Introduction to Physics Experiments

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§ 1Requirements and notes

i) Please try not to be late. The class begins at 14:30, and you should come into the lab before that time. If you are late for the class over 15 minutes you will not be permit to do the experiment, and you will not be permit to make up for the experiment unless you are in special and pressing circumstances(On those occasions, approval must be in advance. E.g. you are ill and can be verified by a doctor's note.). If you are late for the class within 15 minutes the instructor will mark B、C or D on your pre-lab report, and he(she) will deduct part of your score ,when your report is graded.

ii) Please prepare for the due experiment and write pre-lab report. You will not permit to do the experiment if you haven't the pre-lab report.

iii) The class will be over at 17:00, and you should finish the scheduled experiment before this. You can prepare your experiments in the labs if you worry that you can't finish the experiment during the scheduled time. The labs open from Monday to Friday during the course.

iv) Please bring your calculator. You will have to process some data during experiments.

v) You should submit your lab report with pre-lab report together before next scheduled time or on that day.

vi) Don't copy your classmate's results of experiments and reports or else you will get zero regardless of how well you may be performing.

You can download the material from internet.
Adders: ftp://202.116.5.9
User: stu
Password:stu

§ 2 About the course

Course information

The course covers mechanics, electronics, electromagnetics and optics. Twelve experiments are scheduled, but everyone only need do 11 among them. Each experiment takes approximately two and a half hours to complete. All the 11 experiments must be complete to pass the course. Of course, the experiments should generally be done at the regularly scheduled time. You can make-up the experiments that may be missed **because of special and pressing circumstances.** but you should schedule your make-up with your teacher or laboratory assistant at least a week beforehand, if possible.

The average of all your laboratory reports scores will be your course score.

Every lab is divided into three sections: preparation for an experiment and to write the pre-lab, operation in lab, and to write lab report after class. They are worth 10 %, 50 % and 40 % of the entire experiment, respectively.

1. Pre-lab

Prepare the teaching materials of the experiment(you can refer to the corresponding Chinese book). Be sure you understand the teaching materials before coming to the laboratory to avoid waste of valuable laboratory time and figure out what should be done.

The Pre-lab should include:

i) Objective
ii) Principle
iii) Content and procedures
iv) Data recording table(s)

Write them in your words based on your understanding of the materials. Don't copy the material directly.

You must use the unified lab reports paper of Ji nan University

The teacher will check you Pre-lab report when you come to the laboratory.

2. operation In the lab

After writing the Pre-lab report, you may do the due experiment following this procedure:

i) Sign your name when you come into the lab.

ii) After the teacher introducing the experiment and the corresponding equipments, you may do the experiment according to the teaching material.

iii) Write down the phenomena and your understanding during the experiment. If some problem baffles you, re-check the text to see what you missed. Then look at the full solution to see whether that helps to clarify things. If it does not, you need to talk to someone about it. Look for help. Other students are often the most immediately available source of help, but do not hesitate to ask the teacher, and sooner rather than later.

iv) Record all data in the blank table(s) in your Pre-lab report. Use a pen NO PENCILS please. Line out with a single line (e.g. ~~Ooope)~~ anything written in error (data or text). Do not use "scratch" data sheets from which data are to be transcribed onto the blank ones in you pre-lab. The teacher is interested in an original data sheet and is willing to see the direct recording of the actual data taken in the laboratory. Record the settings and conditions in your Pre-lab report. under which the data was taken.

v) Complete some data processing in your Pre-lab report required by the teacher.

vi) Pre-lab report must be initialed by your teacher after data processing.

vii) Put the equipments in order before you leave the laboratory.

3. Lab reports

You have to write a lab report after having done the experiment and hand it in along with the pre-lab initialed by the teacher at the beginning of the next experiment. The report will be grated and returned as soon as possible. If your lab report is overdue you will suffer a five or more points penalty (Note that

even then the report must be submitted, since that is a course requirement which is independent of the score which the lab report might earn.) The basic idea is that lab reports are tasks to be finished, and not to be belabored: write it up and hand it in!

If your pre-lab is clean and neat you can continue the following items in pre-lab:

i) ***All the required calculation.*** **Give the data processing and estimate uncertainties (errors)(that will be introduced later)**

ii) ***Graphs and diagrams.*** **Use a straight edge to draw lines, which are supposed to be straight (graph axes, column lines, etc).**

iii) ***A summary or discussion of the results.*** **The summary is included in tabular from under the data. It usually involves a comparison of the computed results with the accepted values together the percent uncertainty (error) involved. You are encouraged to add a brief discussion of the source of these errors and any other comments you would like to make about the working of the experiment.**

iv) ***Answers to the questions at the end of the experiment.*** **Take care to use complete sentences and to make the answers as clear and readable as possible.**

All of the above together with your pre-lab will form the experimental report.

But if your pre-lab is dirty and chaos your need collate and transcribe your pre-lab, then continue the above, and you need attach the original pre-lab initialed by your teacher when you hand in you experimental report.

You must write your own report independently, and the report should be as neat as possible. Use a single "X" to indicate any sections that you do not wish to be read.

§ 3 about the elementary knowledge of the course

- Uncertainty in measurement.

- Significant figure in measurement and during data processing.

- Data processing methods often used in experiment.

Uncertainty in measurement.

1. Measurement

Measurement can be divided into direct measurement and indirect measurement

Direct measurement:

The value of some physical quantity can be directly obtained by measuring it using a proper instrument.

Indirect measurement:

We can obtain the desired quantity using the function (or formula) that gives the relation between the direct measurement quantities and the desired quantity.

