Introduction to college physics experiments

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Classrooms of experiments

- 0. Introduction, J2-532
- 1. Spectrometer, J2-532
- 2. Michelson Interferometer, J2-534
- 3. Oscilloscope, J2-418
- 4. Double Bridge, J2-417
- 5. Wheatstone Bridge, J2-416
- 6. Dielectric constant measurement, J2-429
- 7. Torsional Pendulum, J2-427

Part 1

Rules of this course

1. Preparations

Key-points：

➢**Reference books, Handouts**

➢**Goals, methods, principles**

➢**Experimental conditions**

➢**Preparation reports**

Preparation report includes：

1. Title；

2. Your name, student ID, date;

3. Experimental goals；

4. Experimental principles;

5. Experimental apparatus (models, specifications) ;

6. Data Tables

2 . Experiments

At the beginning of the class, I will :

➤**Check your preparation reports of this lesson;**

➤**Ask for your previous experiment reports;**

➤**Show the experimental principles and the operation.**

During the experiments, you should:

➤**Follow the operating rules;**

➤**Observe experimental phenomena;**

➤**Record the data.**

➢**Experimental data and phenomenon；**

Record: date, time, place, temperature, pressure, instrument serial number, title, specifications, original data and phenomenon…

● **Requirement:** smooth writing, plotting (when necessary), data, results.

● **Good habit: process experimental data and submit reports in time.**

3、 Contents of experimental reports：

1、 Title

2、 Goals

3、 Instruments

4、 Principles

Before class

5、 Contents & steps

6、 Data processing

after class

7、 Discussions and analysis

Part 2

Measurement error and instrumental error range in physics experiments

1、 Measurement data & unit

➤ **data = value+unit**

e.g. : *175.0* **cm**

value   **unit**

The international system of units
(SI)：meter (m)、kilogram (kg)、second (s)、ampere (A)、Kelvin (K)、mole (mol)、candela (cd)

2、Measurement classification

direct

passive

e.g.

The cylinder's density

$$\rho = \frac{4\,m}{\pi D^2 h}$$

3、 Significant digit and more…

(1). Significant digit ： total digit number from first non-zero digit to the last one.

4.60cm≠4.600cm

(2). Significant digit's nature

a). Significant digit tells the precision of measuring instrument

length measurement with different precision

steel ruler： L=46.0mm, $\Delta_{仪}$= 0.1mm,

E_r=0.13%

Vernier calipers: L =46.00mm, $\Delta_{仪}$= 0.02mm ,

E_r=0.026%

micrometer: L=46.000mm, $\Delta_{仪}$= 0.004mm ,

E_r=0.006%

b) Significant digit have nothing to do with decimal point's location and unit

e.g. 4.60 cm   0.0460m   46.0mm

measurement results

0.0125m=1.25cm   1.0900cm≠ 1.09cm

8.88m=8880mm?

(3). Scientific notation

Scientific notation : $a \times 10^n$ (单位)

$8.88m = 8.88 \times 10^3 mm$

$80.30g = 0.0803kg? = 80300mg?$

$80.30g = 8.030 \times 10^1 g = 8.030 \times 10^4 mg$

$= 8.030 \times 10^{-2} kg$

(4). rules for rounding

•If the last digit of a number is less than 5, drop it;

•If it is more than 5, the number to be rounded add 1;

•If it is 5, make the last digit be even.

e.g.： if m=3.065kg,　　u_{cm}=0.042kg

m=(3.06±0.05)kg

e.g.

7.146 rounded to two digits $\quad 7.1$

0.086 rounded to one digits $\quad 0.09$

2.4352 rounded to three digits $\quad 2.44$

17.415 rounded to four digits $\quad 17.42$

17.425 rounded to four digits $\quad 17.42$

(5). algorithms

a) addition and subtraction

e.g.

$$A + B + C = 14.7\overline{\overline{8}} + 0.004\overline{7} - 1.50\overline{3}$$

$$= 13.2\overline{8}\,\overline{1}\,\overline{7} = 13.2\overline{8}$$

Shortest decimal

b) Multiplication and division

e.g.

$$A \times B \times C = 24.56\overline{8} \times \boxed{3.4\overline{\overline{5}}} \times 128.\overline{4}$$

$$= 10883.13264 = \boxed{1.09} \times 10^4$$

Shortest digit

(6)、 the rule to read data(direct)

