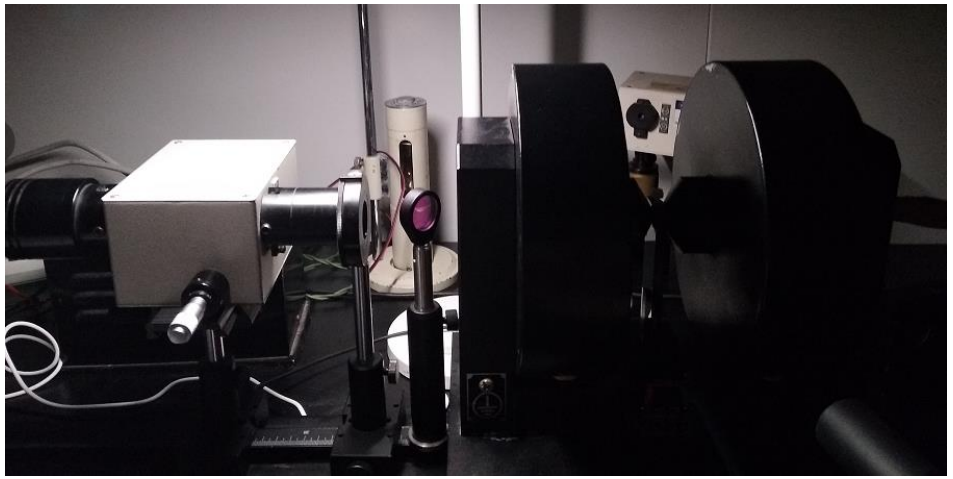


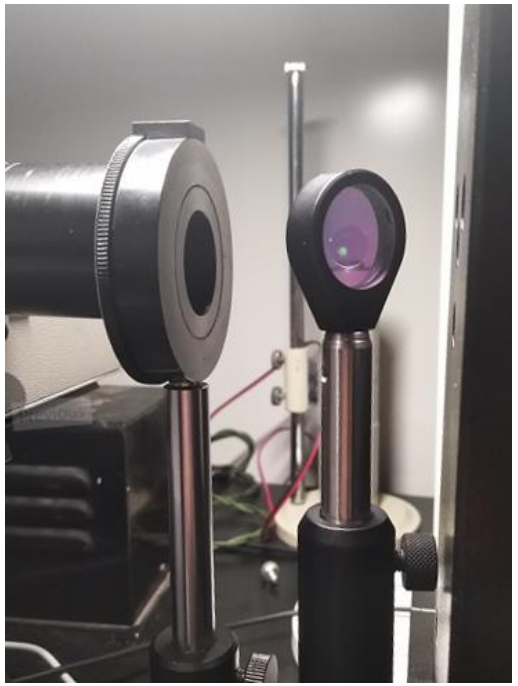


实验设计

- 反射







光强太小！

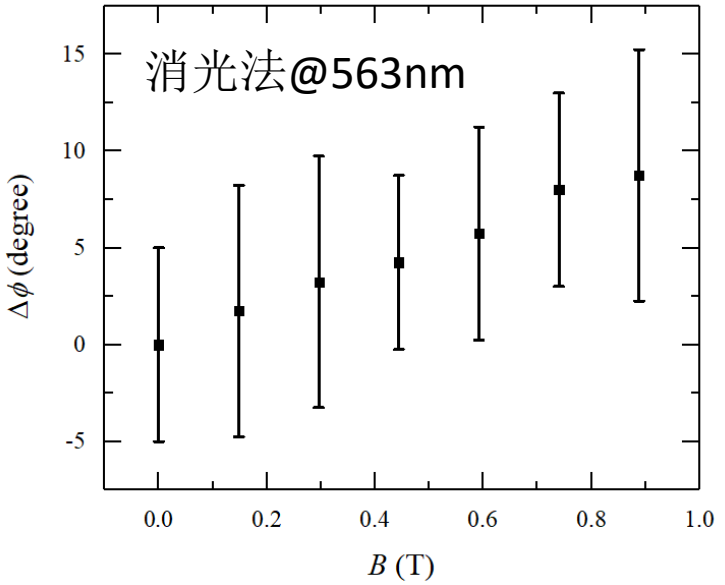
实验设计

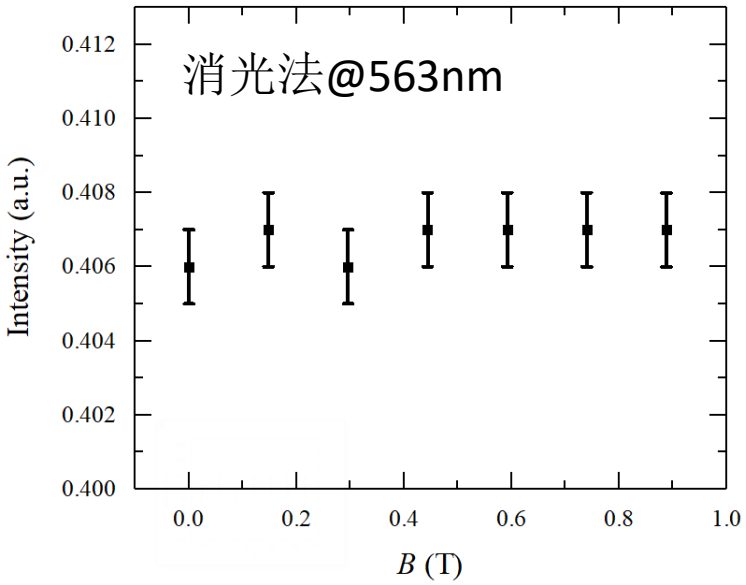
- 检验方法

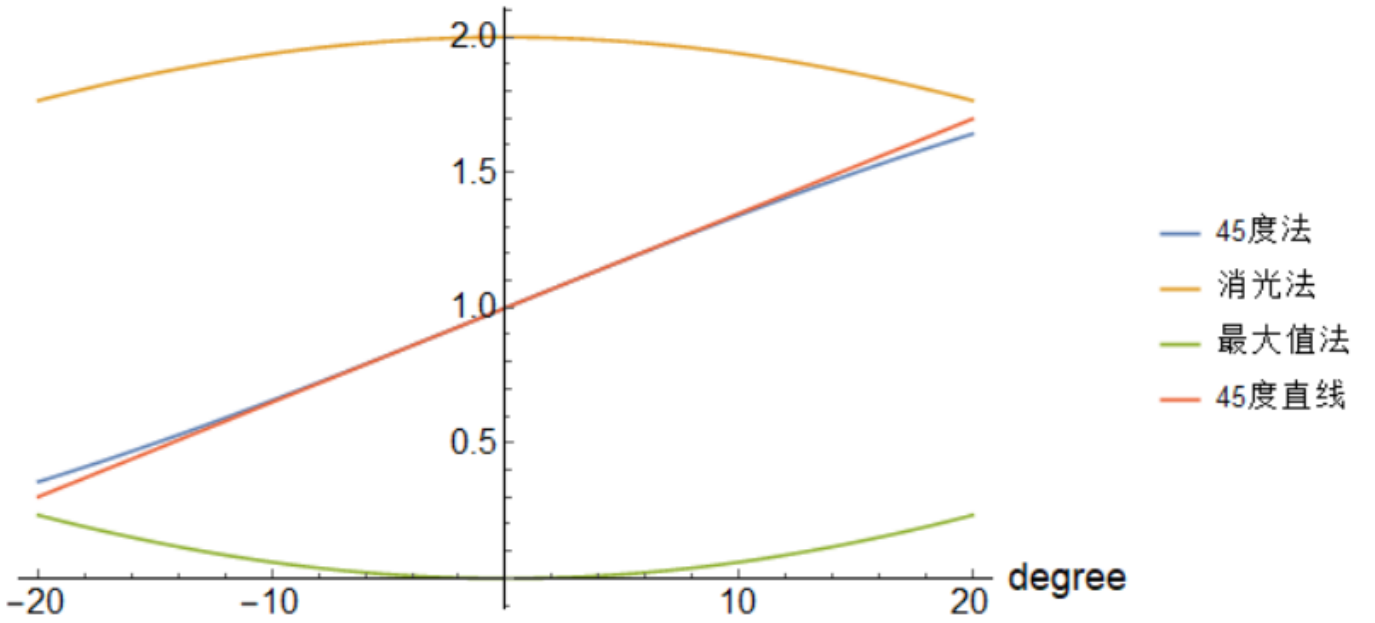
$$U(\theta) = U_0 \cos^2\theta$$

$$\frac{dU}{d\theta} = -2U_0 \sin 2\theta$$

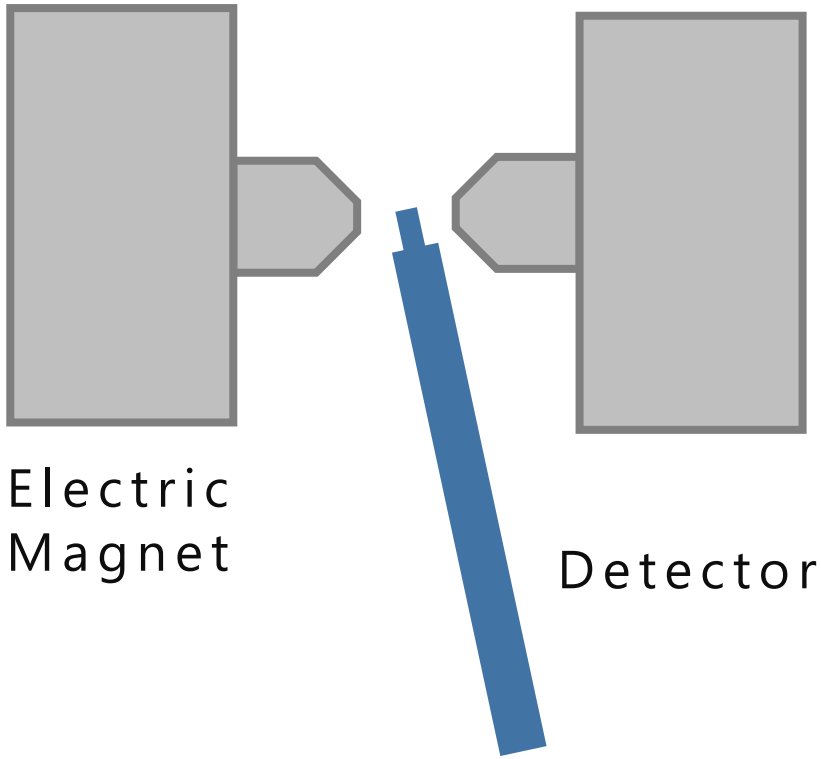
@45度 $\Delta U = \frac{dU}{d\theta}\Delta\theta \propto B$

