Experiment 1

Familiarize with Apparatus of Fundamental Measurements and Data Analysis

1、 Purpose

Understand the design principles of common apparatuses and learn how to perform fundamental measurements.

1. Understand the concept of measurements and experimental data acquisition.
2. Understand the source of experimental errors ~~data~~ and learn how to process the experimental data.
3. Build skills in data analysis.

2、 Methods and Principles of Data Analysis: See detailed handouts of the experiment.

Measured Value: There will be uncertainties and errors in measured experimental data.

(1) Physical Quantities: quantity+precision+unit, e.g. a.bc ± d x10^n meter

(2) Significant Figures: a number of precise digits+an estimated number (3.13 cm). Precision depends on the accuracy of measuring apparatus.

(3) Experimental Errors: two sources

(a) systematic error: errors of apparatus, environment and human.

(b) statistical / random error

Multiple measurements increase the precision of physical quantities and lower experimental errors. The processes of data analysis are as follows. Calculate the average value with multiple measurements of data. Calculate deviations afterwards. Below are three ways to correct errors:

$$\text{average value} = \underline{x} \equiv \frac{x_1+x_2+\cdots+x_n}{n} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (1)$$

$$d_n = x_n - \underline{x}$$

Measured value of n and deviation of average value

(1) average deviation：

$$D \equiv \frac{|d_1|+|d_2|+\cdots+|d_n|}{n} = \frac{1}{n}\sum_i |d_i| \quad (2)$$

(2) standatd deviation：

$$\sigma \equiv \sqrt{\frac{d_1^2+d_2^2+\cdots+d_n^2}{n}} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} d_i^2} \quad (3)$$

When times of measurements *n* is finite, more correct standard deviation should be:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} d_i^2} \qquad (4)$$

(3) average standard deviation：

With statistical theory, $\sigma_{\bar{x}}$ can be calculated from σ

$$\sigma_{\underline{x}} = \frac{\sigma}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_i d_i^2} \qquad (5)$$

Statistical Theory

(1) Binomial Distribution: IF an incident only occurs in the form of *X* and *Y*. The probability of occurrence of *X* is *p*, and that of *Y* is *q*, $q = 1 - p$. In *N*, the number of experiments, the distribution of probability of occurrence of *X* is shown below, which is called binomial distribution of functions.

$$P_B(n) = \frac{N!}{n!(N-n)!}p^n q^{N-n} \qquad (6)$$

(2) Poisson's Distribution: When $N\rightarrow\infty$**,** the above distribution of functions is approaching Poisson's Distribution.

$$P_p(n) = \frac{m^n e^{-m}}{n!} \qquad (7)$$

In the equation, *m* is the average value of *n*. The standard deviation is:

$$\sigma = \sqrt{m} \qquad (8)$$

The bigger the value of *m*, the more symmetrical the distribution graph is. From equation (8), we can see σ / m is smaller. Poisson's distribution is often adopted in the experiments of atomic physics and nuclear physics to fetch better statistical errors.

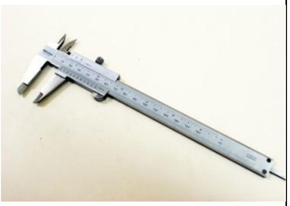
(3) Normal Distribution: It is also known as **Gaussian Distribution**. When *m* in Poisson's Distribution becomes great, or *N*□□ and *m* is also great, the distribution of measured values is close to the distribution of functions below:

$$P_G(x) = \frac{1}{\sqrt{2\pi}}\frac{1}{\sigma}e^{-(x-x_0)2/2\sigma^2} \qquad (9)$$

In the equation, x_0 is the value of *x* at the peak of Normal Distribution, meaning the most probable measured result. σ is standard deviation. The unit of σ and *x* are the same. Data shown in normal distribution have its average value on the symmetrical center of normal curve, or x_0.

Values after analysis of physical quantities of direct measurements contain certain precision and significant figures.

3、 Apparatus

			
vernier caliper	micrometer caliper	straight ruler	Geiger counter + Co^{60}
			
triple beam balance	electric balance	precision balance	sphygmomanometer

Instructions on apparatus before and during use

1. Vernier caliper and micrometer caliper: zero point error of and how to read numerical values (precision).
2. Triple beam balance: horizontal adjustment and zeroing.
3. Electric balance and precision balance: horizontal adjustment, zeroing and parameter setting (switch of units and position).
4. Check the accuracy of apparatus (significant figures).
5. Students shall not adjust the Geiger counter by themselves, which operates on high voltage. It must be set by technicians or instructors.
6. The cuff of electric sphygmomanometer must level with the upper arm and heart (see manual).

4、 Experimental Steps

(1) Familiarize with the following apparatus and list (i) its principles of design and operation, (ii) how it operates, (iii) how accurate it is and (iv) operation notices

1. vernier caliper
2. micrometer caliper
3. triple beam balance
4. electric balance
5. precision balance
6. Geiger counter

(2) Measure the density of objects: objects to be assigned by teachers or assistants.

1. Members in each group take turns using straight rulers (from different readings each time), vernier caliper and micrometer caliper to measure the dimension, size or diameter of objects ten times each and document results in Chart A.

2. Members in each group take turns using triple beam balance, electric balance and precision balance to measure objects such as wood block or steel ball ten times each and document results in Chart A.
3. Calculate the density of data fetched from apparatus. (Note the propagation of error while calculating values)
4. Calculate the average value, average deviation, standard deviation and average standard deviation.

(3) Measuring counting rate of radiation from radioactive source with Geiger counter

1. Measure the counting rate of 20 seconds of radioactive source with Geiger counter. Repeat 50 times.
2. Share data fetched from the same counter with other groups. Compare distribution graphs of 1 to 10 data sets. (increasing by 50 times).
3. Calculate the average value of fetched data. Calculate standard deviation and average standard deviation with equations (4) and (5).
4. Using equations (1) and (8), recalculate the average value, standard deviation and average standard deviation of results from step 1. Compare those to the calculation of step 2. Write down your conclusion.

5、 Questions

1. When measuring the height and diameter of a metal cylinder, should you measure the same position multiple times or different positions and directions? Why?
2. What is the reason that you measure multiple times from different readings on the straight ruler?
3. Measure a rectangular object. Take length and width ten times each. While calculating the area, should you multiply the average length with average width or multiply length with width each time and take the average value? Explain.
4. There are two error sources: systematic error and statistical error. Please explain what kind of systematic errors there are with the apparatus used in the experiment.
5. Design a vernier caliper with the accuracy of 0.02 mm.
6. Compare the graphs of Poisson's Distribution and Gaussian Distribution.
7. What is the difference in results using equations (15) and (18) to calculate the standard deviation of x^2? Which one is correct? Why?
8. What is the difference between accuracy and precision?

Chart A

Object to be measured: metal ball

	Mass(g)			diameter (cm)			value(cm^3)			density (g/cm^3)			
	M1	M2	M3	R1	R2	R3	V1	V2	V3	M1+V1	M2+V2	M3+V3	M3+V1
	Tirple beam balance	Electric balance	Electric analytical balance	Straight ruler	Vernier caliper	Micrometer caliper	Straight ruler	Vernier caliper	Micrometer caliper	Triple beam balance + Straight ruler	Electric balance + Vernier caliper	Electric analytical balance + micrometer caliper	Electric analytical balance + straight ruler
accuracy													
Significant figures													
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
Average value													
Deviation													
Average deviation													
Standard deviation													