The Fundamental Knowledge for Physics Laboratory

Contents

The Expression for Physical Quantities

- **Units**

There are two types of units for physics. One is the MKS (or called SI), and the other is the CGS. The MKS stands for meters for length, kilograms for mass, and seconds for time, respectively. The CGS stands for centimeters, grams, and seconds respectively. For most introductory physics labs, we use MKS units. The unit of force, newtons, is also the MKS unit. There is also the unit of force in CGS, which is known as dyne. It is important not to mix them up to calculate. You cannot use kilograms and centimeters, or grams and meters at the same time. The following table shows MKS and CGS units for each physical quantity.

	MKS (SI)	CGS
Mass	**kg**	**g**
Length	**m**	**cm**
Velocity	**m/s**	**cm/s**
Acceleration	**m/s²**	**Gal** (galileo) [cm/s^2]
Force	**N** (newton) [$kg \cdot m/s^2$]	**dyne** [$g \cdot cm/s^2$]
Energy	**J** (joule) [$kg \cdot m^2/s^2$]	**erg** [$g \cdot cm^2/s^2$]
Momentum	**N·s** [$kg \cdot m/s$]	(**dyne·s** [$g \cdot cm/s$])
Power	**W** (watt) [$kg \cdot m/s^3$]	(**erg/s**)
Charge	**C** (coulomb)	**esu**
Current	**A** (ampere)	**esu/s**
Electric potential	**V** (volt)	**statvolt**
Magnetic field	**T** (tesla)	**G** (gauss)
Resistance	**Ω** (Ohm)	**cm/s**
Pressure	**Pa** (pascal)	**bar**

How about $^{\circ}\mathrm{C}$, g, and cal? Those are usually used for chemical or thermal physics. In fact, those are not genuine physics units. The unit of temperature should be K (kelvins) in physics. The unit, cal (calorie), has the dimension of energy (see above).

- **The expression of experimental results**

The basic format to express an experimental result is:

(Average Value)±(Standard Deviation) (units).

As a rule, the average value uses the significant figures. Let us explain it with an example of some experimental result.

5.3±0.1g

This expresses that the data have the uncertainty (fluctuation) in the first decimal place. The fluctuation of the data is ±0.1. Notice that the following expression does not make sense.

5±0.1g

You should write it as

5.0±0.1g.

Values, 5 and 5.0, are different. When you take data up to the first decimal place, you cannot omit zero even if the average is 5.0.

How to Perform the Experiment

These are important tips to perform a successful experiment:

- ❖ First, you should learn how the equipment works.
- ❖ Second, you should know how to use measurers, such as a meter stick, a caliper, a stopwatch, a multimeter, a balance, etc.
- ❖ Third, you should understand the experimental procedure.
- ❖ Forth, you should know how to verify the data.

Without realizing those, you might have troubles. Specific reasons and suggestions will be given as follows:

⌦ Not learning how the equipment works would be dangerous. You might be injured during experiment. Some equipment is fragile or worn out easily, so please read every warning on the data sheet and listen to your laboratory instructor.

⌦ Not knowing how to use measurers would cause wrong experimental results since your reading for the final result will propagate errors, and you therefore have to repeat the experiment.

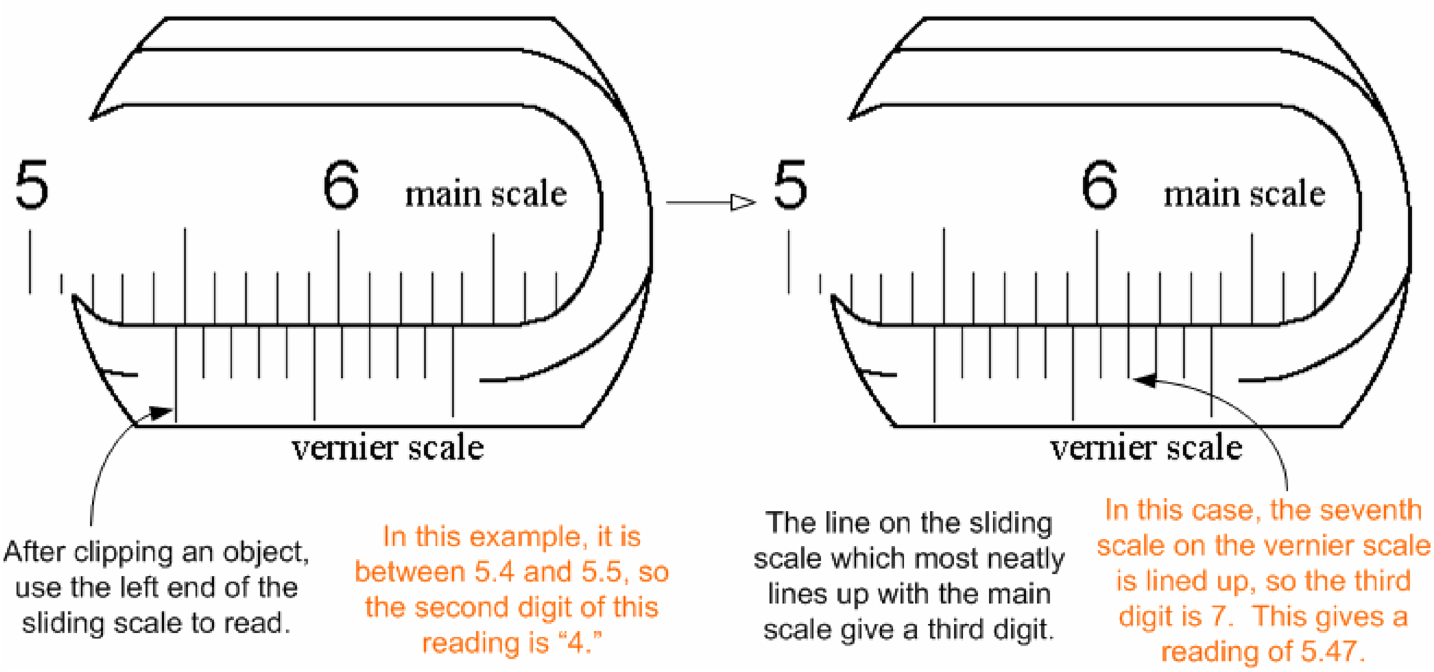
⌦ Conducting different procedures might give you unreasonable results. However, if you want to challenge or explore the experiment itself, it will be encouraged.