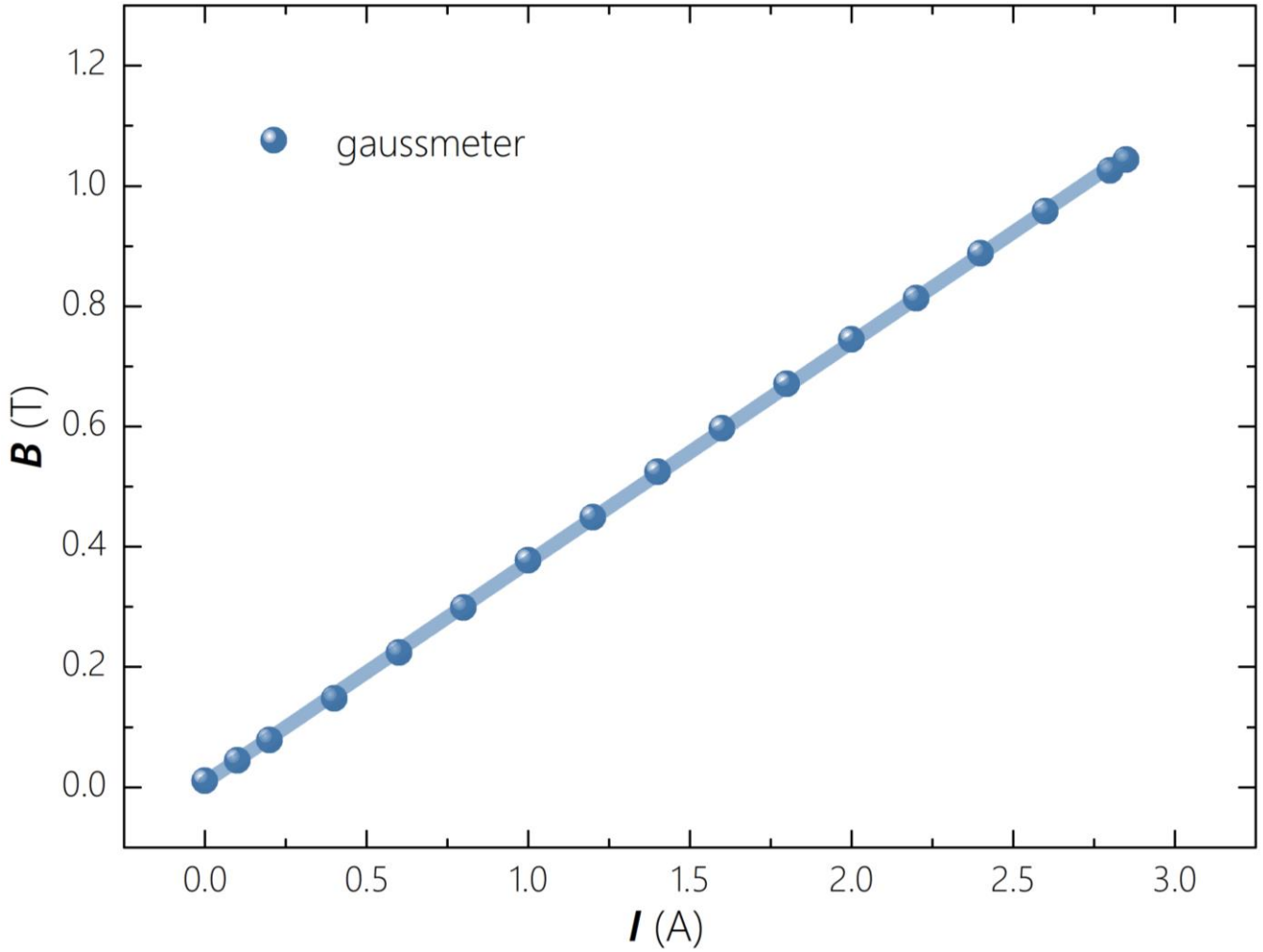






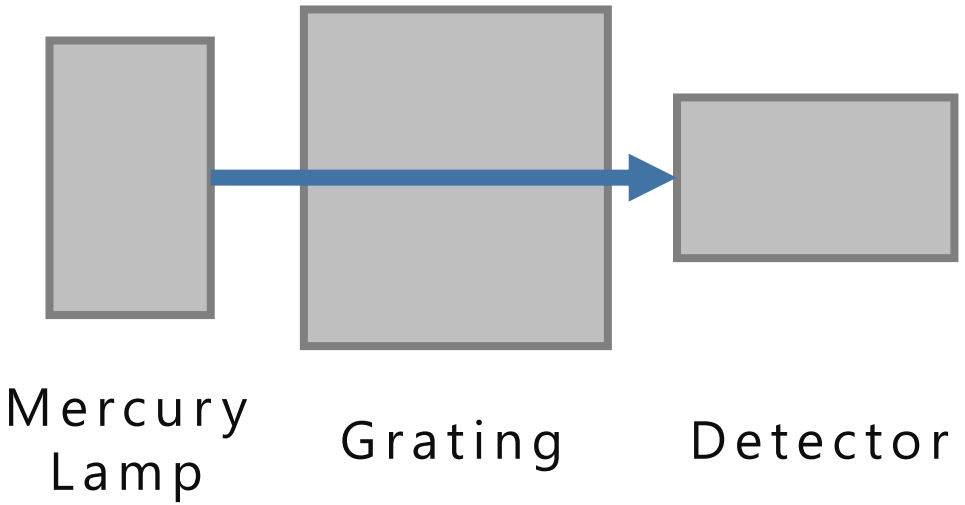
实验分析

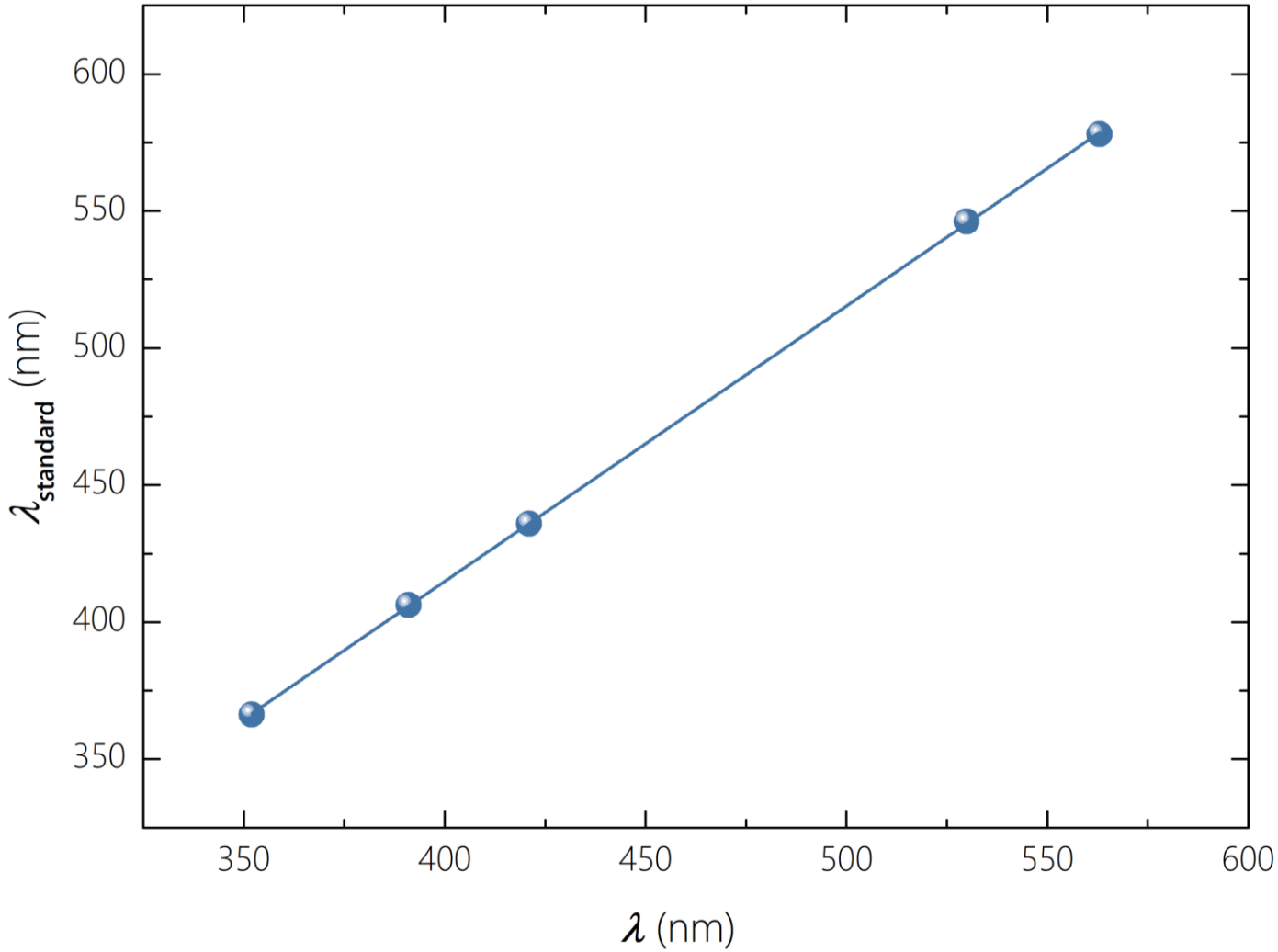




$$\boldsymbol{B} = [(3.656 \pm 0.011) \times 10^{-1}\boldsymbol{I}(\mathrm{A}) + (8.0 \pm 1.8) \times 10^{-2}](\mathrm{T})$$

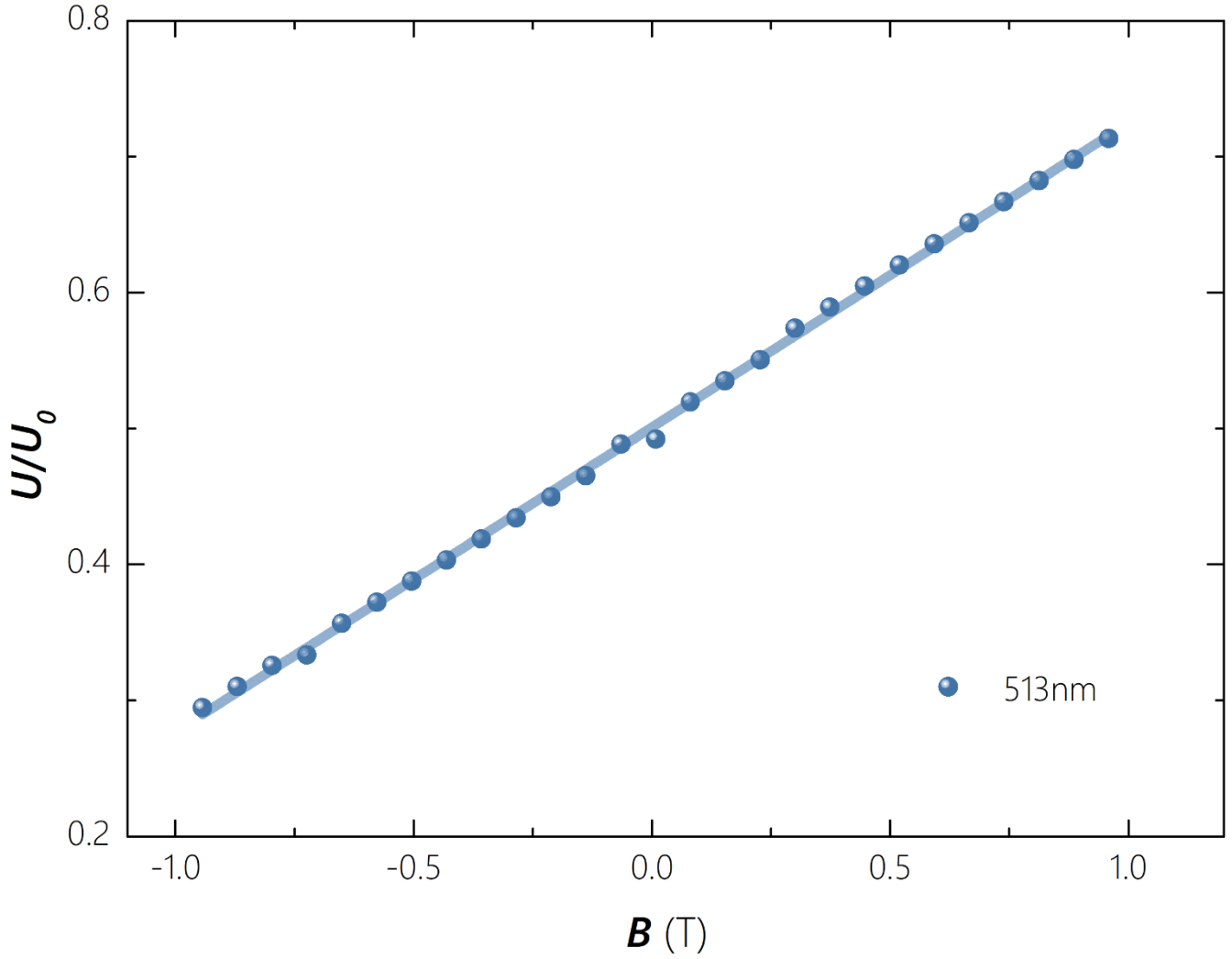
实验分析





$$\lambda_{standard} = [(1.004 \pm 0.003)\lambda(\mathrm{nm}) + (13.0 \pm 1.4)](\mathrm{nm})$$