(e.g. measure the acceleration of gravity by using the period equation of single pendulum oscillation)

2. Uncertainties (errors)

No measurement is absolutely accurate or exact. Human and instrumental limitations cause unavoidable deviations from the "true" values of the quantities we are measuring. The deviation of the value of a particular measurement from its "true" value is called the uncertainty (error) in that measurement.

A measurement or experimental result is of little value if nothing is known about the probable size of its uncertainty. We know nothing about the reliability of a result unless we know something about the probable uncertainties, which were used to obtain that result. So uncertainties are necessary in measurement results. The less the uncertainty is, the higher the reliability of the value for measurement is.

As this course is focused on getting experience using basic instrument, building circuits, etc, you do not need to do formal uncertainty (error) analysis. Still, this is a physics lab, and some attention must be paid to the uncertainties in your data and analysis. Uncertainty estimates come from consideration of the measurement itself, not from the comparison of theory and experiment. Uncertainties can be classified two kinds: statistical uncertainty (Δ_A) and systematic uncertainty (Δ_B).

The following are some concept about uncertainty.

Statistical uncertainty (Δ_A):

You measure a quantity many times, but in the range of values for your measurement, you can't reliably state that one answer is better than the others. This is roughly the statistical uncertainty. And it can always be easily assigned.

Systematical uncertainty (Δ_B):

No mater how you actually measure something the values for measurement are always different from what you are intending. This is roughly the systematical uncertainty. And it may require more thought to quantify.

the resultant uncertainty(u)

$$u = \sqrt{\Delta_A{}^2 + \Delta_B{}^2}$$

3. Measurement result

We should express the measurement result as following:

$$x = \bar{x} \pm u(units\ of\ x) \quad or$$

$$x = \bar{x}(1 \pm u_r)(units\ of\ x)$$

Here x is the value of a quantity (measured many times or one time), $\bar{x}$ is the average value of the quantity, u is the resultant uncertainty, $u_r = u / \bar{x}$ is the percent uncertainty.

How to calculate the uncertainty? Please refer to the appendix.

- **Significant figure in measurement and during data processing.**

Significant figures in a number are all of the figures that are obtained directly from the measuring process and that exclude those zero that are included solely for the purpose of locating the decimal point. The last number is an estimate and we must not neglect it, even if it is zero.

$$0.258 \neq 0.2580 \qquad\qquad 0.120m \neq 12cm$$

So you must not change the significant figure when you make unit transform.

1. **The measurement result of the quantity directly measured should answer the precision of the device.**