⌦ To see if your result is correct, please discuss it with your partners. However, if you still do not figure it out, ask your instructor. You cannot leave the class with wrong experimental results.

To improve your experiment, you should calculate the result and make sure if it is close to the expected one after you did <u>the first trial of experiment</u>. If the result is close enough, keep up good work and try to obtain better results. If not, look back what you performed in the experiment and try to find the causes of error. You may ask your TA to help you out. However, taking all the data first without confirming is not recommended because you may have all wrong results, and will have to repeat the experiment.

How to use a caliper

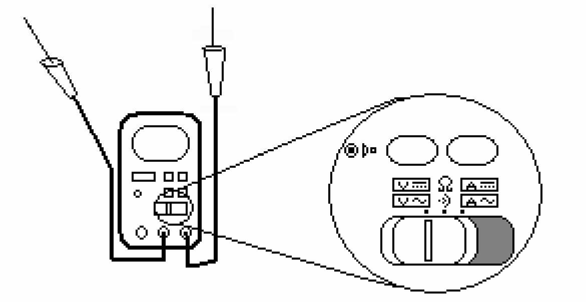
Use the left end of vernier scale to read the main scale. You can read three digits with the caliper.



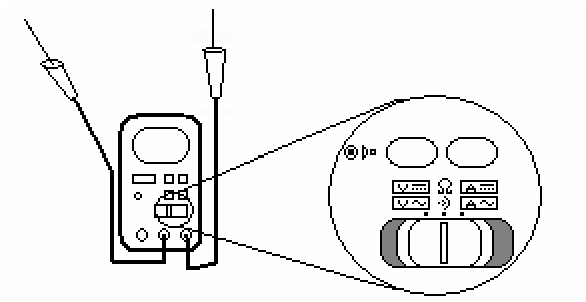
Please read the above instruction from left to right.

How to use a multimeter

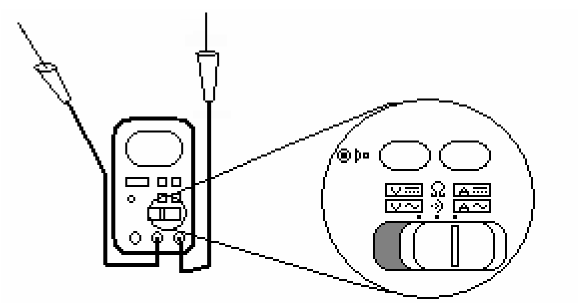
A typical multimeter can measure voltages, resistances, and currents.



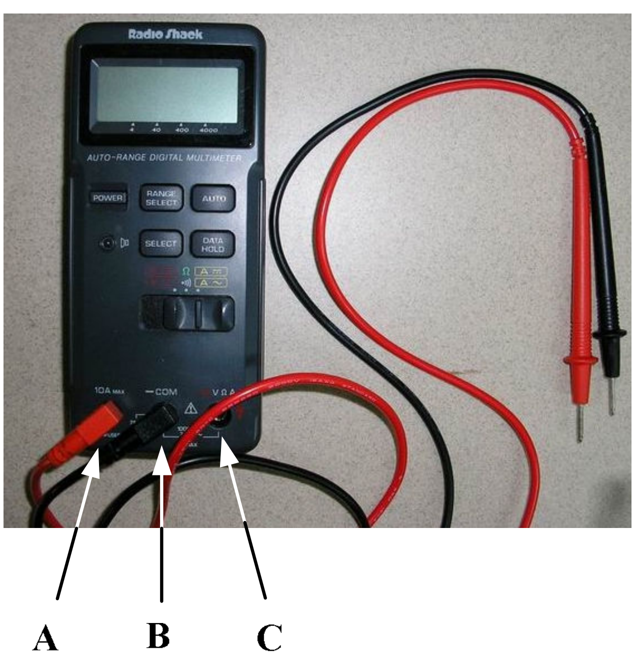
When measuring a voltage, select the mode indicated by the symbol ‘V.’



