近代物理实验报告

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复旦大学物理系实验教学中心

Faraday Magneto-Optical Effects

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Outline

- Objective

- Faraday effect

- Experimental analysis
- ✓ Magnet calibration
- ✓ Faraday rotation and the measurement of Verdet constant
- ✓ The measurement of the angle of minimum deviation and the apex angle of the flint glass prism
- ✓ The measurement of e/m

- Results

1. Objective

To observe the interaction of light and matter, as modified by the presence of a magnetic field, and to apply the classical theory of matter to the observations. You will measure the Verdet constant for this glass and obtain the value of e/m, the charge to mass ratio for the electron.

2.1 Faraday Effect

Presentation of linearly polarized light as a superposition of circularly polarized components

$$\boldsymbol{E}(x,t) = \boldsymbol{E}_r + \boldsymbol{E}_l,$$

where

$$\boldsymbol{E}_r(x,t) = \{0,\ (A/2)\cos[\omega(t - nx/c)],\ (A/2)\sin[\omega(t - nx/c)]\}$$

and

$$\boldsymbol{E}_l(x,t) = \{0,\ (A/2)\cos[\omega(t - nx/c)],\ -(A/2)\sin[\omega(t - nx/c)]\}$$

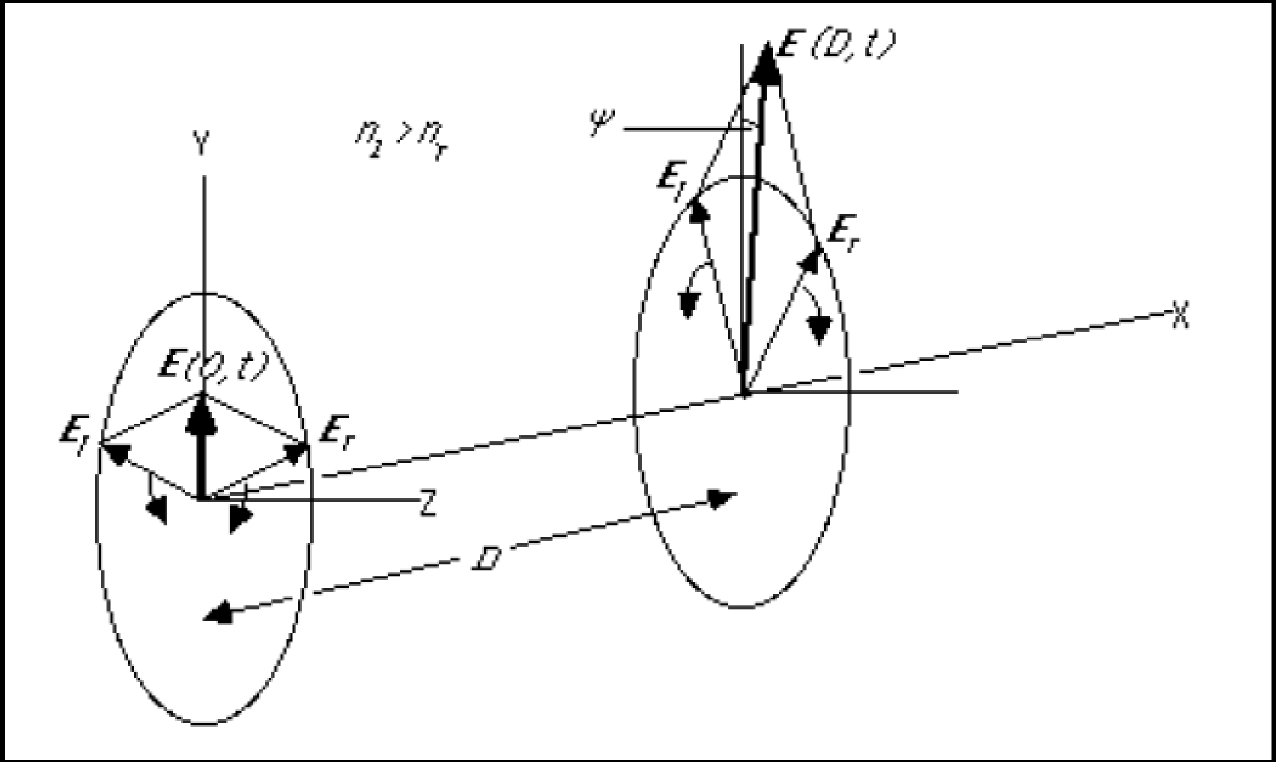
2.1 Faraday Effect

Referring to the difference between the velocities for the right and left circularly polarized waves, we replace n with nr and nl.

$$E(D,t) = \{0,\ A\cos[\omega(t-(n_r+n_l)D/2c)]\cos[\omega(n_l-n_r)D/2c],$$
$$A\cos[\omega(t-(n_r+n_l)D/2c)]\sin[\omega(n_l-n_r)D/2c]\}.$$

2.1 Faraday Effect

Addition of right and left circularly polarized components on two planes defined by x=0 and x=D, respectively. Because nl > nr, El is more retarded in phase at x=D relative to x=0 than Er, with the result that their sum at x=D is rotated clockwise by the angle = (nl-nr)D/λ



http://web.mit.edu/8.13/www/JLExperiments/JLExp08.pdf

2.1 Faraday Effect

- The Faraday effect at moderate field is quite small. However in a typical D/λ >>1, it could be sufficiently large to be observed.

$$\psi = \tan^{-1}\left(\frac{E_z}{E_y}\right) = \frac{\omega\,(n_l - n_r)D}{2c} = \frac{\pi\,(n_l - n_r)D}{\lambda},$$