instrumental error or minimum graduation value

a： ruler
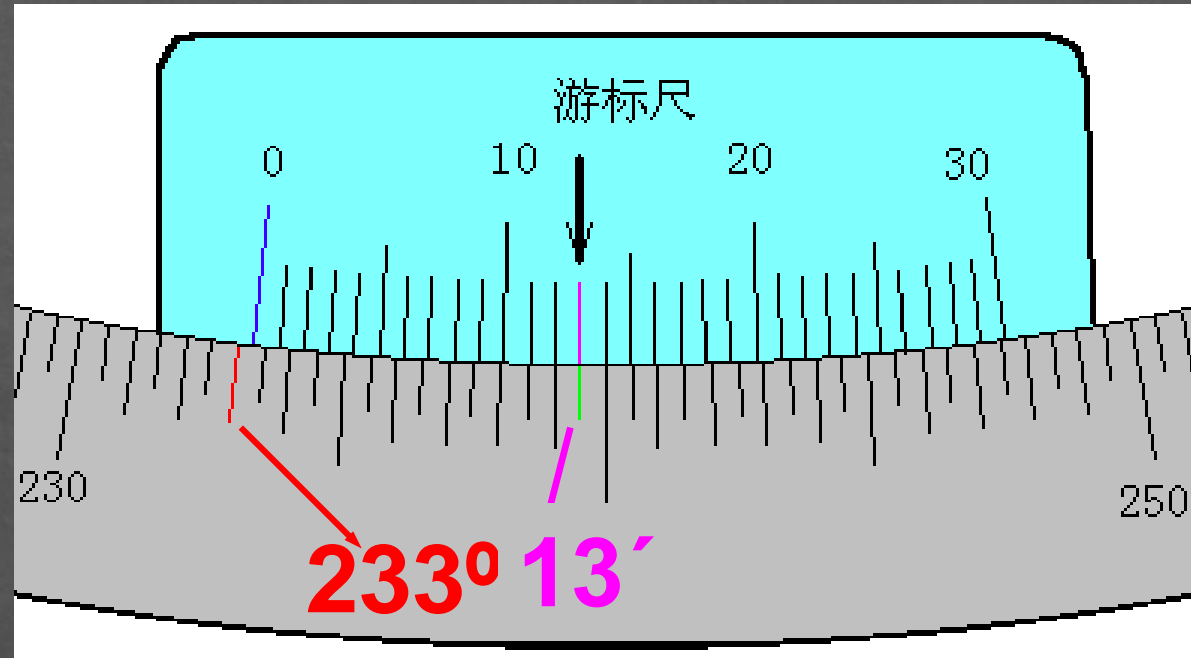
2cm or 20mm?

c m
2

Minimum graduation value 1/5 ~ 1/2

2.00cm or 20.0mm

b：angular vernier

e.g. vernier calipers

c：reading of digital meter

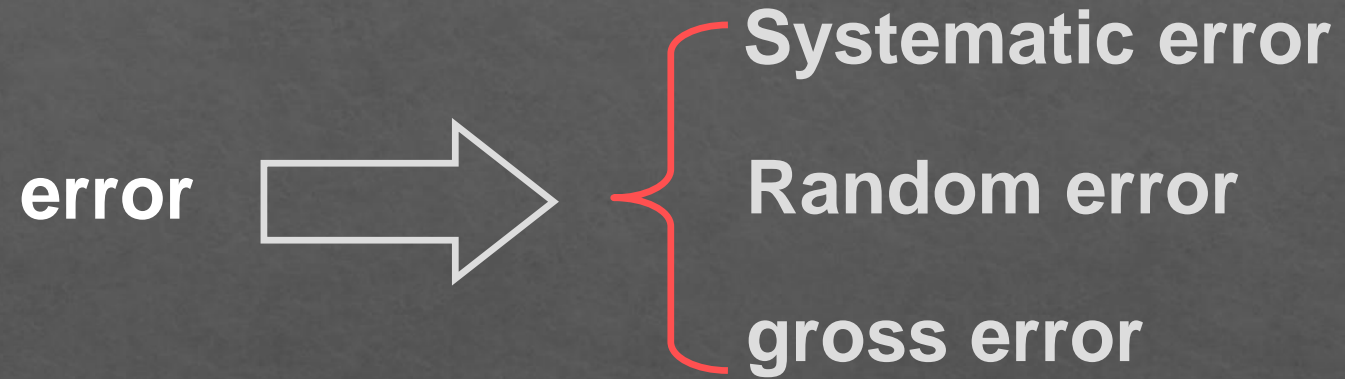reading :23.9℃

4、 error and uncertainty

Error and true value

true value： a

measured value: x

error： ε $\varepsilon = x - a$

Classification of error

error $\Rightarrow$ Systematic error

Random error

gross error

Systematic error

uncertainty

★ **uncertainty:** range of fluctuation

the uncertainty *u*

1. A uncertainty : u_A

2. B uncertainty : u_B

3. Synthetic uncertainty：

$$u = \sqrt{u_B{}^2 + u_A{}^2}$$

A uncertainty

$$u_A = \frac{st}{\sqrt{n}} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{(n-1)}} \cdot \frac{t}{\sqrt{n}}$$

t distribution factor，n measurement times，probability P=0.95：

n	2	3	4	5	6	7	8	9	10
t	12.71	4.30	3.18	2.78	2.57	2.45	2.36	2.31	2.26
$\frac{t}{\sqrt{n}}$	8.99	2.48	1.59	1.24	1.05	0.93	0.84	0.77	0.72

_B_ uncertainty

instrument error ,Limit error

instrument error ： Δ

instrument error =Level ✕ range

B uncertainty

$$u_B = \Delta_{ins}$$

Synthetic uncertainty

$$u = \sqrt{u_B{}^2 + u_A{}^2}$$

measurement result：

$$N = N_M \pm u \ \text{(unit)}$$

$u =$ Synthetic uncertainty,

$N_M =$ best estimation of measurement data

Single measurement, Multiple/Repeated measurement

1、 result of single direct measurement

single direct measurement

estimated true value： result of single measurement

$$u = u_B = \Delta_{仪}$$

$$N = N_m \pm \triangle \text{ (unit)}$$

N_m *have same decimal as* $\triangle$

$$N = \overline{N} \pm u \ \text{(unit)}$$

estimated true value： $\overline{N}$

uncertainty：

$$u = \sqrt{u_A{}^2 + u_B{}^2}$$

$$\mu_A = \sqrt{\frac{\sum (N_i - \overline{N})^2}{(n-1)} \cdot \frac{t}{\sqrt{n}}} \qquad \mu_B = \Delta_{\text{仪}}$$