实验分析

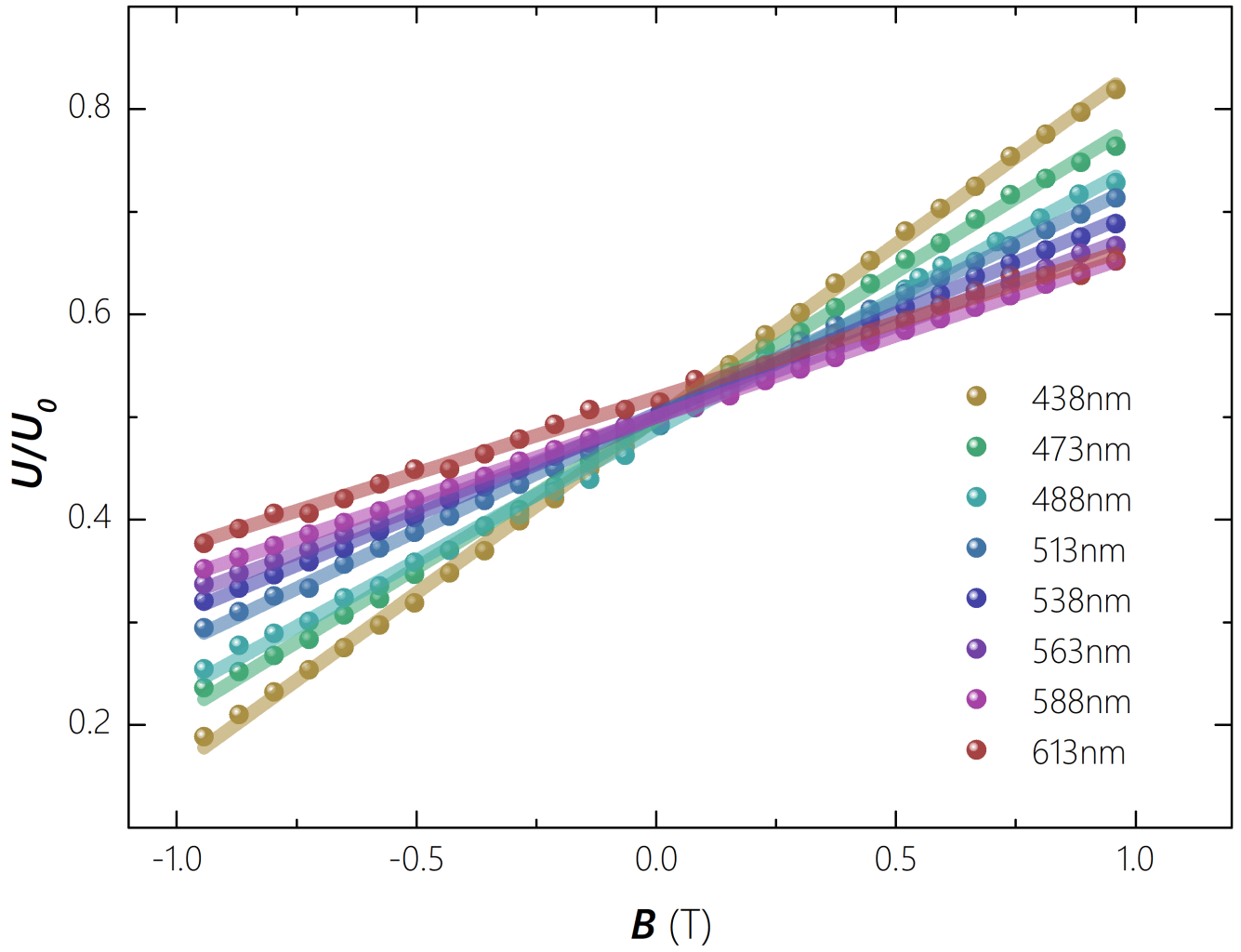


@45度 $\Delta U = \frac{dU}{d\theta}\Delta\theta \propto B$

$r^2 = 0.9994$

实验分析

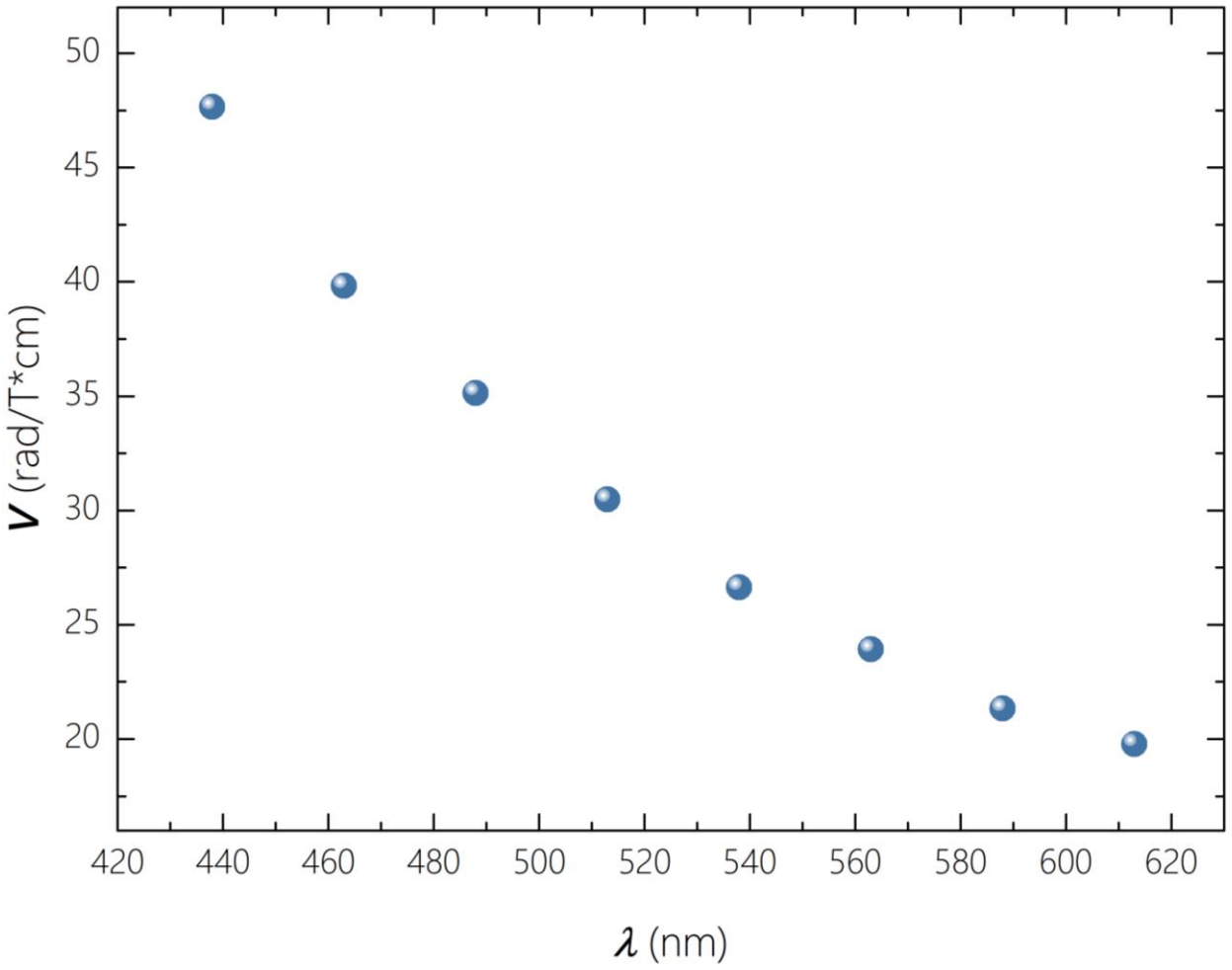
V



@45度 $\Delta U = \frac{dU}{d\theta}\Delta\theta \propto B$