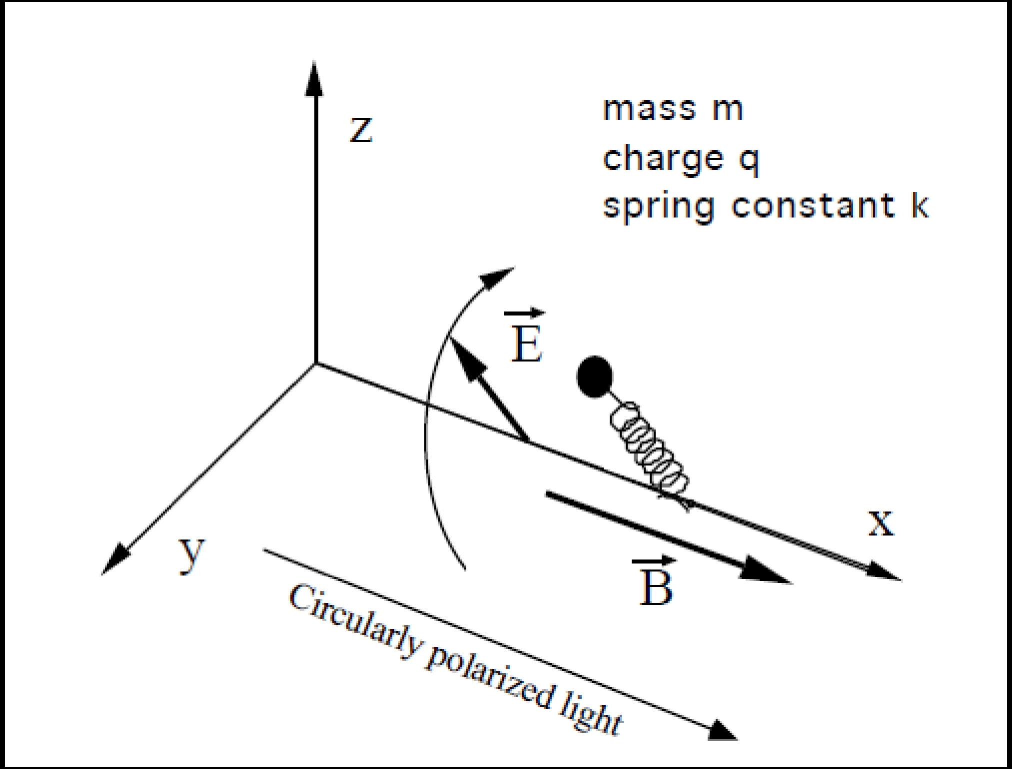
2.2 Becquerel's theory

- Experimentally, the Faraday rotation angle is proportional to the product of *D and the magnetic field B.*

$$\Phi = VDB$$

where *V is a proportionality factor called the Verdet constant.*

2.2 Becquerel's theory



- A varying electric field of constant magnitude E rotating clockwise with respect to B

$$-m\omega^2 r = -kr + Eq + Bq\omega r/c \ ,$$

$$r = (Eq/m)/(\omega_0^2 - \omega^2 - Bq\omega/mc) \ ,$$

where

$$\omega_0 = (k/m)^{1/2} \ .$$

$$n_l - n_r = (dn/d\omega)(\Delta\omega_l - \Delta\omega_r) = (dn/d\lambda)(\lambda^2/2\pi c)(Bq/mc),$$

http://web.mit.edu/8.13/www/JLExperiments/JLExp08.pdf

2.2 Becquerel's theory

$$\psi = \frac{dn}{d\lambda}\frac{\lambda}{2c^2}\frac{q}{m}DB$$

Faraday rotation

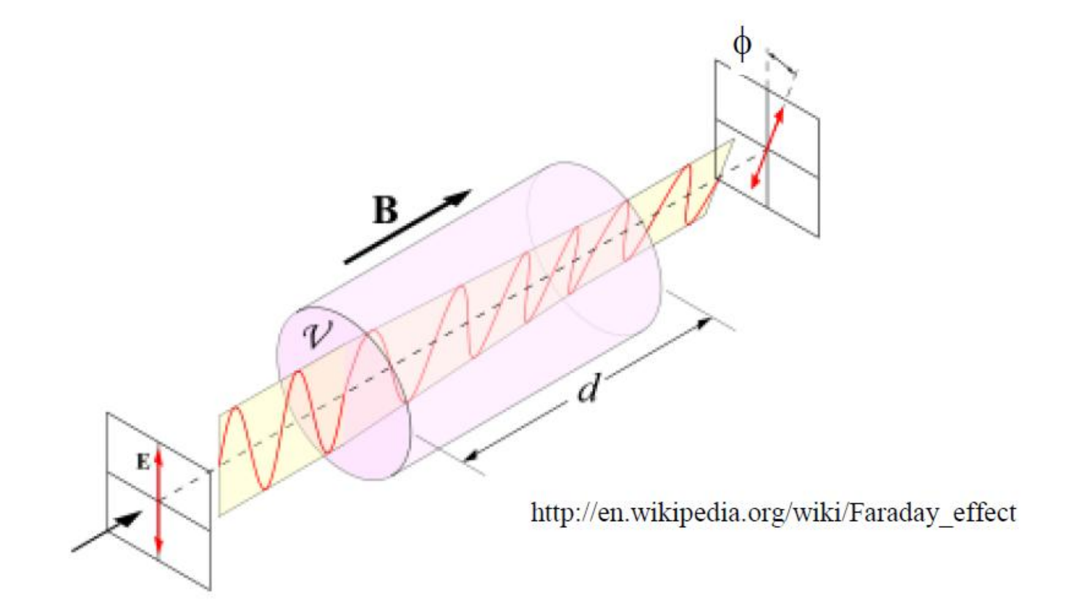
$$V = \frac{dn}{d\lambda}\frac{\lambda}{2c^2}\frac{q}{m}$$