Example 1: Vernier caliper(division:50）, cylinder diameter, 10 times.

times	1	2	3	4	5	6	7	8	9	10
d_i(cm)	19.78	19.80	19.70	19.78	19.74	19.76	19.72	19.68	19.80	19.72

$$\overline{d} = \frac{\sum\limits_{i=1}^{10} d_i}{10} = 19.75mm$$

$$u_A = S_{\overline{d}} \cdot \frac{t}{\sqrt{n}} = \sqrt{\frac{\sum\limits_{i=1}^{10}(d_i - \overline{d})^2}{9}} \cdot 0.72 = 0.0108mm$$

$$u_B = \Delta_{仪} = 0.02 mm$$

uncertainty

$$u = \sqrt{u_A{}^2 + \Delta_{仪}{}^2} = \sqrt{0.0108^2 + 0.02^2}$$

$$\approx 0.0227 mm \approx 0.023 mm$$

diameter

$$d = \bar{d} \pm u_d = 19.750 \pm 0.023 (mm)$$

Same decimal

relative uncertainty

$L_1 = (170.0 \pm \textcolor{orange}{0.3})$ (cm) $E_{r1} = 0.18\%$

$L_2 = (17.0 \pm \textcolor{orange}{0.3})$ (cm) $E_{r1} = 1.8\%$

relative uncertainty,E_r

$$E_r = \frac{u}{\overline{N}} \times 100\%$$

(3) percentage error

$$E_0 = \frac{|N - N_0|}{N_0} \times 100\%$$

$E_r = 1.54\%$ → $E_r = 1.6\%$

$E_r = 3.82\%$ → $E_r = 3.9\%$

$E_0 = 5.04\%$ → $E_0 = 6\%$

Indirect measurement

if, $N = f(x, y, z....)$

$x, y, z....$ direct measurement

if $\bar{x}, \bar{y}, \bar{z}\cdots \cdots$ best estimates of direct measurement

best estimates of indirect measurement

$$\overline{N} = f(\bar{x}, \bar{y}, \bar{z}\cdots \cdots)$$

Estimate of uncertainty （indirect measurement）

N **uncertainty**

$$u_N = \sqrt{(\frac{\partial f}{\partial x})^2 u_x{}^2 + (\frac{\partial f}{\partial y})^2 u_y{}^2 + \cdots}$$

N **relative uncertainty**

$$E_r = \frac{u_N}{N} = \sqrt{(\frac{\partial \ln f}{\partial x})^2 u_x{}^2 + (\frac{\partial \ln f}{\partial y})^2 u_y{}^2 + \cdots}$$

Result of indirect measurement

$$N = \overline{N} + \mu_N$$

$$\overline{N} = f(\overline{x}, \overline{y}, \cdots)$$

1、 direct measurement *(x， y， ⋯)* **uncertainty** （*u_x， u_y， ⋯*）

2、 function

$$N = f(x, y, \cdots)$$

N　　**total derivative**

$$dN = \frac{\partial f}{\partial x}\,dx + \frac{\partial f}{\partial y}\,dy + \cdots$$

3、 *N* uncertainty u_N

$$u_N = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 u_x{}^2 + \left(\frac{\partial f}{\partial y}\right)^2 u_y{}^2 + \cdots}$$

★**calculation processing** （**relative uncertainty**）

1、 direct measurement uncertainty u_x, u_y, …;

2、 function $\quad N = f(x, y, \cdots)$

logarithm $\ln N = \ln f(x, y, \cdots)$

ln N total derivative $\dfrac{dN}{N} = \dfrac{\partial \ln f}{\partial x} dx + \dfrac{\partial \ln f}{\partial y} dy + \cdots$

3、 relative uncertainty of *N*

$$E_r = \frac{u_N}{N} = \sqrt{\left(\frac{\partial \ln f}{\partial x}\right)^2 u_x^{\,2} + \left(\frac{\partial \ln f}{\partial y}\right)^2 u_y^{\,2} + \cdots}$$

Example 2: **Using pendulum to measure acceleration of gravity:** $g=4\pi^2 l/T^2$,

$T=2.000 \pm 0.002s, l=100.0 \pm 0.1cm$, **try to write a gravitational acceleration g expression.**

answer:

$$g = \frac{4\pi^2 l}{T^2}, \ln g = \ln 4\pi^2 + \ln l - 2\ln T$$

$$\frac{\partial \ln g}{\partial l} = \frac{1}{l}, \frac{\partial \ln g}{\partial T} = -\frac{2}{T}$$

$$E_r = \frac{u_g}{g} = \sqrt{(\frac{\partial \ln g}{\partial l})^2 u_l^2 + (\frac{\partial \ln g}{\partial T})^2 u_T^2}$$