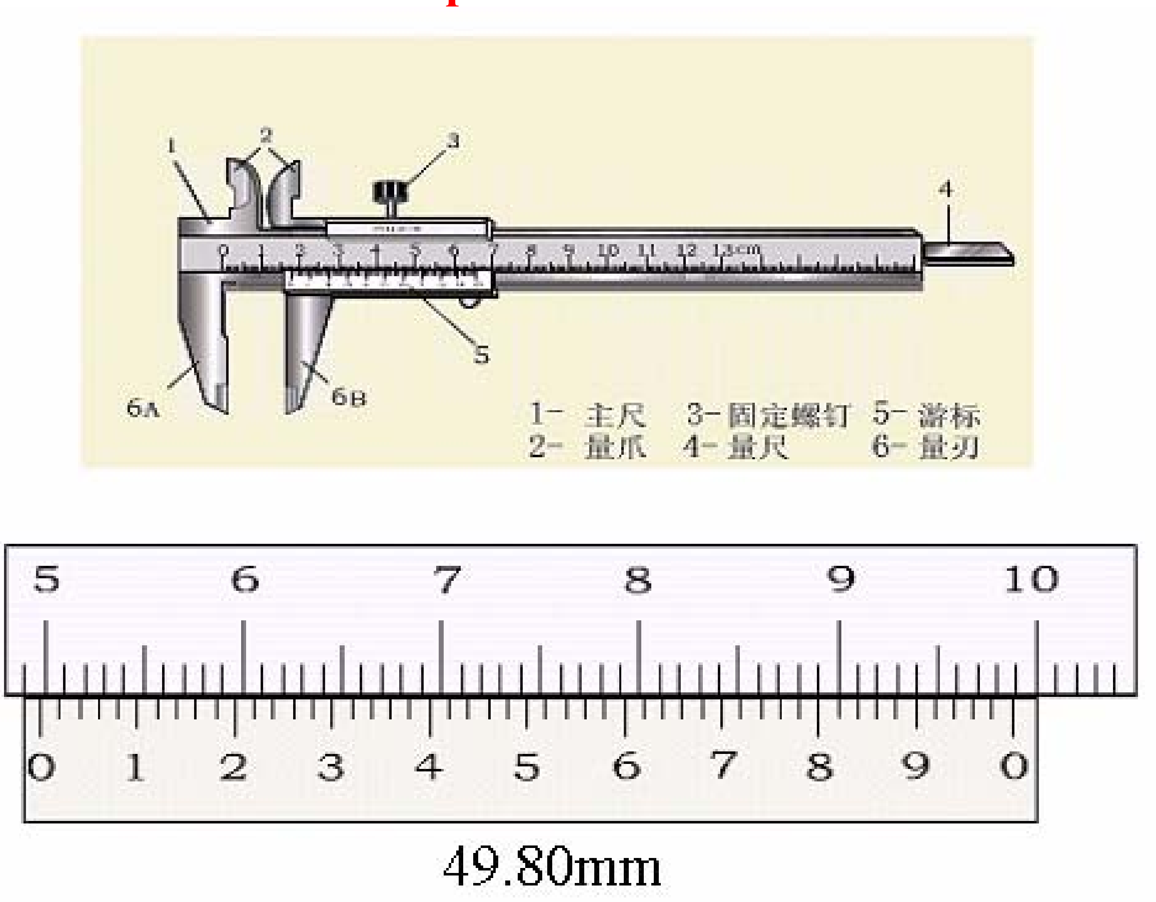


Fig.1 vernier caliper

Fig.2 the digital meter and the resistance box

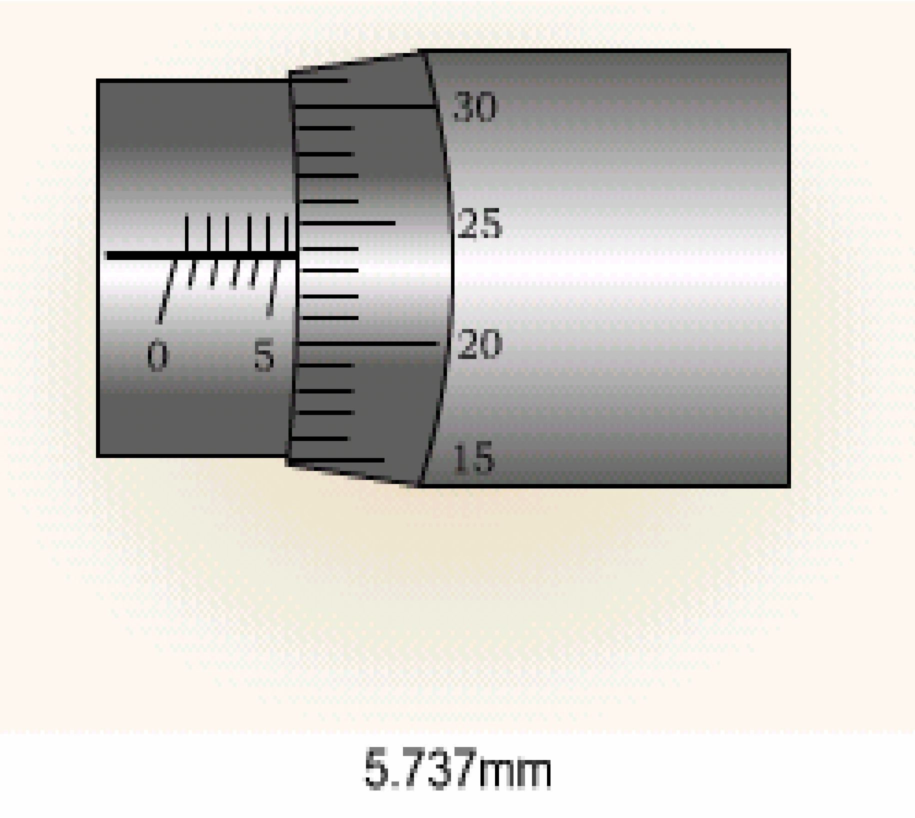


Fig.3 micrometer caliper

2. The significant figure of uncertainty

We only retain one significant figure in the uncertainty of an experiment result.

For example

When U =0.548mm, the uncertainty should be quoted as U =0.6mm.

When U =1.17 Ωmm, the uncertainty should be quoted as U =2Ω. (round up after the decimal point)

3. The significant figure in the result expression

A measurement and its experimental uncertainty should have their last significant digits in the same location (relative to the decimal point).

Examples are 54.1 ± 0.1, 121 ± 3, 8.674 ± 0.002, and (5.67 ± 0.01) × 10^3

4. Significant figures in calculations

- i) In addition or subtraction of experimental data it is a simple matter to determine what figures to carry and how many figures must be retained in the final result. The final result should contain the same accuracy as the least accurate quantity used in the calculation. (加、减法：诸量相加（相减）时，其和（差）数在小数点后所应保留的位数与诸数中小数点后位数最少的一个相同）。

$$\begin{array}{r} 4.178 \\ +\ 21.3 \\ \hline 25.478 = 25.5 \end{array}$$

- ii) In multiplication, division and other mathematic operations with experimental data, things are not so obvious. The basic rule to be remembered when doing calculations with data is: The final result should contain the same significant figure as the least one entering into a calculation. (乘、除法：诸量相乘（除）后其积（商）所保留的有效数字，只须与诸因子中有效数字最少的一个相同)。

$$\begin{array}{r} 4.178 \\ \times\qquad 10.1 \\ \hline 4178 \\ 4178 \\ \hline 421978 = 42.2 \end{array}$$

● Data processing methods often used in experiment.

Data processing refers to the process in which we obtain a conclusion from the data got during labs. Data processing methods often used are the tabulation method, the graphical method, the successive difference method, etc.

1. The tabulation method

Requirement:

1) All tables must have a title.
2) All the data in the table(s) should be original.
3) Quantities and units should be showed.