Verdet constant in Becquerel's theory

$$V = \phi/dB = -\frac{1}{2}\frac{e}{m}\frac{\lambda}{c}\frac{dn}{d\lambda}$$

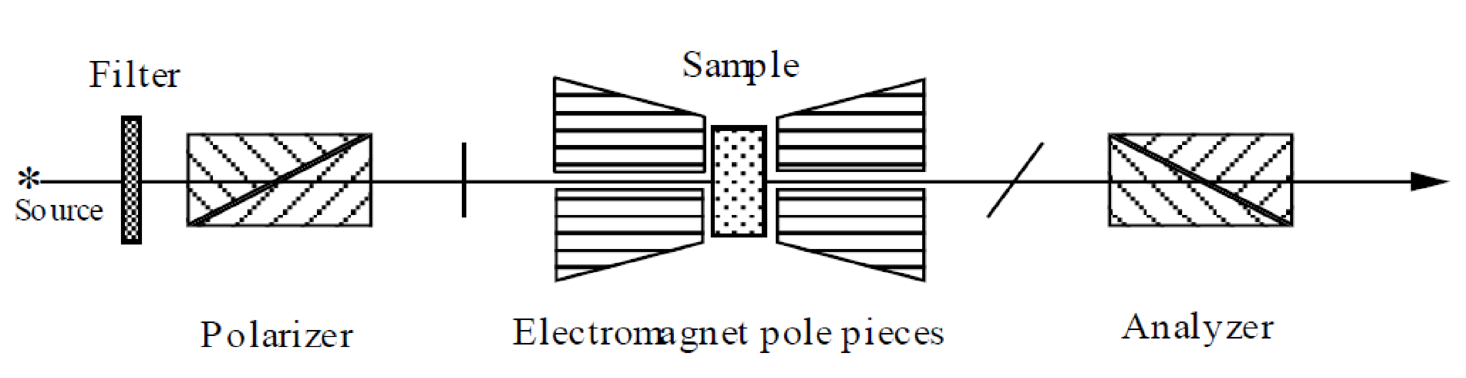
Verdet constant in experiment

3.0 Set up



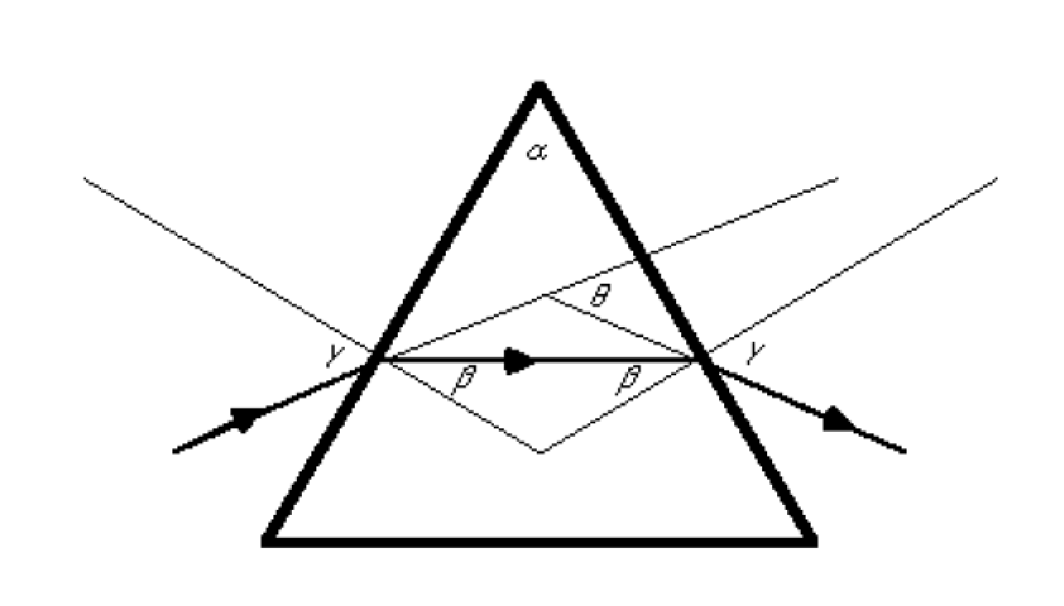
$$V = \phi/dB = -\frac{1}{2}\frac{e}{m}\frac{\lambda}{c}\frac{dn}{d\lambda}$$