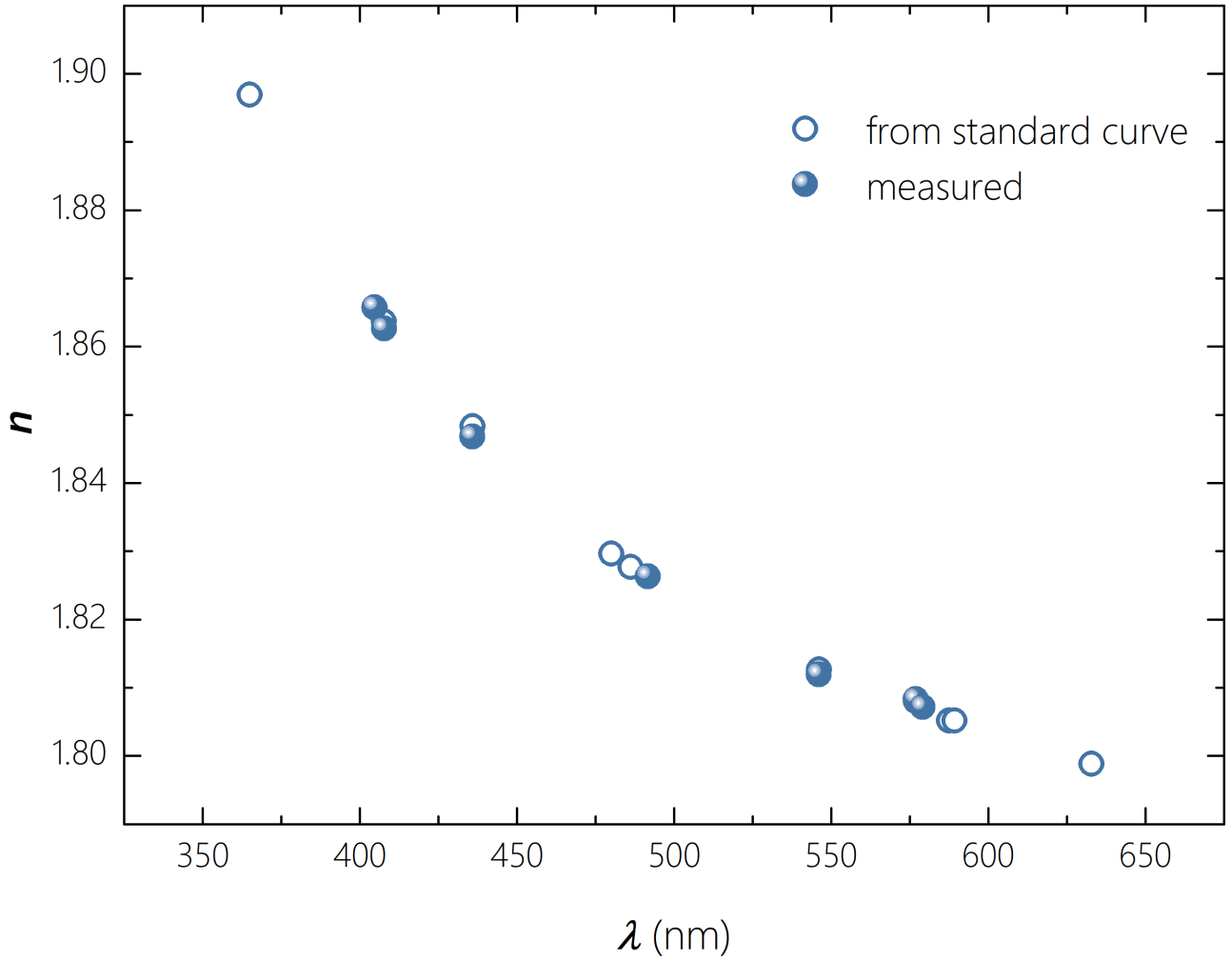
$$\Delta\varphi = \frac{\Delta\theta}{2} = -\frac{e}{2mc}\lambda\frac{\mathrm{d}n}{\mathrm{d}\lambda}DB$$

实验分析


50
45
40
35
30
25
20
V (rad/T*cm)
420
440
460
480
500
520
540
560
580
600
620
λ (nm)