Thus:

$$E_r = \sqrt{(\frac{u_l}{l})^2 + 4(\frac{u_T}{T})^2} = \sqrt{(\frac{0.1}{100})^2 + 4(\frac{0.002}{2.000})^2}$$

$$= 2.24 \times 10^{-3} = 0.23\%$$

$$g = \frac{4\pi^2 l}{T^2} = \frac{4 \times 3.1416^2 \times 100.0}{2.000^2} = 987.0(cm/s^2)$$

$$u_{cg} = E_r \cdot g = 2.24 \times 10^{-3} = 2.3(cm/s^2)$$

Round to the nearest tenth , carry only!

acceleration of gravity   **g=(987.0 ± 2.3) (cm/s^2)**

align

Part 3
Methods of data processing

1. Tabulation

Notes:

a. Table design: reasonable，straightforward，complete.

b. Title bar: physical quantity's name、mark,unit.

c. Data: effective number.

d. instruction and parameter（table name, measuring instrument specifications, environment condition).

e. main->original data, important intermediate result.

Table   Data of wire diameter measurement

Instrument：micrometer caliper，Level：1，range：0～25mm，error：± 0.004mm,initio data:-0.005mm

Order	data（mm）	diameter D_I(mm)	$D_i - \bar{D}$ (mm)	$(D_i - \bar{D})^2 (\times 10^{-8} mm^2)$
1	0.280	0.285	0.0022	484
2	0.278	0.283	0.0002	4
3	0.275	0.280	-0.0028	784
4	0.284	0.289	0.0062	3844
5	0.272	0.277	-0.0052	2704
6	0.278	0.283	0.0002	4
Average		0.282 8		$\sum (D_i - \bar{D})^2 = 7824$

$$S_{\bar{D}} = 1.7 \times 10^{-3} mm, \sigma_{仪} = \frac{\Delta_{仪}}{\sqrt{3}} = \frac{0.004mm}{\sqrt{3}} = 2.3 \times 10^{-3} mm,$$

$$u_{cD} = \sqrt{S_{\bar{D}}^2 + \sigma_{仪}^2} = 2.9 \times 10^{-3} mm = 0.003mm,$$