- Faraday rotation Φ
- Light path d
- Magnetic field B
- Light wavelength λ



3.0 Set up

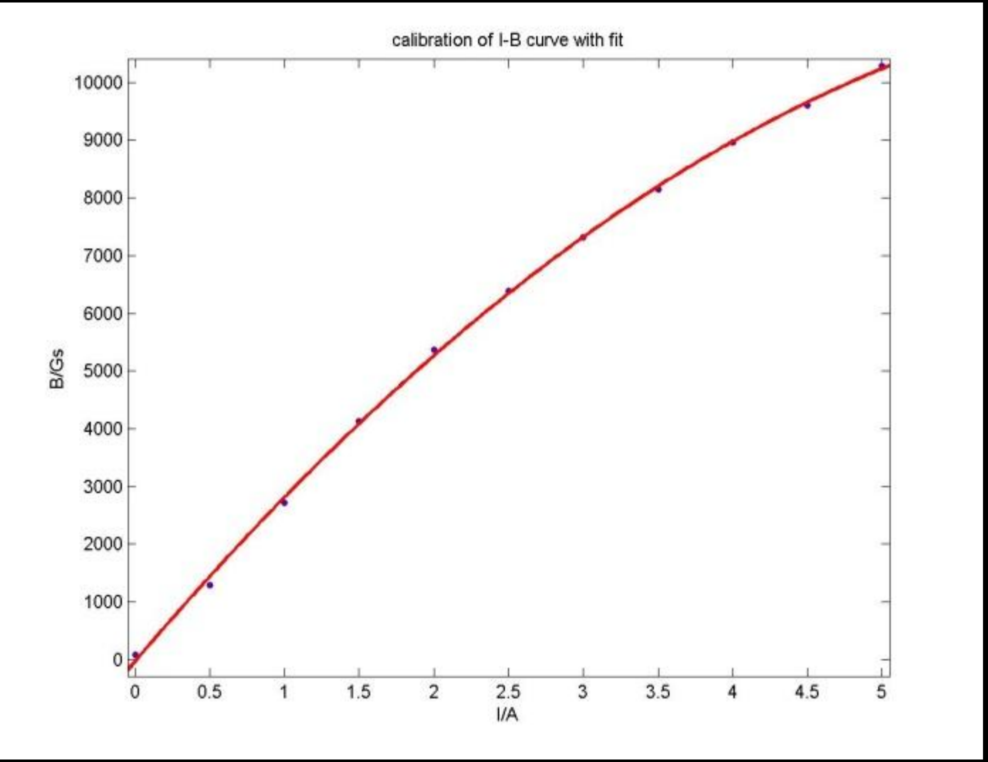
$$V = \phi/dB = -\frac{1}{2}\frac{e}{m}\frac{\lambda}{c}\frac{dn}{d\lambda}$$



- Index of refraction n

$$n = \frac{\sin\frac{(\theta + \alpha)}{2}}{\sin\frac{\alpha}{2}} \quad .$$

3.1 Magnet Calibration



- In general, one should never interrupt a magnet current suddenly by opening a wall switch or flipping a reversing switch.
- With the current set at 11 amperes measure the field for three times between the pole pieces from one side of the gap to the other along the axis of the pole pieces.

Model: f(x) = p1*x^2 + p2*x + p3

Coefficients (with 95% confidence bounds):

p1 = -197.9 (-227.1, -168.6)

p2 = 3044 (2892, 3196)

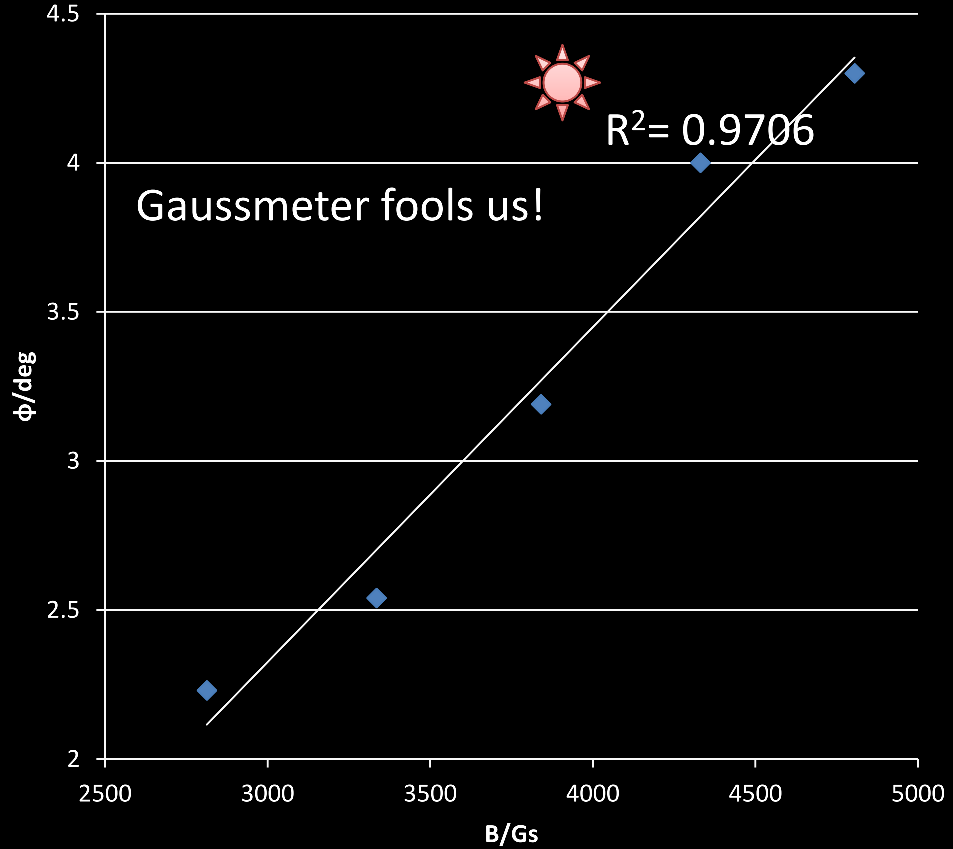
p3 = -32.65 (-195.8, 130.5)