实验分析

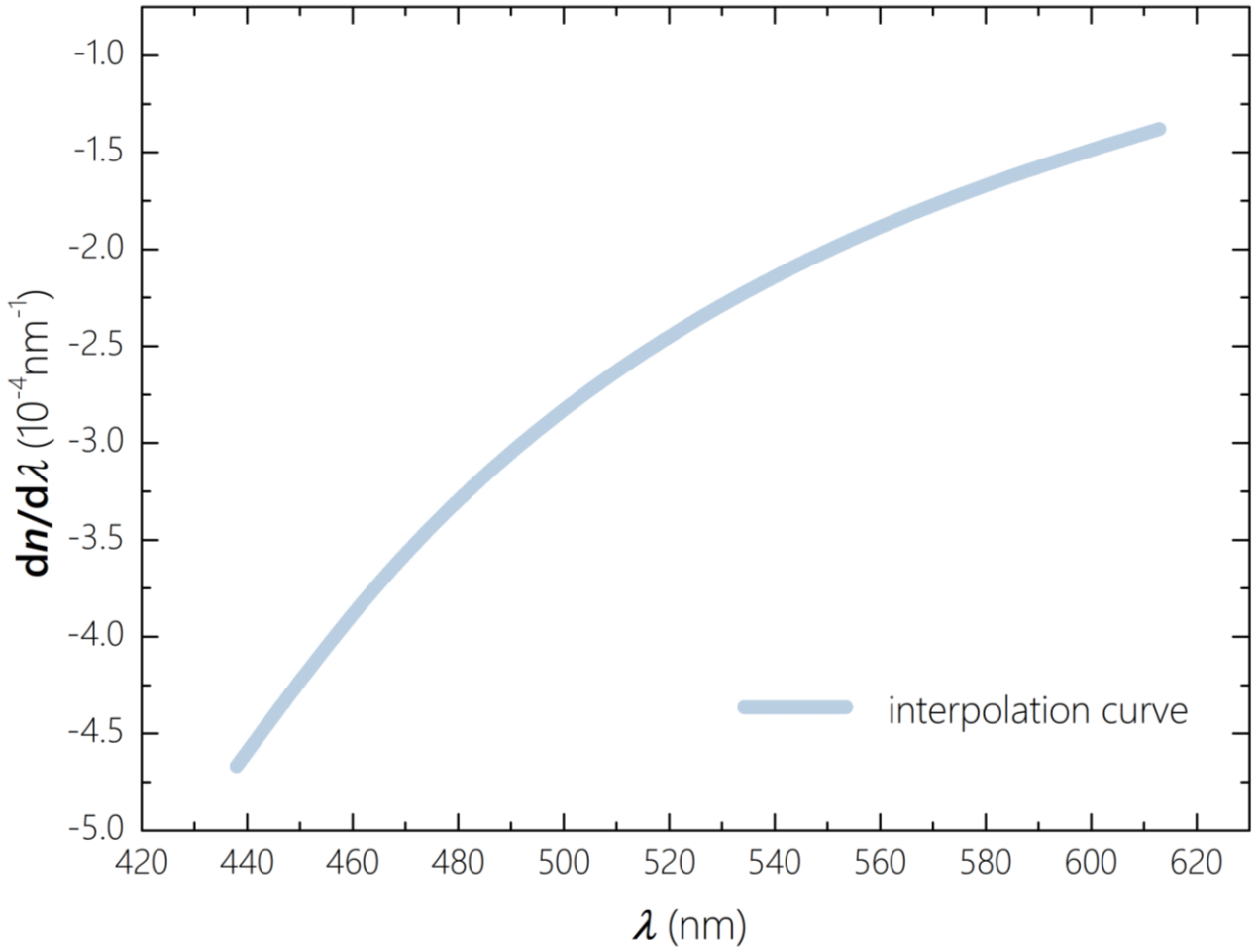
$n \sim \lambda$



https://refractiveindex.info/?shelf=glass&book=CDGM-ZF&page=ZF7

实验分析

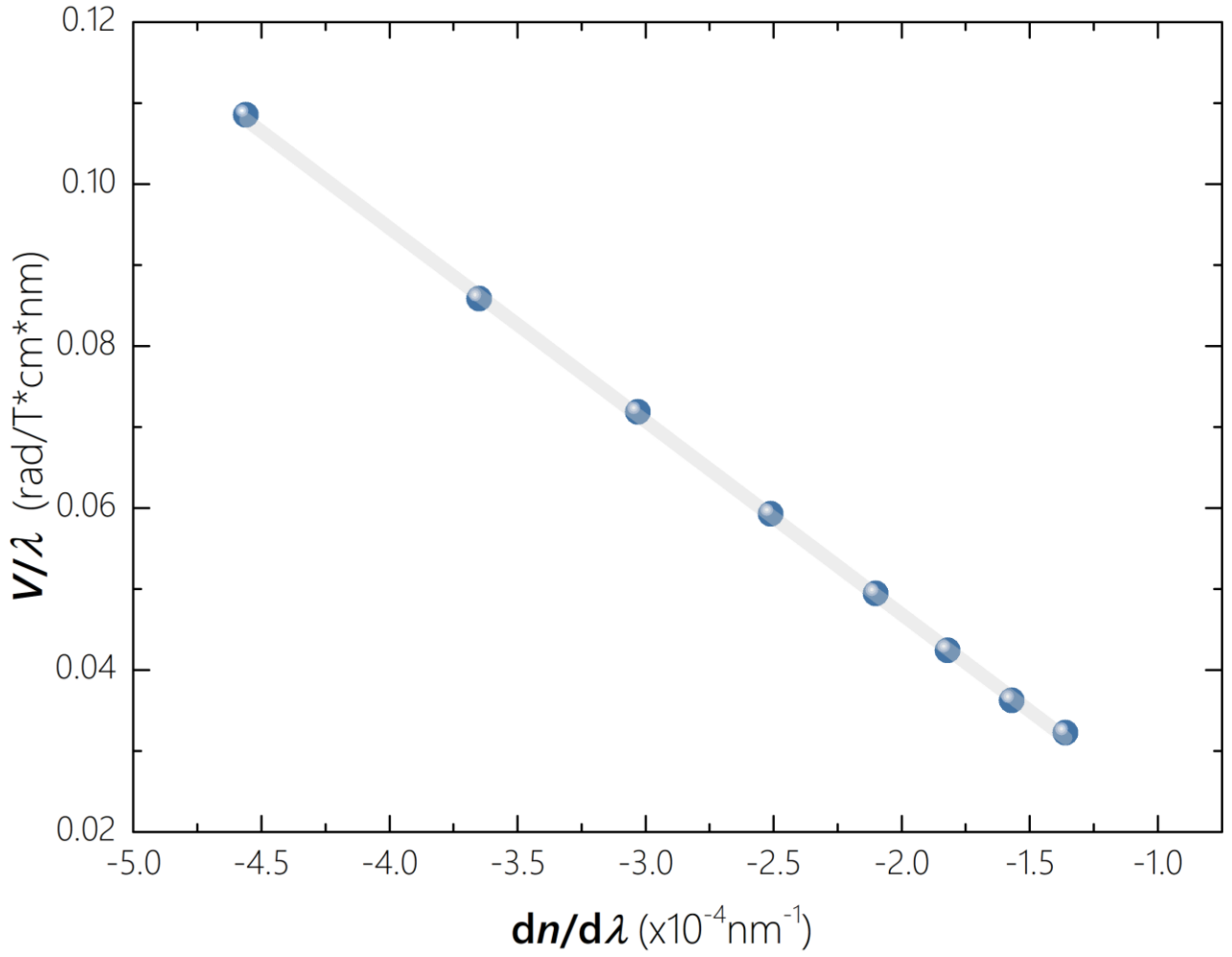
$d n/d \lambda \sim \lambda$



Method:
Spline

实验分析

e/ m



$$\frac{V}{\lambda} = -\frac{e}{2m^*c}\frac{\mathrm{d}n}{\mathrm{d}\lambda}$$

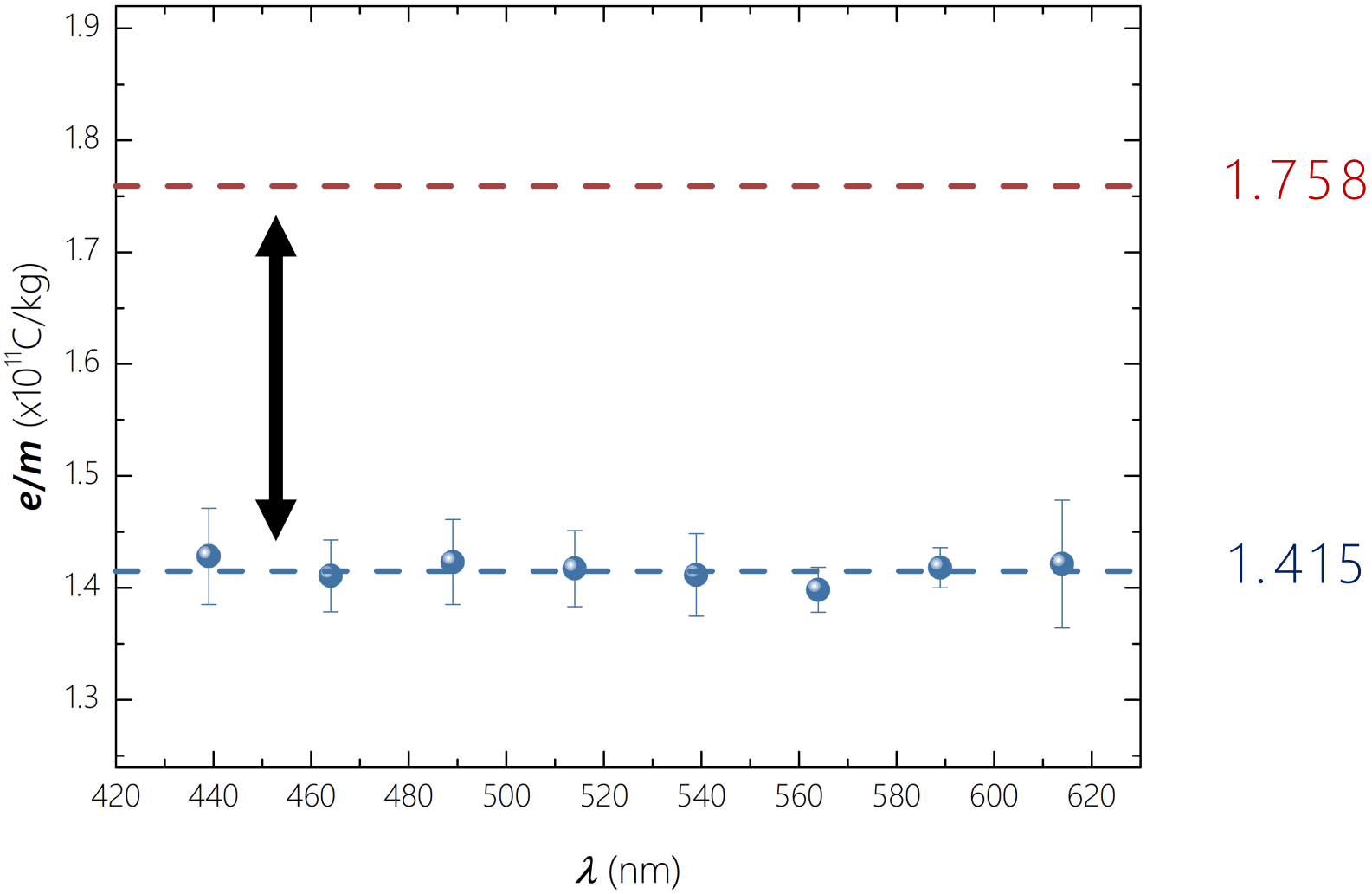
$$r^2 = 0.9997$$

实验分析

e/ m

~20%

电子有效质量



误差分析　　e/m不确定度

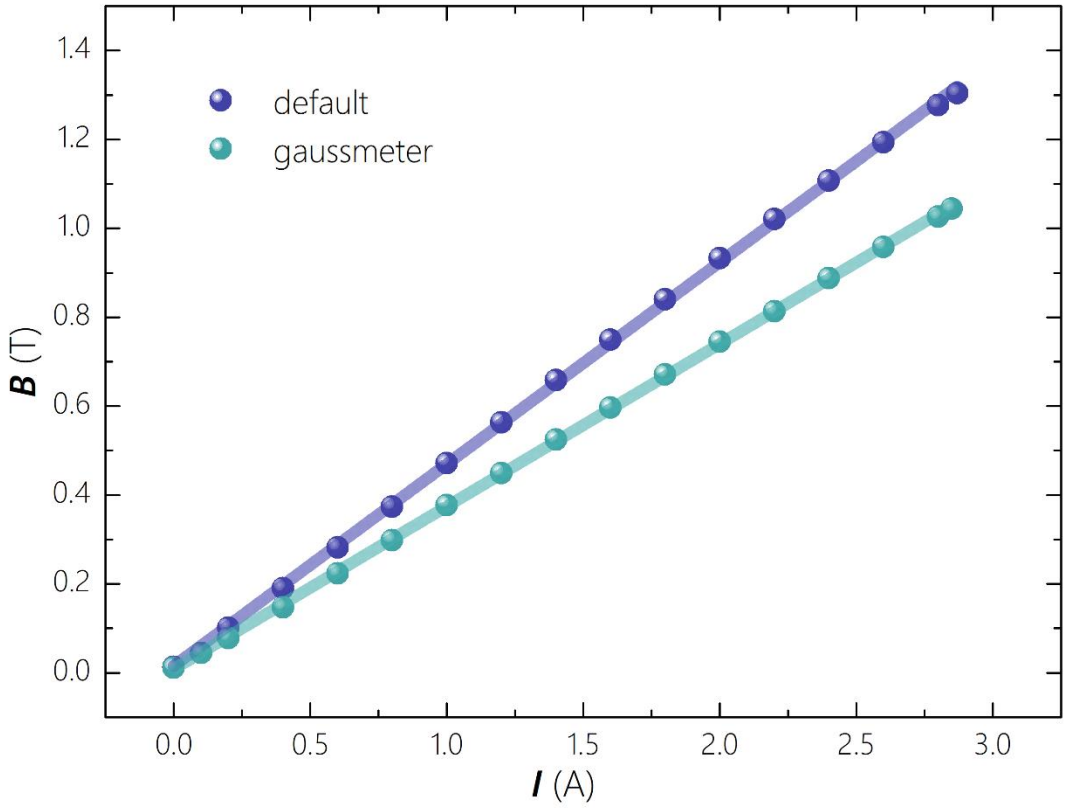
- 旋光角与磁场的关系　$\Delta\varphi = \frac{\Delta\theta}{2} = -\frac{e}{2mc}\lambda\frac{\mathrm{d}n}{\mathrm{d}\lambda}DB$　$\Delta U = \frac{dU}{d\theta}\Delta\theta \propto B$
- 色散关系$n \sim \lambda \rightarrow \mathrm{d}n \sim \mathrm{d}\lambda$

$$\frac{e}{m} = -\left(\frac{c}{D}\right)\Delta U\frac{d\theta}{dU}\left(\frac{1}{\lambda B}\right)\frac{\mathrm{d}\lambda}{\mathrm{d}n}$$