4) **For repetitious measurement, sequence number should be labeled and blank should be reserved for the average and uncertainty.**
5) **Row or column sequence should answer the relation between independent variable and dependent variable.**

For example

Table1 measuring parallel resonance curve

F(Hz)	**1000**	**1200**	**1400**	**1500**	**1550**	**f_1**	**1650**	**1700**	**1800**	**2100**	**2300**	**2500**
U_{RO}(V)												
I(mA)												
Z(Ω)												

2. The graphical method

A purpose of many experiments is to find the relationship between measured variables. A good way to accomplish this task is to plot a graph of the data and then analyze the graph. These guidelines should be followed in plotting your data:

1. **Use a sharp pencil. A broad-tipped pencil will introduce unnecessary inaccuracies.**
2. **Draw your graph on a full page of graph paper. A compressed graph will reduce the accuracy of your graphical analysis.**
2. **Give the graph a concise title**
3. **The dependent variable should be plotted along the vertical(y) axis and the independent variable should be plotted along the horizontal(x) axis.**
4. **Label axes and include units.**
5. **Select a scale for each axis so that the curve extends over most of the graph sheet and so that decimal parts of units are easily determined. This can be done if each small division is made equal to one, two, five, or ten units.**
6. **Each point should be plotted as "+", "*", or a dot surrounded by a small circle. Draw a beeline or curve using a Square or a French curve. The beeline or curve need not get across every point, but it must be smooth and the points not on it must distribute equably besides it.**
7. **Show the character value of the beeline or curve by graphic solution.**

Example

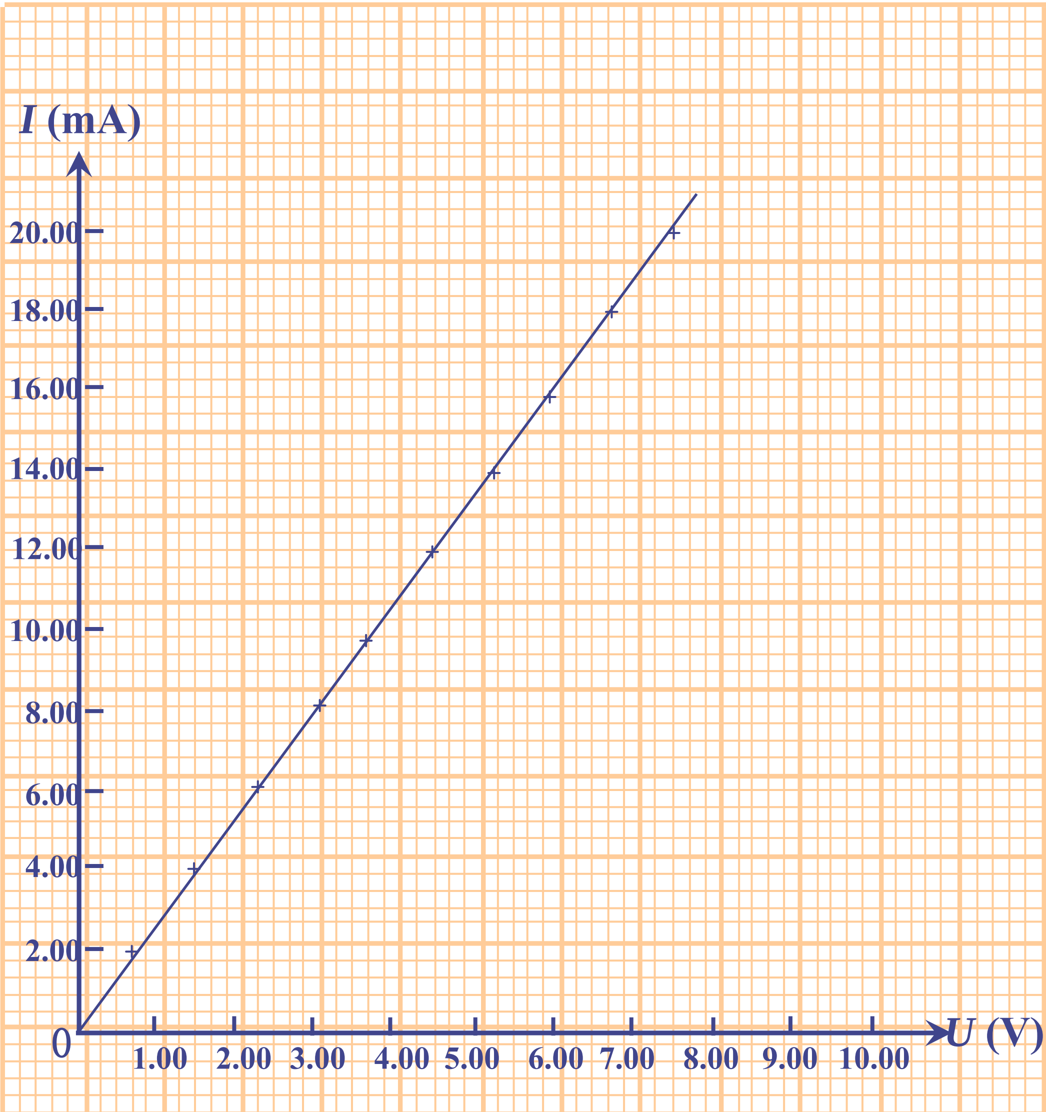
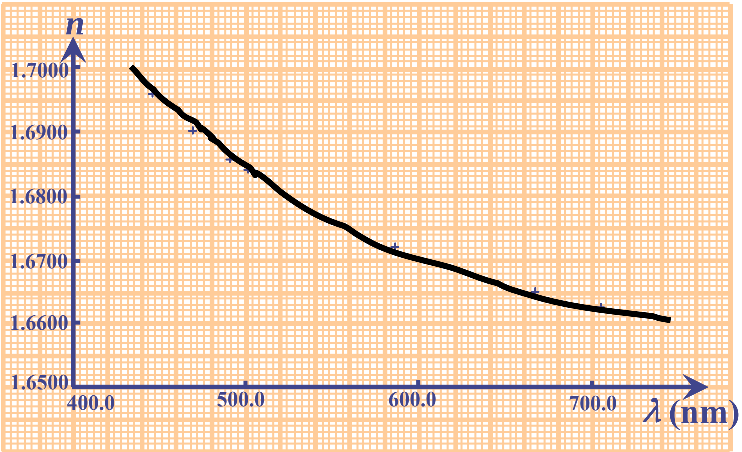
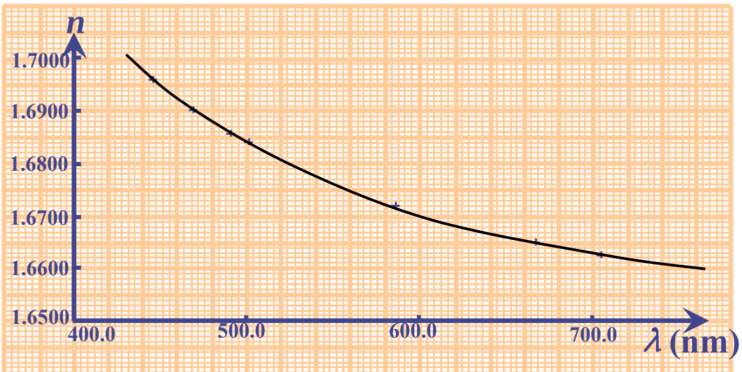