R-square: 0.9994

Not linear

3.2 Measurement of Faraday Rotation

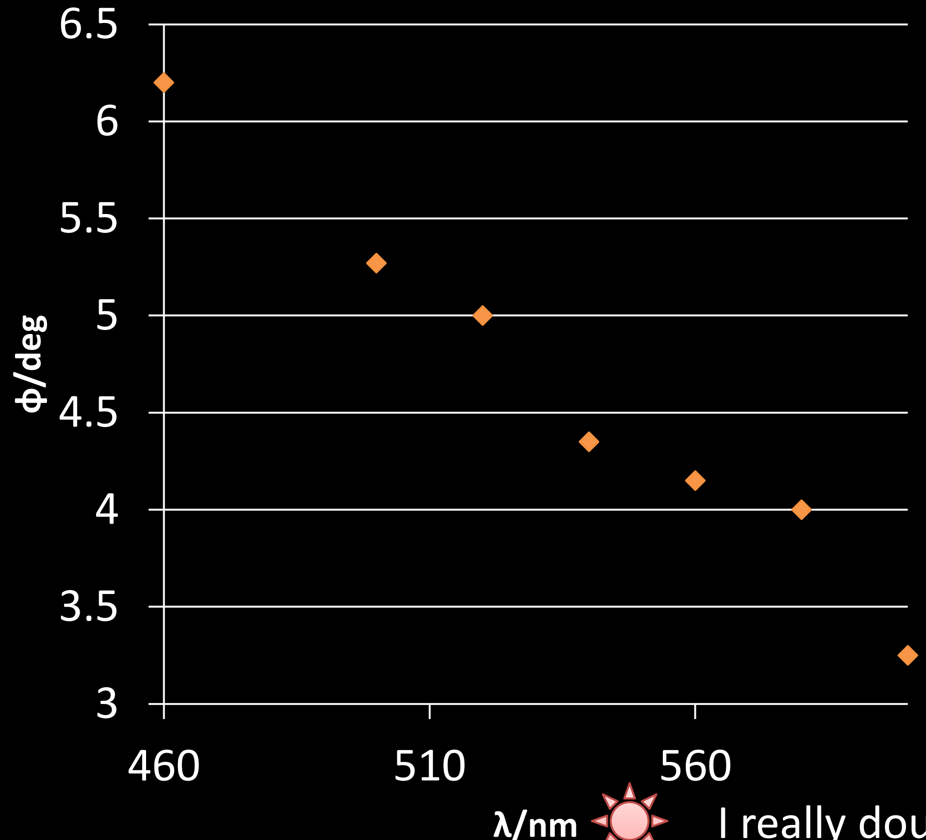
λ=580nm



$$V = \phi/dB = -\frac{1}{2}\frac{e}{m}\frac{\lambda}{c}\frac{dn}{d\lambda}$$

3.2 Measurement of Faraday Rotation

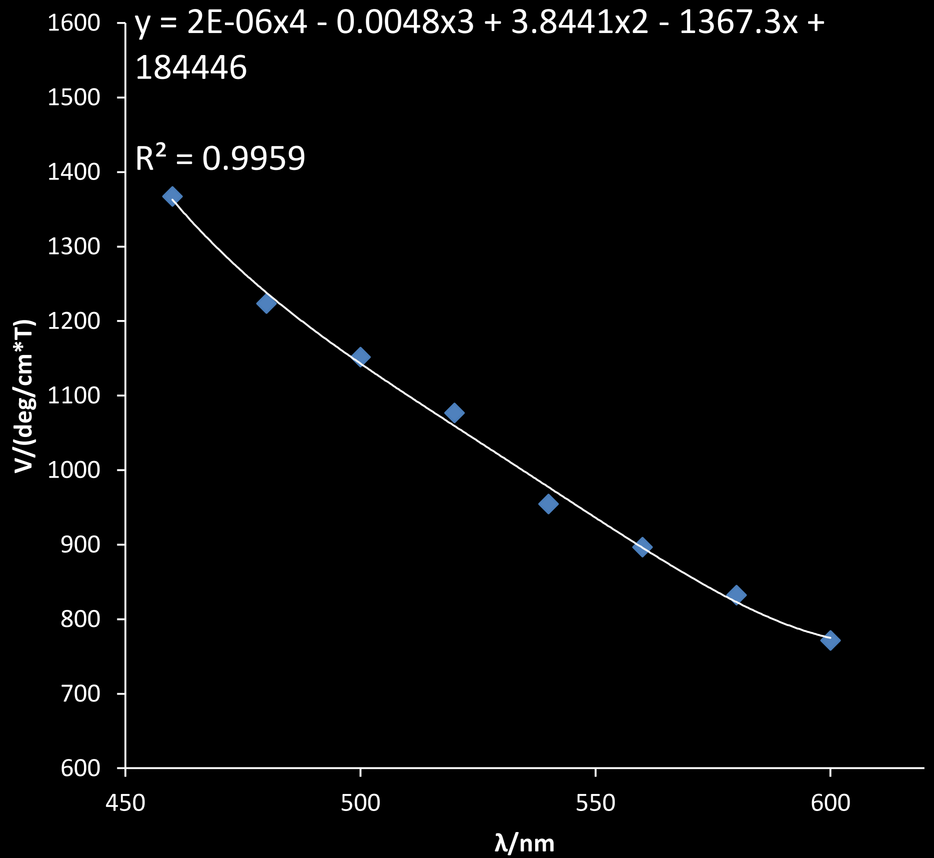
B=4331.126Gs



I really doubt it!

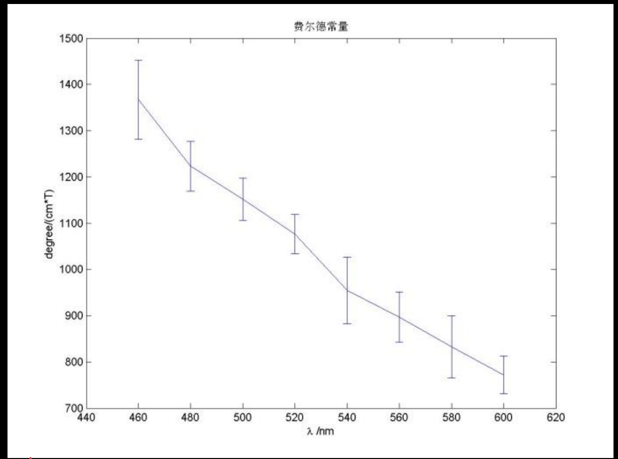
$$V = \phi/dB = -\frac{1}{2}\frac{e}{m}\frac{\lambda}{c}\frac{dn}{d\lambda}$$

3.2 Measurement of Faraday Rotation



Verdet Constant

$$V = \phi/dB = -\frac{1}{2}\frac{e}{m}\frac{\lambda}{c}\frac{dn}{d\lambda}$$



Very large uncertainty!