  - 拟合(与插值法)不确定度：$\frac{d\theta}{dU}$，　λ，　B，　$\frac{d\lambda}{dn}$　　$\sim 2\%$
  - 测量不确定度：　B

误差分析

e/m不确定度



核磁共振
永磁体检验

$$\boldsymbol{B_{default}} = [(4.54 \pm 0.02) \times 10^{-1}\boldsymbol{I}(\mathrm{A}) + (1.5 \pm 0.3) \times 10^{-2}](\mathrm{T})$$

$$\boldsymbol{B_{gaussmeter}} = [(3.656 \pm 0.011) \times 10^{-1}\boldsymbol{I}(\mathrm{A}) + (8.0 \pm 1.8) \times 10^{-2}](\mathrm{T})$$

误差分析　　e/m不确定度

- 旋光角与磁场的关系　$\Delta\varphi = \frac{\Delta\theta}{2} = -\frac{e}{2mc}\lambda\frac{\mathrm{d}n}{\mathrm{d}\lambda}DB$　$\Delta U = \frac{dU}{d\theta}\Delta\theta \propto B$
- 色散关系$n \sim \lambda \rightarrow \mathrm{d}n \sim \mathrm{d}\lambda$

$$\frac{e}{m} = -\left(\frac{c}{D}\right)\Delta U\frac{d\theta}{dU}\left(\frac{1}{\lambda B}\right)\frac{\mathrm{d}\lambda}{\mathrm{d}n}$$

  - 拟合(与插值法)不确定度：　$\frac{d\theta}{dU}$，　λ，　B，　$\frac{d\lambda}{dn}$　　~2%
  - 测量不确定度：　B　　~1%