Fig. 1 The volt-ampere characteristic of resistance

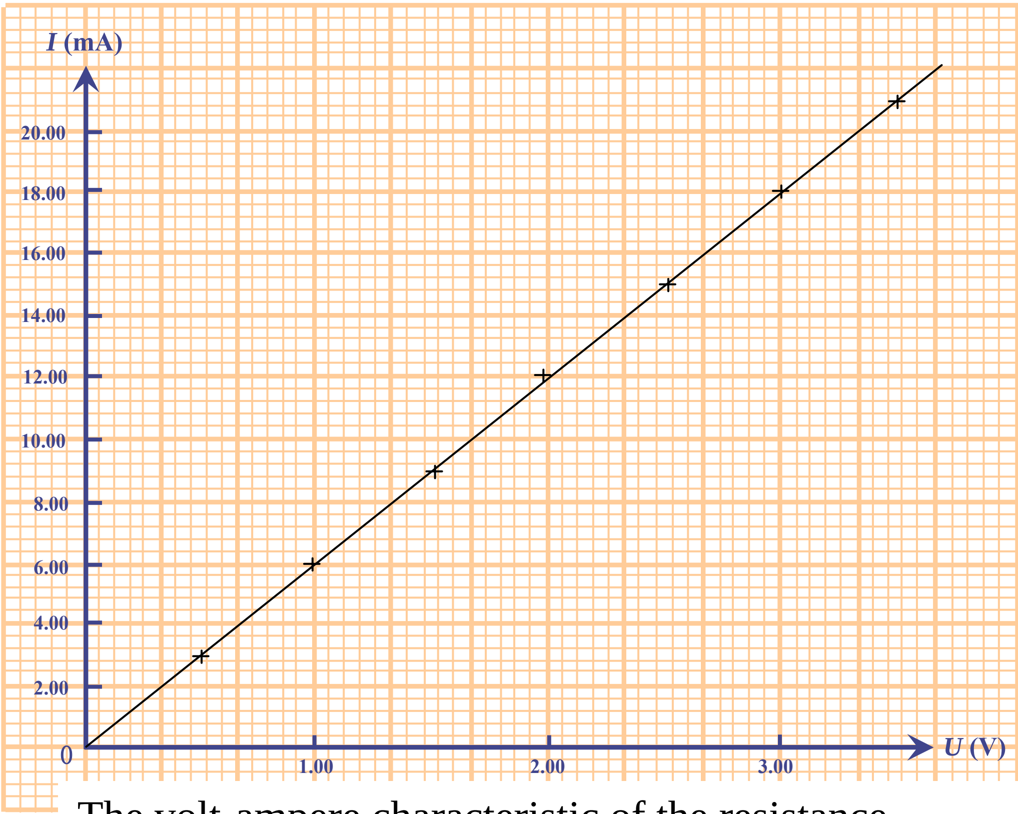


The dispersion curve of a glass material

correction curve

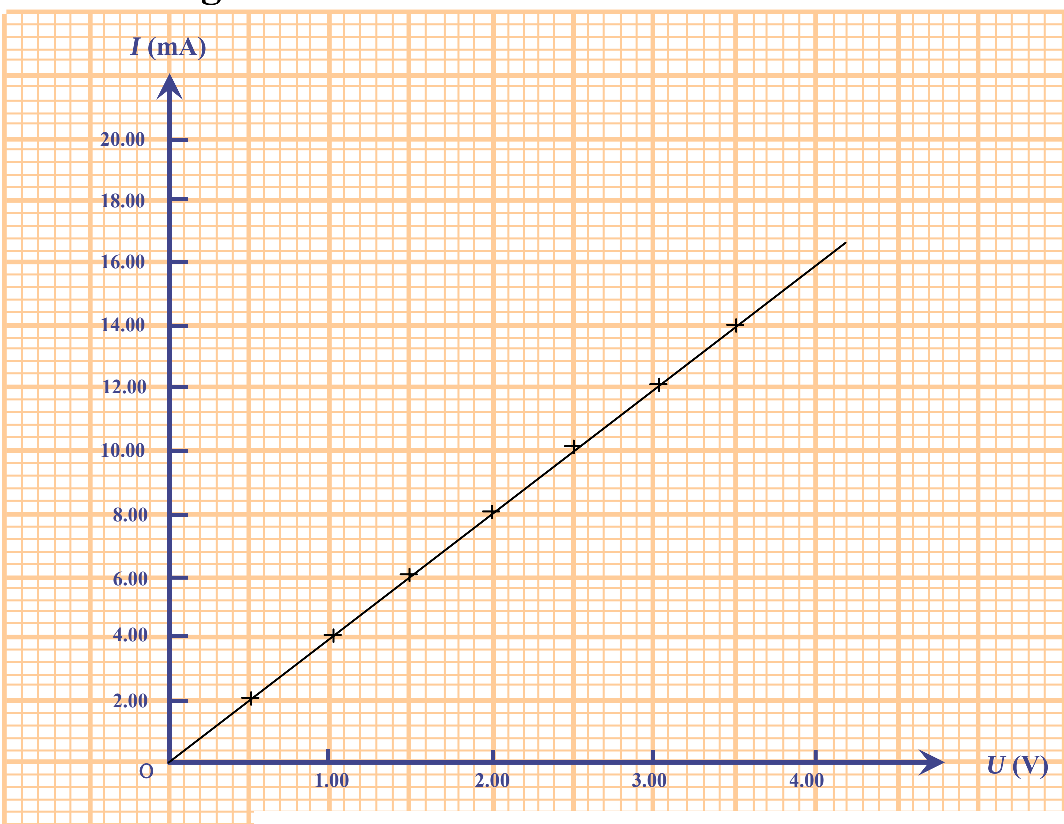


The dispersion curve of a glass material

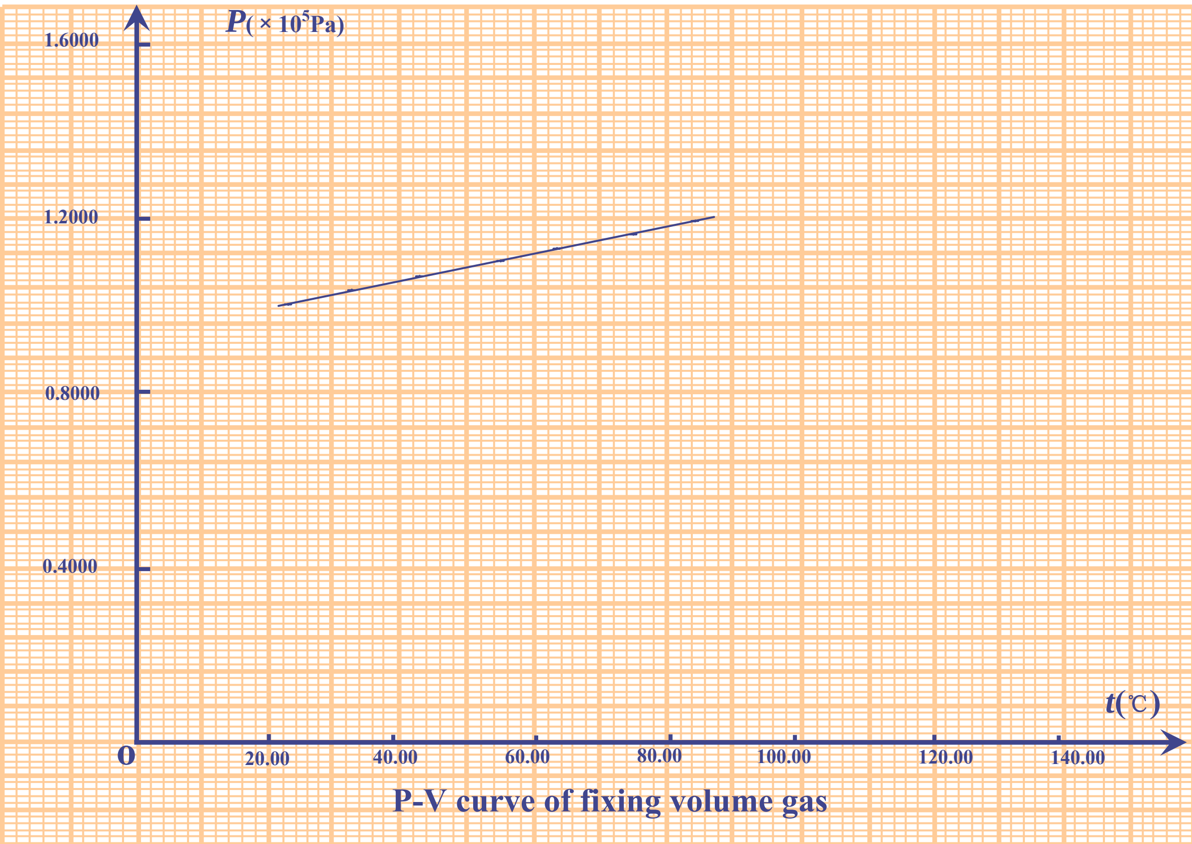


The volt-ampere characteristic of the resistance

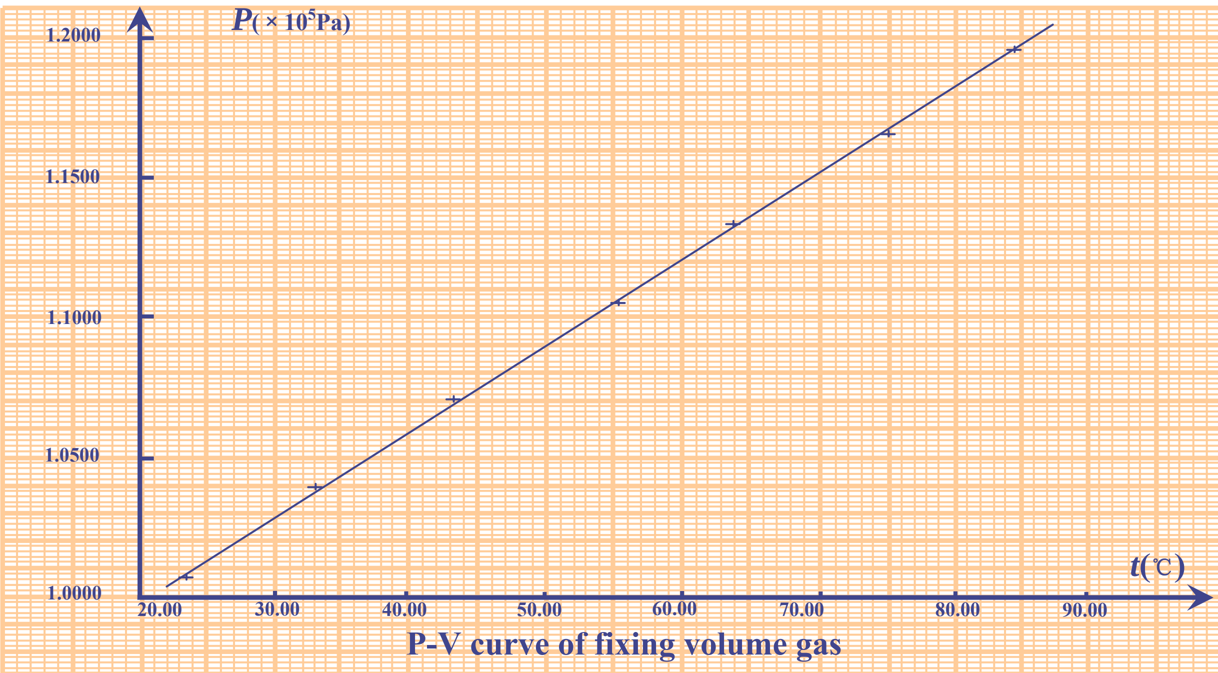
Correction diagram

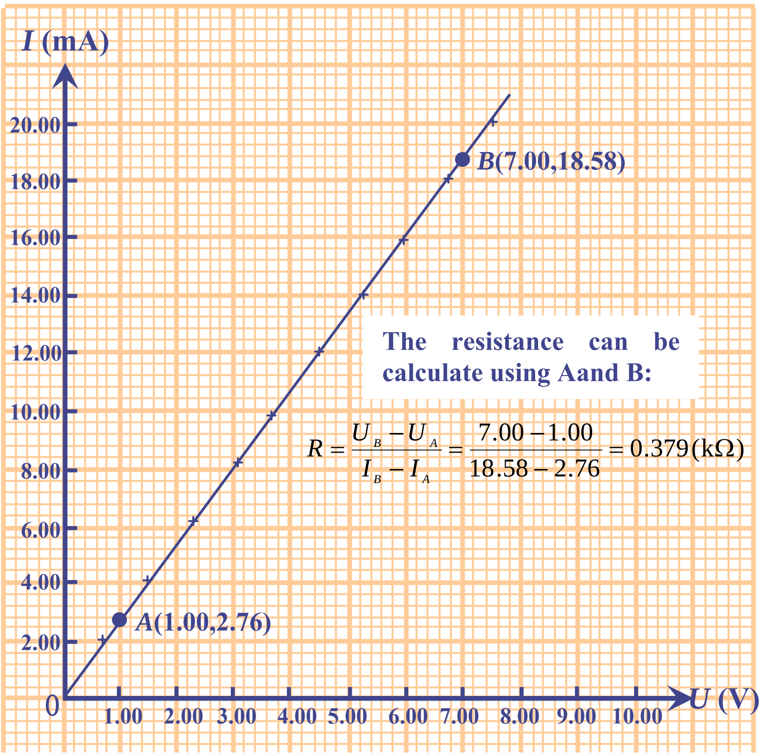


The volt-ampere characteristic of the resistance



Correction diagram





The volt-ampere characteristic of the resistance

3. The successive difference method

Successive difference method can be used under the condition that the independent variable equably changes, and the relation between two physical quantities is liner.

e.g. K=ΔI/ΔP

Suppose I_1, I_2, I_3…I_6 are the values of I measured *6* times.
Then,

$$\overline{l}=\frac{1}{5}\left[\left(l_2-l_1\right)+\left(l_3-l_2\right)+\left(l_4-l_3\right)+\left(l_5-l_4\right)+\left(l_6-l_5\right)\right]$$

$$=\frac{1}{5}\left(l_6-l_1\right)$$

$$P=\frac{1}{5}\left(P_6-P_1\right)$$

$$k=\frac{\overline{l}}{\overline{P}}=\frac{l_6-l_1}{P_6-P_1}$$

Here, we can see that I_2, I_3, I_4, I_5 haven't be used. If we divide these values to two groups, that is (I_1, I_2, I_3) and (I_4, I_5, I_6),then

$$k = \frac{1}{3}\left\{\frac{l_4 - l_1}{p_4 - p_1} + \frac{l_5 - l_2}{p_5 - p_2} + \frac{l_6 - l_3}{p_6 - p_3}\right\}$$