3.3 Determination of the Dispersion as a Function of Wavelength

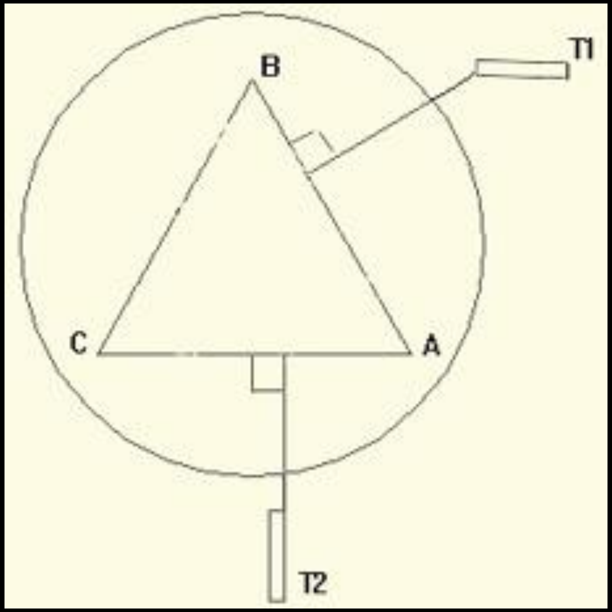
- Apex angle measurement
- 59º58’ 120º1’ 120º0’
- Result

1.04766rad

1.04749rad

1.04720rad

A = 1.04710 rad = 60º



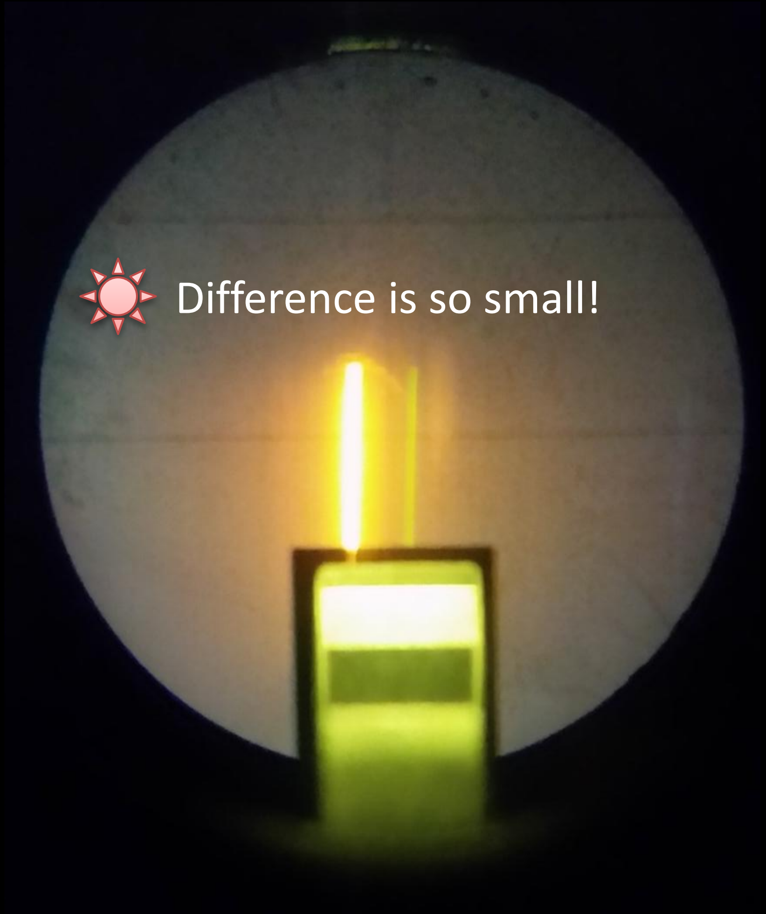
http://phylab.jhun.edu.cn/Lesson/11072_1_f_2/fgjyuanli.htm

3.3 Determination of the Dispersion as a Function of Wavelength

- Na source

☼ Width of the image!

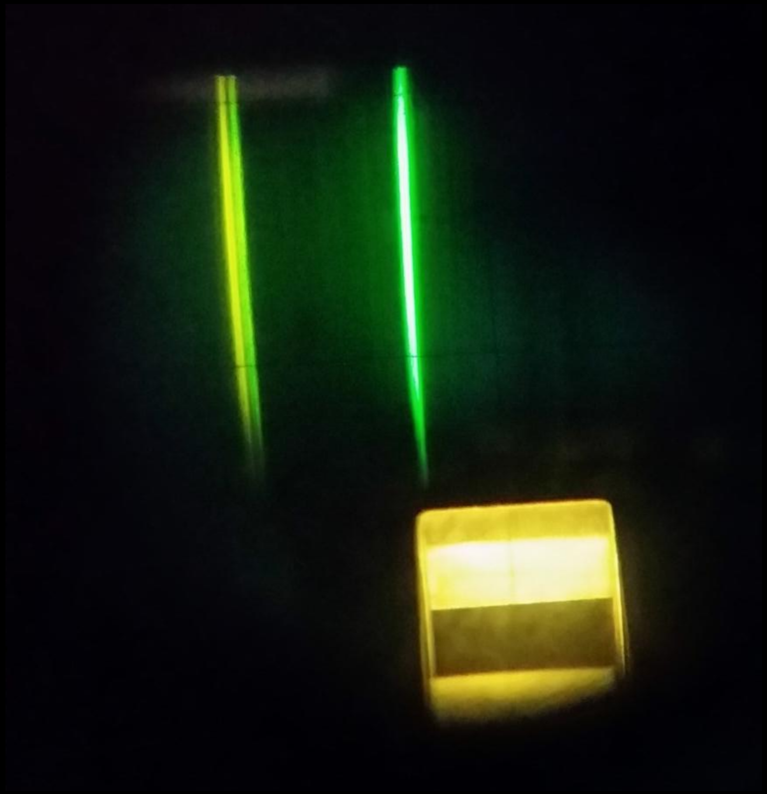
Color	Wavelength	Angel of minimum deviation	Refraction index n
Red(I, II)	589.29	62.15	1.7505
Orange	568.56	62.10	1.7500
Green	498.15	62.89	1.7567
Violet	330.06	64.56	1.7705