$$D = \bar{D} \pm u_{cD} = (0.283 \pm 0.003)mm$$
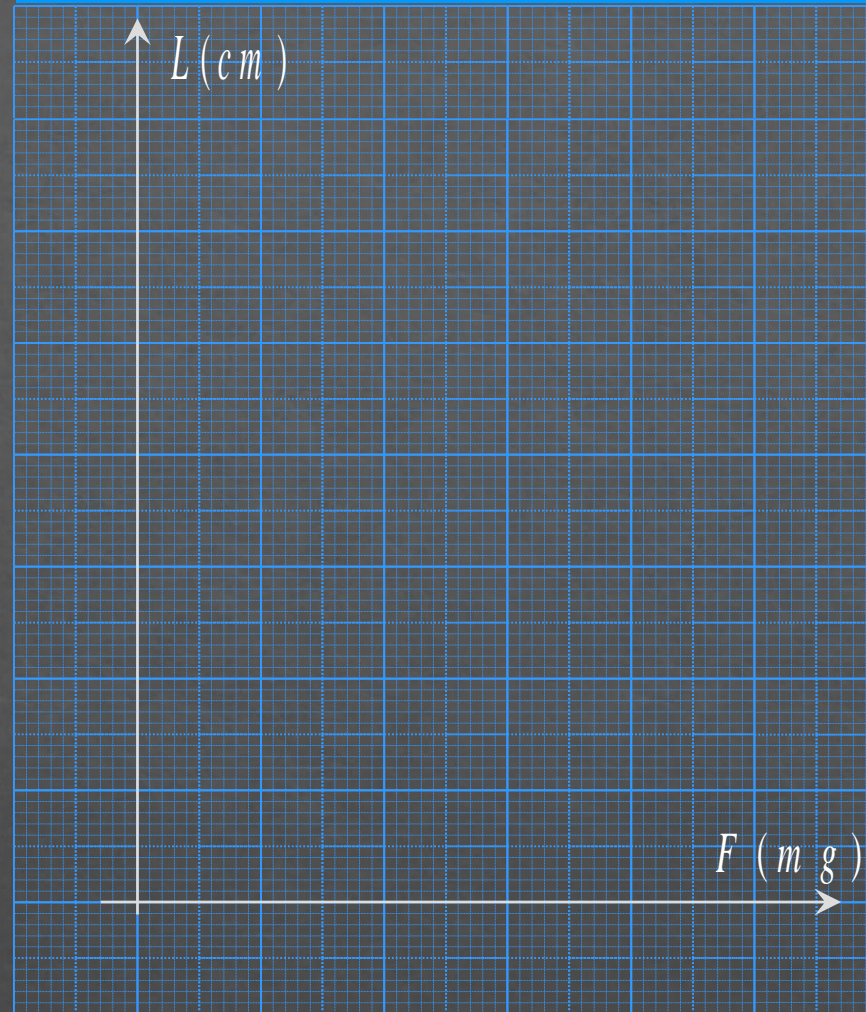
2. Graphical method
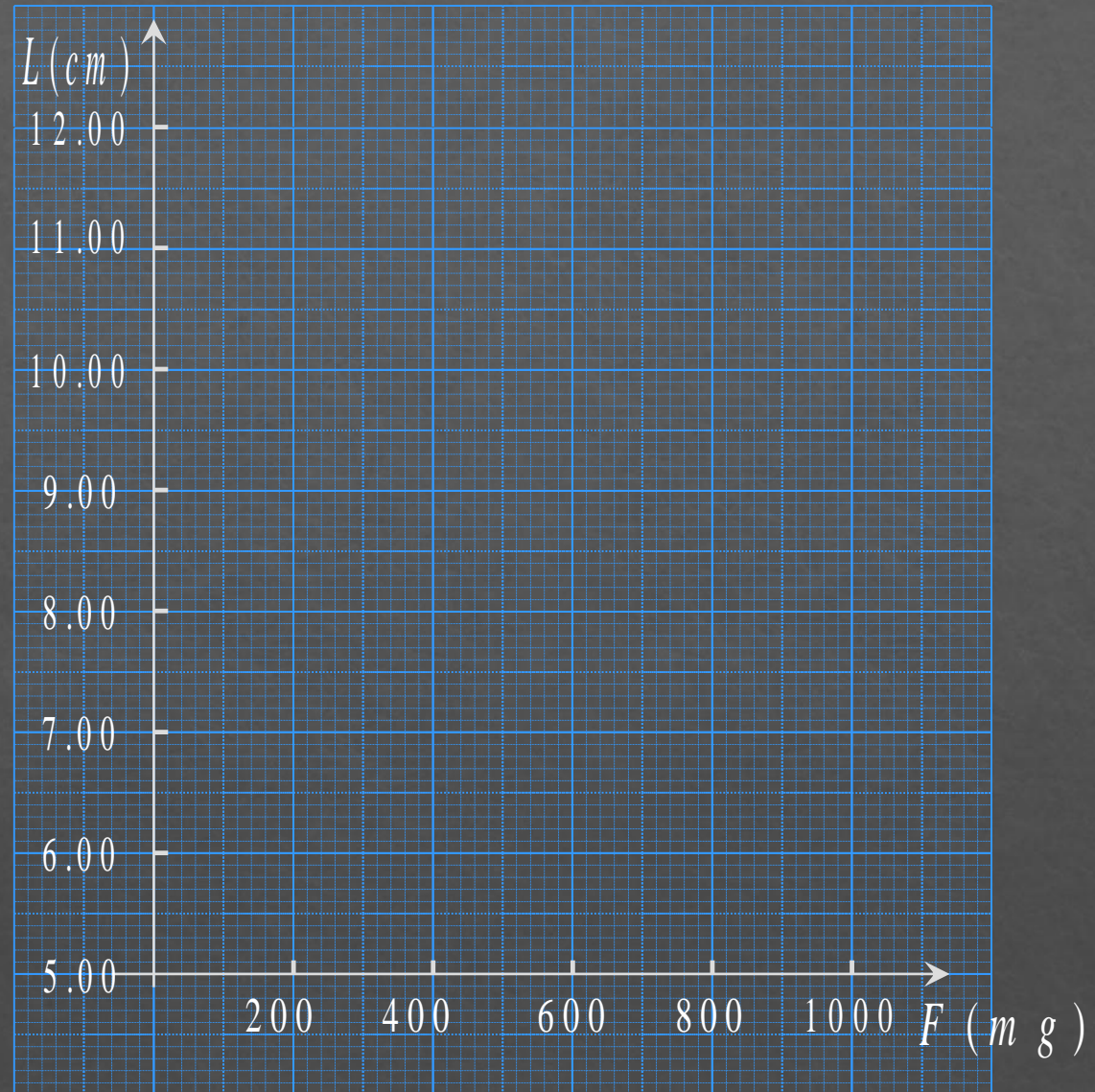
- ➢ **Numbers, Lines**