Exercises:

1. **One quantity has been measured 10 times, and the values are: 1.57, 1.55, 1.56, 1.58, 1.54, 1.55, 1.59, 1.57, 1.55, 1.58. Please calculate the average and the uncertainty.**
2. **Correct errors:**

   6.674 ± 0.03 , 56800 ± 200, 1.1m=1100mm

Appendix: calculating uncertainty in measurement

The rigorous calculation is very complicated. For the beginner, we simplify the calculation as following:

Calculating the uncertainty of quantity directly measured

i) If the quantity is measured many times the uncertainty include Δ_A and Δ_B , but we only calculate Δ_A and neglect Δ_B that is, $u = \Delta_A$

Suppose x_1, x_2, $x_3 \ldots x_n$ are the values of a quantity measured *n* times, $\overline{X}$ is the average of the values, then

$$\overline{x} = \frac{1}{n}(x_1 + x_2 + x_3 + \cdots + x_n) = \frac{1}{n}\sum_{i=1}^{n} x_i$$

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

statistical uncertainty $\Delta_A = t_p u_A$ t_p **can be looked up in table1.**

Table1 the relation between t and n

t \ n, p	3	4	5	6	7	8	9	10	15	20	∞
0.68	1.32	1.20	1.14	1.11	1.09	1.08	1.07	1.06	1.04	1.03	1
0.90	2.92	2.35	2.13	2.02	1.94	1.86	1.83	1.76	1.73	1.71	1.65
0.95	4.30	3.18	2.78	2.57	2.46	2.37	2.31	2.26	2.15	2.09	1.96
0.99	9.93	5.84	4.60	4.03	3.71	3.50	3.36	3.25	2.98	2.86	2.58

Then the uncertainty can be obtained:

$$u = \Delta_A = t_p u_A \qquad (2)$$

When the uncertainty is obtained the probability should be given at the same time. (e.g. p=0.683)

ii) If the quantity is measured only one time the uncertainty consists of only Δ_B

The uncertainty under this condition is:

$$u = \frac{\Delta_B}{C} = \frac{\sqrt{\Delta_{device} + \Delta_{estimate}}}{C} \qquad (3)$$

Here C is a device- related constant. When calculating the uncertainty, you can neglect it. Generally $\Delta_{device} >> \Delta_{estimate}$ **So**

$$u \approx \Delta_{device}$$

Under some special circumstances $\Delta_{device} << \Delta_{estimate}$,

then $u \approx \Delta_{estimate}$

Calculating the uncertainty of quantity indirectly measured

Propagation of Errors

The propagation of uncertainties is simply a method to determine the uncertainty in a value where the value is calculated by using two or more directly measured values with known uncertainties. This method will be discussed separately for the addition and subtraction of measurements, and for the multiplication and division of measurements.

Suppose that *x, y,* and *z* are three directly measured values and the uncertainties are $u_x, u_y, and\ u_z$, **respectively. The results of the three measurements would be reported in the form**

$$x \pm u_x,\ y \pm u_y, z \pm u_z$$

If *f* is some known function of the directly measured values, $f = f(x, y, z)$ **, then we may calculate *f* and its uncertainty.**

To determine u_f **, we start by calculating the differential *df*:**

$$df = \frac{\partial f}{\partial x} dx + \frac{\partial f}{\partial y} dy + \frac{\partial f}{\partial z} dz \qquad (5)$$

We approximate the differentials in equation 5 with *u,* that is,

$$u_f = \frac{\partial f}{\partial x} u_x + \frac{\partial f}{\partial y} u_y + \frac{\partial f}{\partial z} u_z$$

(Incorrect as the uncertainty in *f*)

Statistical theory shows that u_f is the square root of the sum of squares:

$$u_f = \sqrt{\left(\frac{\partial f}{\partial x} u_x\right)^2 + \left(\frac{\partial f}{\partial y} u_y\right)^2 + \left(\frac{\partial f}{\partial z} u_z\right)^2} \qquad (6)$$

$$\frac{u_f}{f}=\frac{\sqrt{\left(\frac{\partial f}{\partial x}u_x\right)^2+\left(\frac{\partial f}{\partial y}u_y\right)^2+\left(\frac{\partial f}{\partial z}u_z\right)^2}}{f} \quad (7)$$

Equation 6 and 7 are the **basic formulas** for uncertainty propagation

1. Addition and Subtraction of Measurements

Suppose that

$$f=ax+by+cz$$

here a, b, and c are known positive or negative constants, and x, y and z are measured values with known uncertainties $u_x, u_y, and\ u_z$

We can obtain u_f by using equation (6)

$$u_f=\sqrt{a^2u_x^2+b^2u_y^2+c^2u_z^2}$$

example:

$z=2x+3y$ **(*x, y* and** u_x, u_y **are known)**

using equation (6):

$$u_z=\sqrt{2^2u_x^2+3^2u_y^2}=\sqrt{4u_x^2+9u_y^2}$$

2. Multiplication and division of Measurements

Suppose that

$$f=kx^ay^bz^c$$

where k, a, b, and c are known positive or negative constants, and x, y and z are measured values with known uncertainties $u_x, u_y, and\ u_z$

We can obtain u_f by using equation (7)

$$\frac{u_f}{f}=\sqrt{\left(\frac{a}{x}u_x\right)^2+\left(\frac{b}{y}u_y\right)^2+\left(\frac{c}{z}u_z\right)^2}$$

example $z=4x^3y^2$ **(*x, y* and** u_x, u_y **are known)**