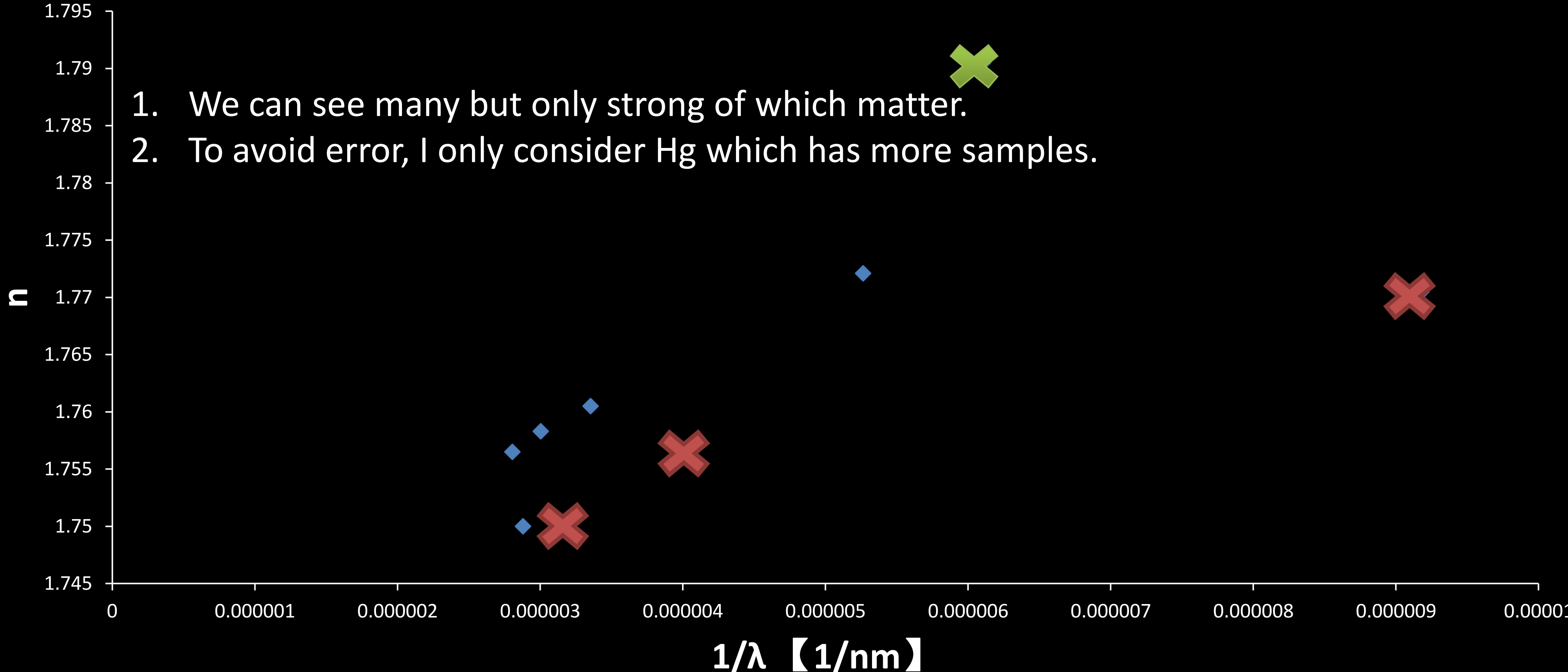
3.3 Determination of the Dispersion as a Function of Wavelength