- ➢ **Mapping rules**

Mapping rules

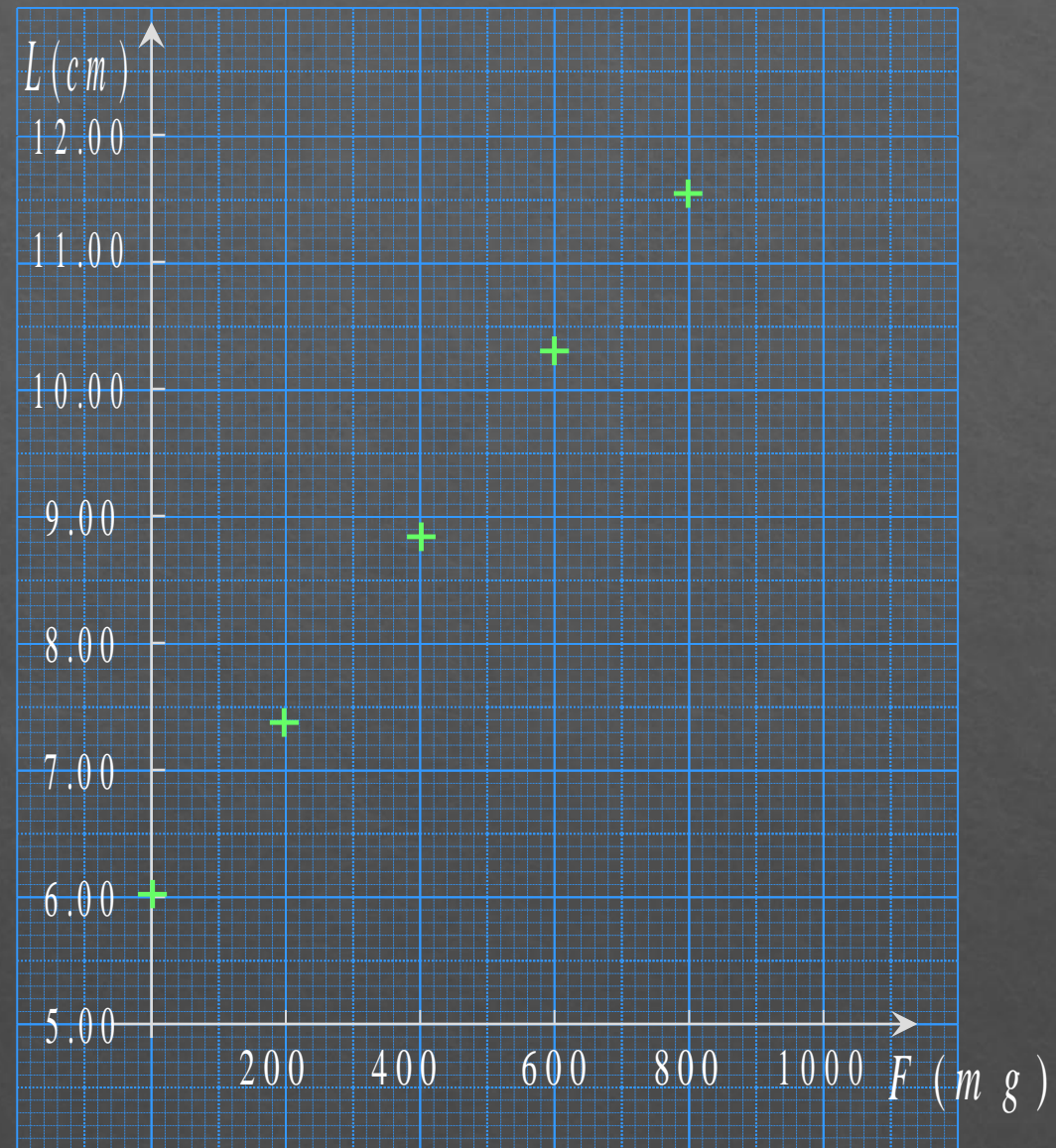1、Plotting From Data table

2、Using coordinate paper

3. Coordinates

4.Coordinate indexing

$L(cm)$

12.00

11.00

10.00

9.00

8.00

7.00