误差分析

$\mathbf{d}n/\mathbf{d}\lambda \sim \lambda$

- 插值法（Method: Spline）
- 拟合？

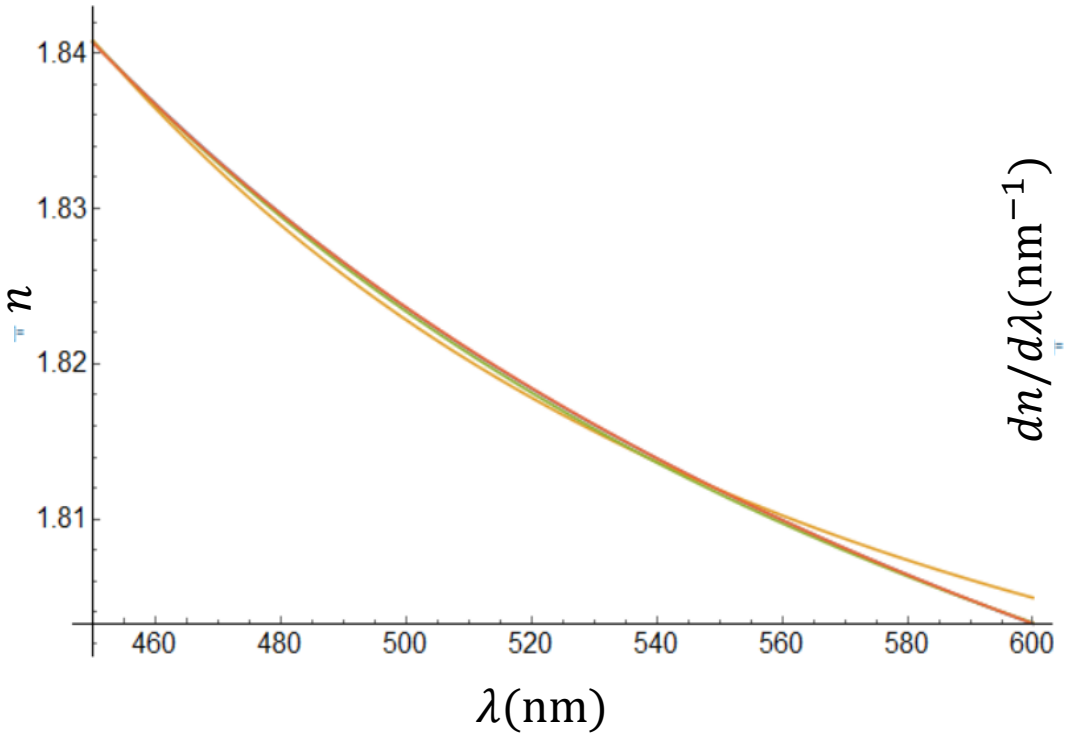
Cauchy经验公式

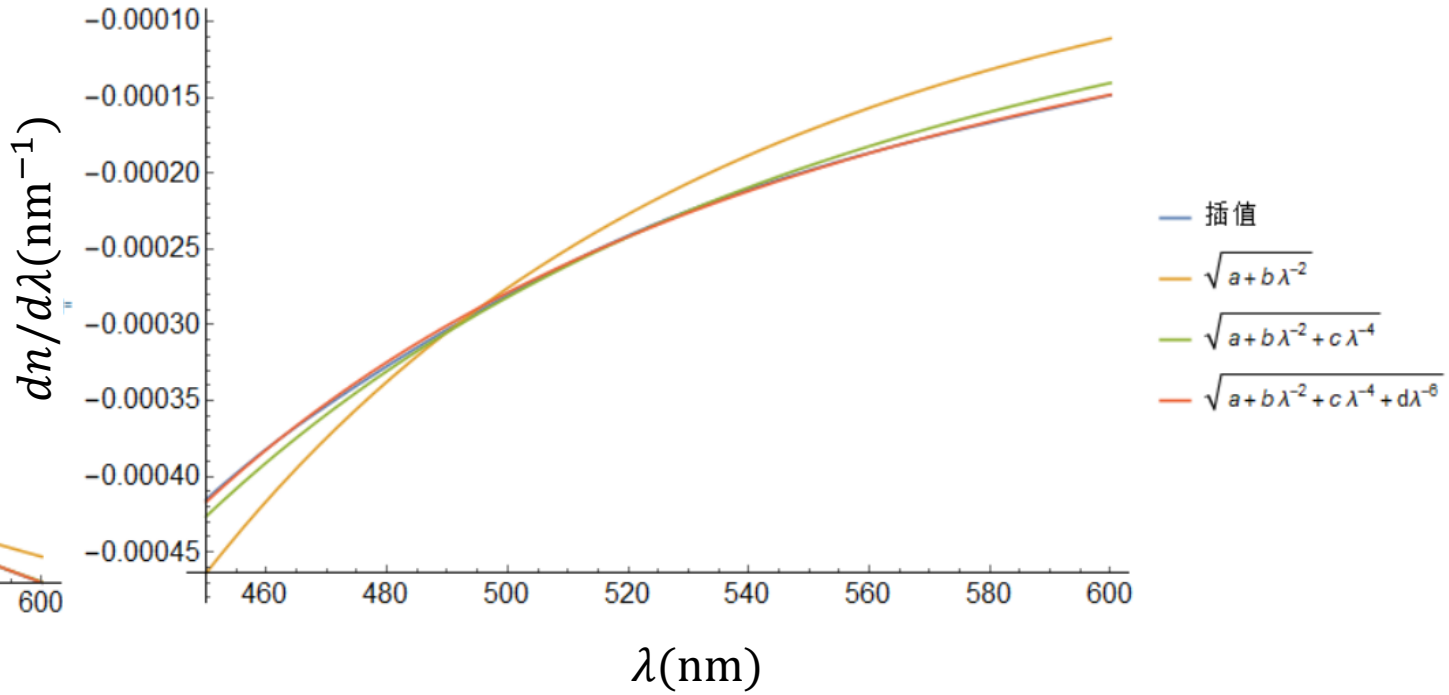
$$y = a + b\lambda^{2} + c\lambda^{-2}$$

$$y = \sqrt{(a + b\lambda^{-2} + c\lambda^{-4})}$$

$$y = \sqrt{(a + b\lambda^{-2} + c\lambda^{-4} + d\lambda^{-6})}$$

误差分析


1.84
1.83
1.82
1.81
n
460
480
500
520
540
560
580
600
λ(nm)

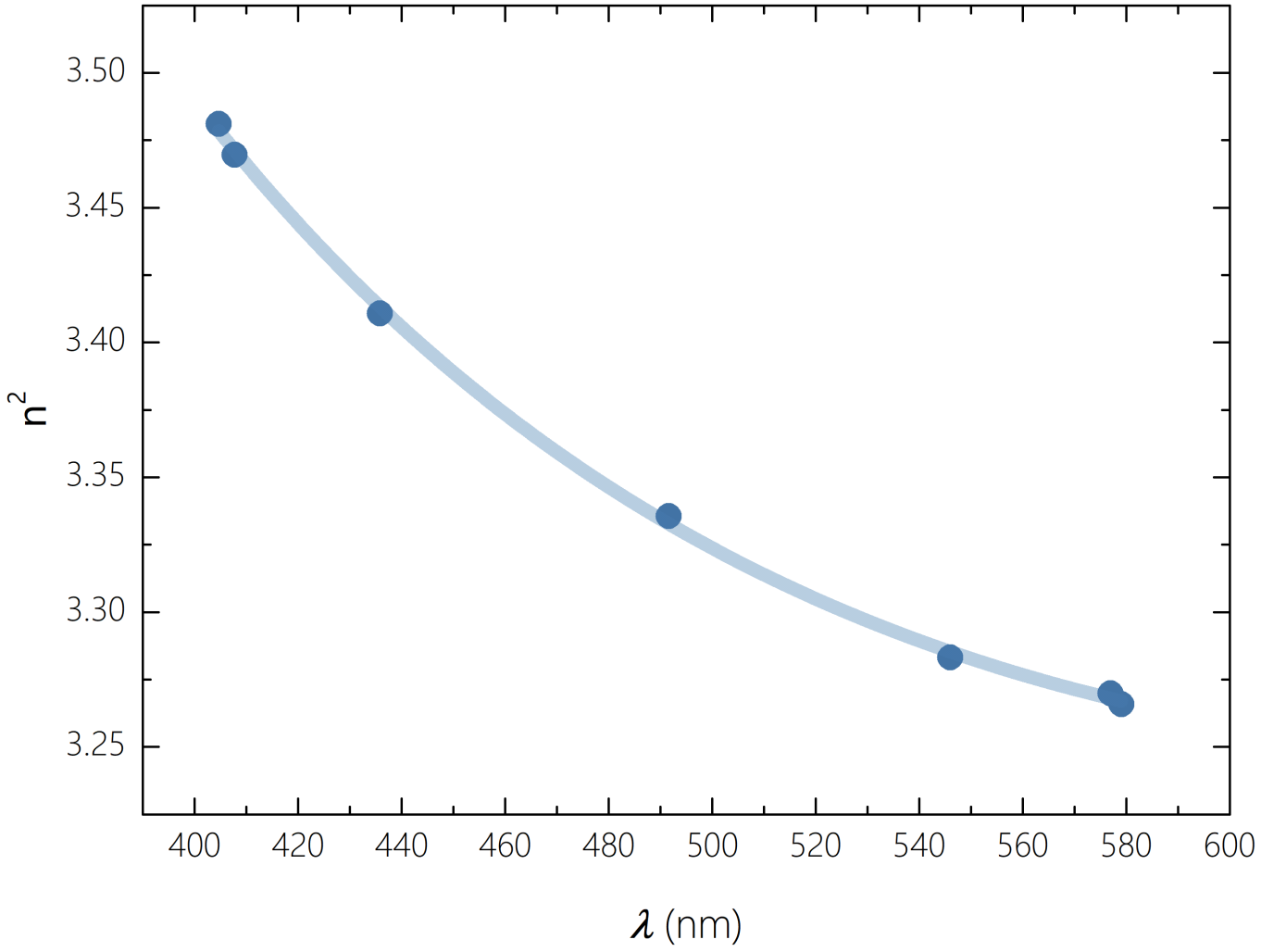

−0.00010
−0.00015
−0.00020
−0.00025
−0.00030
−0.00035
−0.00040
−0.00045
dn/dλ(nm⁻¹)
460
480
500
520
540
560
580
600
λ(nm)
插值
√(a+bλ⁻²)
√(a+bλ⁻²+cλ⁻⁴)
√(a+bλ⁻²+cλ⁻⁴+dλ⁻⁶)

结论

- 检验偏振偏转　$\Delta\varphi \propto B$
- 检验定量常数　$\frac{e}{m^*} = (1.415 \pm 0.003) \times 10^{11}\ (\mathrm{C/kg})$
- 误差分析：拟合、测量

  $(\mathrm{d}n/\mathrm{d}\lambda) \sim \lambda$拟合方法

附录


3.50
3.45
3.40
3.35
3.30
3.25
n^2
400
420
440
460
480
500
520
540
560
580
600
λ (nm)