- Hg source

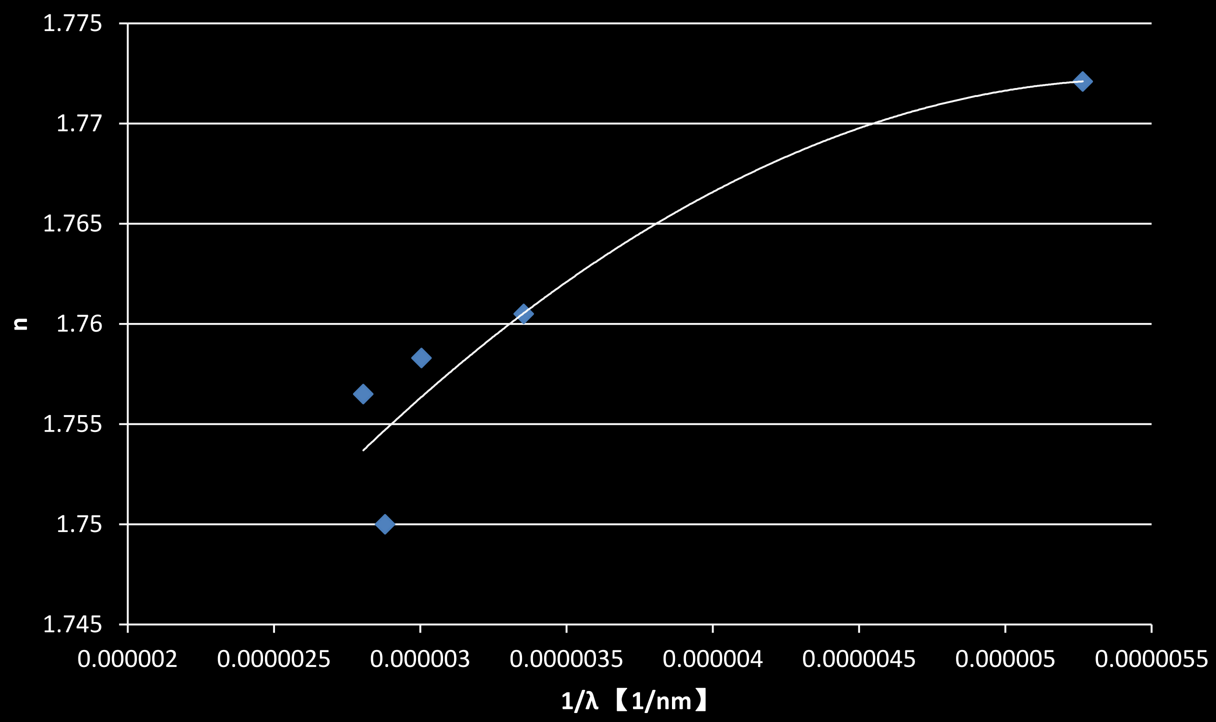
Color	Wavelength	Angel of minimum deviation	Refraction index n
Yellow I	597.07	63.08	1.7583
Yellow II	579.96	62.86	1.7565
Green	546.07	63.43	1.7605
Light green	435.85	64.76	1.7721
Violet	404.66	67.08	1.7905



3.3 Determination of the Dispersion as a Function of Wavelength



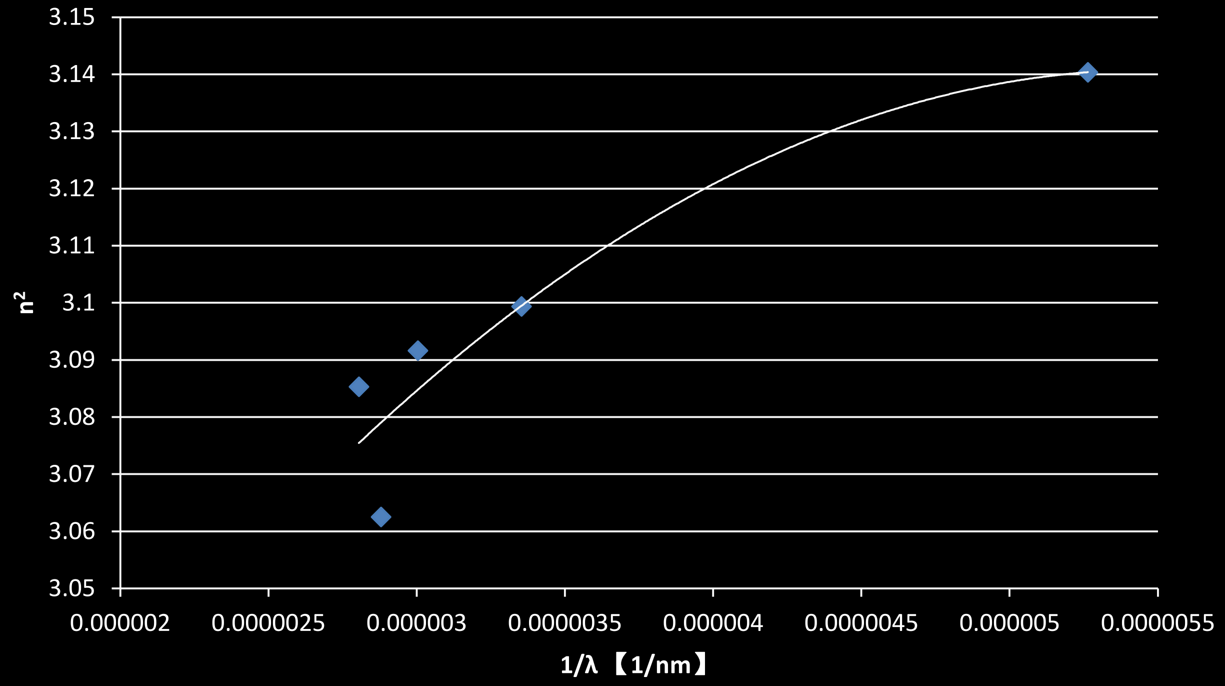
3.3 Determination of the Dispersion as a Function of Wavelength



$$n = A\frac{1}{\lambda^4} + B\frac{1}{\lambda^2} + C$$

A = -10^{-9}
B = 17420
C = 1.7151
R^2 = 0.9025

3.3 Determination of the Dispersion as a Function of Wavelength



$$n^2 = A\frac{1}{\lambda^4} + B\frac{1}{\lambda^2} + C$$

$A = -4\text{x}10^{-9}$
$B = 61425$
$C = 2.9394$
$R^2 = 0.9035$

3.4 Measurements of e/m

Source	Color	dn/dλ (10^{-4}nm)	λ(nm)	V (deg/T*cm)	e/m (10^{11}c/kg)
Na	Yellow (I, II)	0.4650	589.29	803.41	1.0972
Hg	Yellow I	0.4502	597.07	774.52	1.1185
	Yellow II	0.4504	576.96	775.78	1.1169
	Green	0.5958	546.07	954.27	0.9241

e/m = $(1.17 \pm 0.08) \times 10^{11}$c/kg
The ideal value is 1.76×10^{11}c/kg
error 34%

Thanks

FIN.