6.00

5.00

200   400   600   800   1000 $F(mg)$

5. Experimental data points

7. Introductions

Relation between F and L
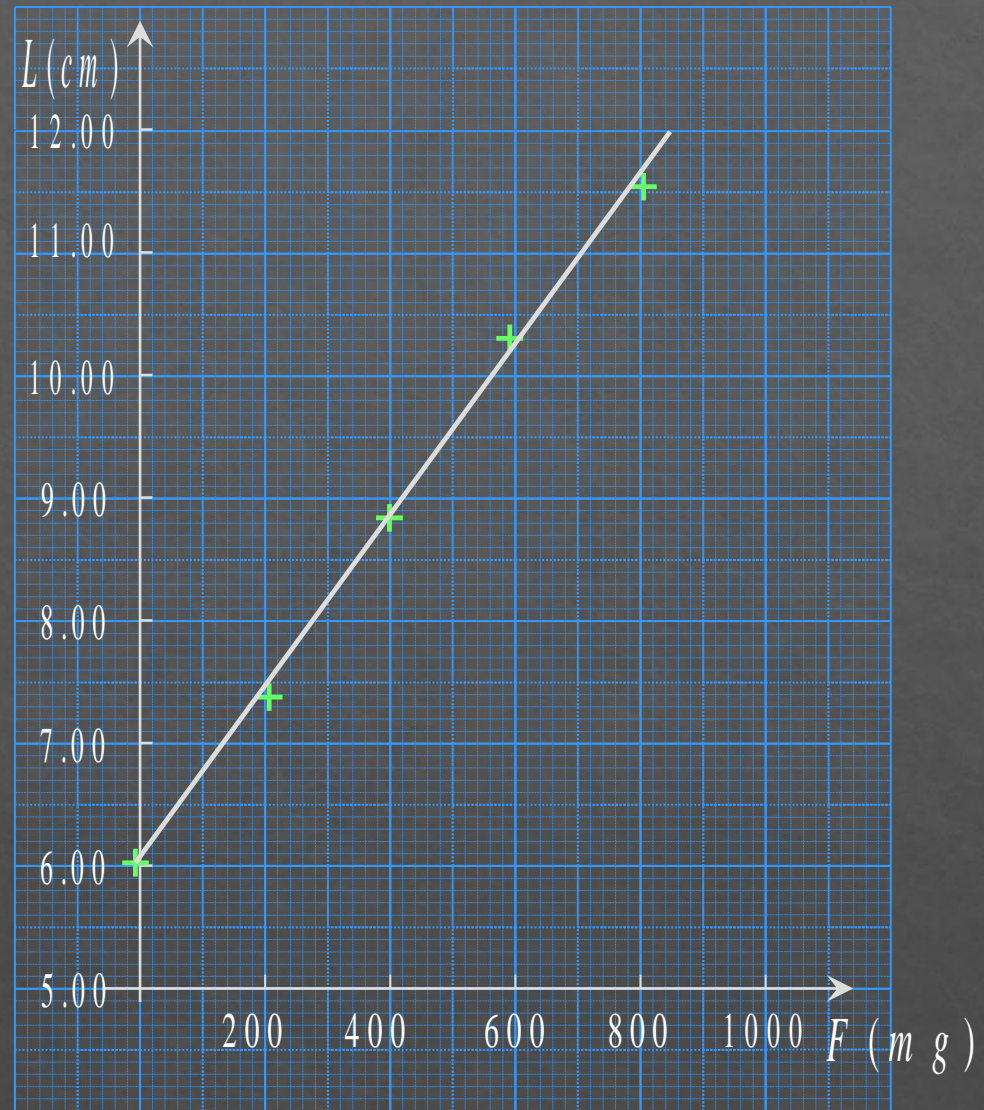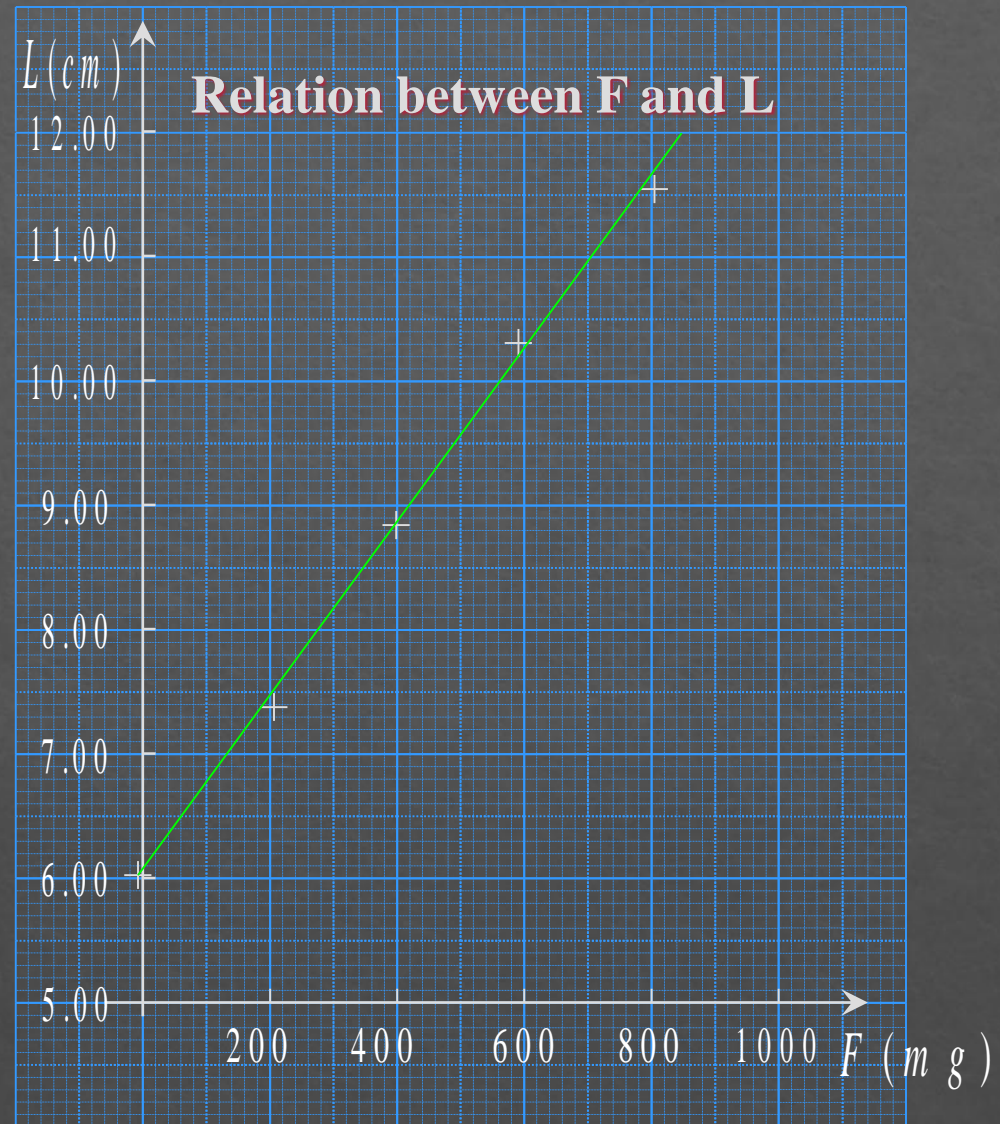
Graphical method

1）**Coordinate values**

$(x_1,\ y_1)$ 、 $(x_2,\ y_2)$ 。

equation of straight line：

$$y\ =\ a\ +\ b\,x$$

2）**slope** b： $$b = \frac{y_2 - y_1}{x_2 - x_1}$$

3）**intercept** a： $$a = \frac{x_2\,y_1 - x_1\,y_2}{x_2 - x_1}$$

The relation between F and L

$L(cm)$

$K = \dfrac{(700 - 100) \times 9.794 \times 10^{-6}}{(10.96 - 6.79) \times 10^{-2}}$
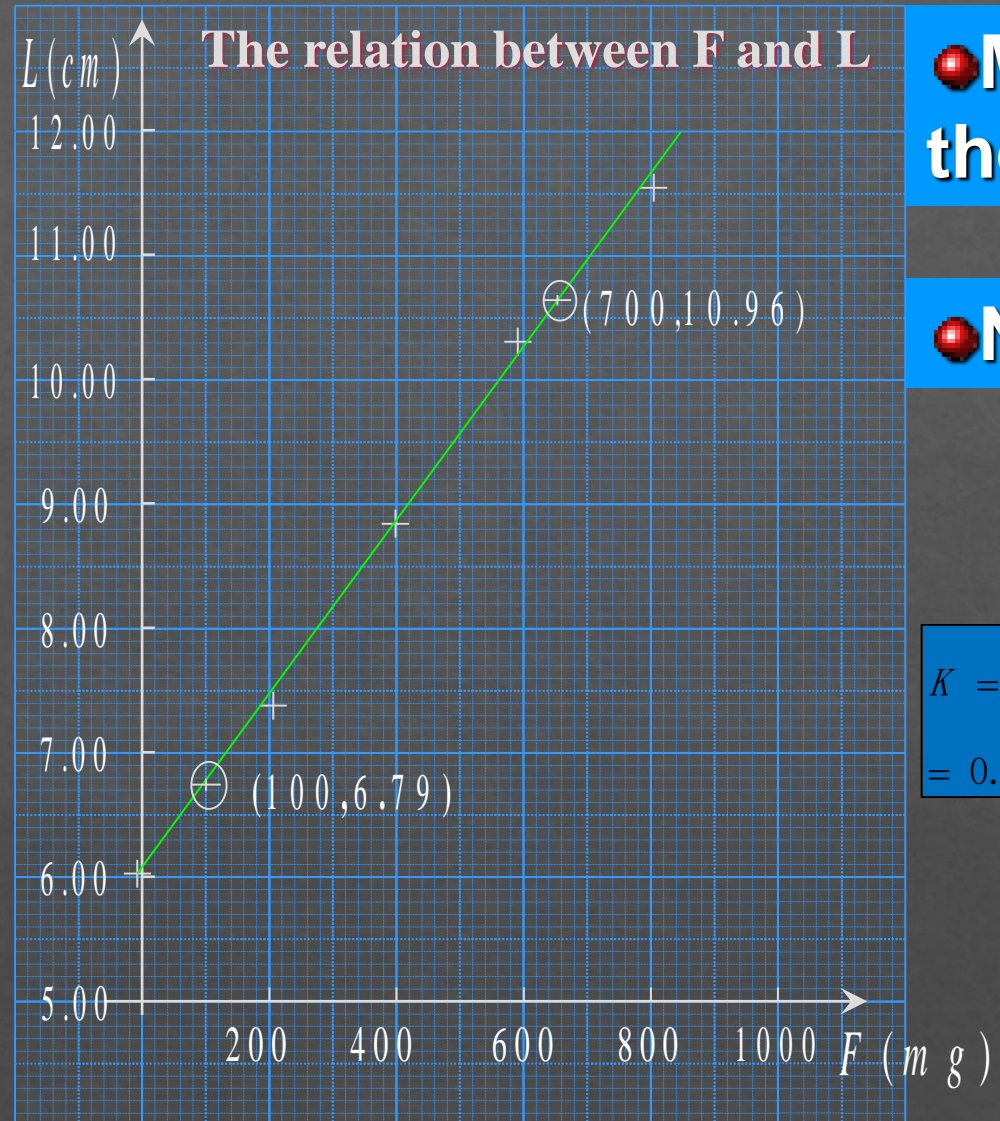
$= 0.141 N / m$

● Mark **2** points on the line.

● Note the distance

Graph points: $(700, 10.96)$, $(100, 6.79)$

Y-axis values: 12.00, 11.00, 10.00, 9.00, 8.00, 7.00, 6.00, 5.00

X-axis: 200, 400, 600, 800, 1000, $F (mg)$

3. Method of successive minus

➢ **method of successive minus**：
  ➢experimental data->table
    verify law of variation of data.
  ➢divide into two groups: high,low
    Make full use of data，reduce measurement error。

➤ **Verify the *linear relationship of L_i* and *F* 。**

$$\Delta \overline{L} = \tfrac{1}{7}\left[(L_1 - L_0) + (L_2 - L_1) + \cdots + (L_7 - L_6) \right]$$

$$= \tfrac{1}{7}\left[L_7 - L_0 \right]$$

Intermediate data ✕

beginning and end ○。

If we divide data into（L_7，L_6，L_5，L_4）and（L_3，L_2，L_1，L_0）。

$$\Delta \overline{L} = \frac{1}{4}[(L_7 - L_3) + (L_6 - L_2) \cdots + (L_4 - L_0)]$$

Make full use of data，Keep all the merits of Multi-times measurement.

Summary

1. Rules of this course;

2. Significant digit，rules for rounding，algorithm，reading

3. Uncertainty calculation，rules for rounding

U_A，U_B，U

Indirect measurement

4. Measurement results：

$$N = N_M \pm u_c \quad \text{(unit)}$$

u_c: *Synthetic uncertainty*， N_M: best estimation of measurement data

5. Data processing methods：

tabulation method， graphical method， method of successive minus

END