When measuring a resistance, select the mode indicated by the symbol ‘Ω.’



When measuring a current, select the mode indicated by the symbol ‘A.’



There are two kinds of power supplies to be measured by a multimeter. One is DC (Direct Current), and the other is AC (Alternate Current). In each case, you have to select the proper mode in the multimeter. When you measure the DC, you have to select to have indication, ⎓, on the window. When you measure the AC, you have to select to have this, ∿, on the window.

For connecting probes, there are three plugs, **A**, **B** and **C** shown in the picture. The black probe represents ground, and should be plugged in **B** denoted as “- COM.” The red probe can be plugged in either **A** or **C**. **C** is for a small current up to 430 mA. **A** is for a large current up to 10 A. If you measure more than the limit indicated, the fuse will be blown up.

How to explain experimental data and its uncertainty

➢ **Uncertainty**

It is very important to consider the uncertainty of experimental results. The reasons are following:

- ❖ To know the accuracy of the experimentation
- ❖ To know how fitted the theoretical prediction is compared with the experimental results
- ❖ To interpret the experimental data
- ❖ To analyze the method of experiment

It is impossible to obtain the absolute true value from an experiment. You have to repeat the trial many times so that you can show that the average of data is the possible value to fit a theory within some uncertainty. In this sense, zero standard deviation cannot exist in our real life. The standard deviation is a specific parameter to identify the uncertainty of experiment. As you notice, the meaning of uncertainty has broader sense than that of the standard deviation does.

➢ **Random and systematic errors** [For following two parts, I referred to, *A Practical Guide to Data Analysis for Physical Science Students, by Louis Lyons, Cambridge*.]

The random error is mostly referred as human's careless performance and poor experimentation. It gives more deviated results (higher standard deviation). On the other hand, the systematic error is referred as the constant misreading of values, systematic mistake of calculation, and systematic mechanical false of equipment. You can also consider the combination of random and systematic errors.

➢ **Examples of the interpretation**

Suppose you measure the gravitational acceleration, and its accepted value is 9.81 m/s^2. After the proper amount of measurement, you obtain 9.72 m/s^2 as the average. Now you can think of following possibilities:

- ❖ (9.72 ± 0.15) m/s^2

  The standard deviation is ±0.15, which satisfactorily agrees with the expected value. You can think of random errors to explain the deviation. If the standard deviation is much smaller and still within the expected value such as (9.80 ± 0.01) m/s^2, your performance is greatly successful and will be referred as the limitation of equipment for the error.

- ❖ (9.72 ± 0.01) m/s^2

  Even though the standard deviation is very small, it does not satisfy the expected value. In this case, you should suspect systematic errors rather than random errors. Or it might be a beginning of world shattering discovery. (However, you have to have a possible reason or other test to verify it.)

- ❖ (9.72 ± 1.00) m/s^2

  This satisfies the expected value, but the deviation is large. You can think of a few things. You should find the source of random error. If it is based on the human error, you should do more trials to minimize and stabilize the deviation. You also want to exclude to calculate obviously fault results from your data sheet, or replace with another trial (In principle, you should not erase any data.). If you obtain (10.9 ± 1.0) m/s^2, you will check both random and systematic errors since the deviation is large and not in agreement with the expected value.

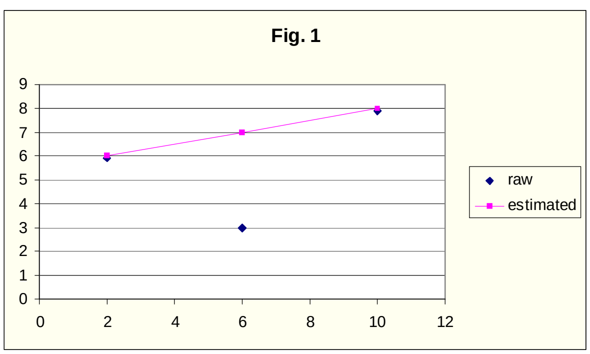
➢ **Error propagation**

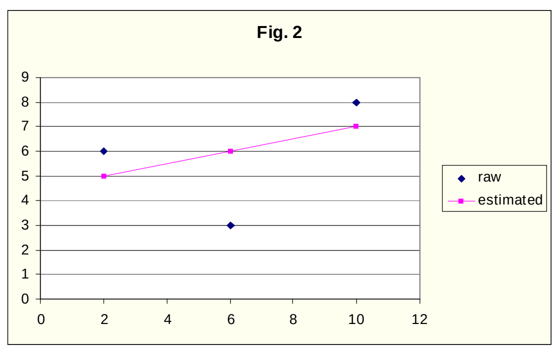
This is to identify the uncertainty of a quantity involving more than one measurement. For example, to obtain a density of a rectangular solid, you will measure the height, width and length. Then, you measure the weight. The density is given by mass ÷ volume. There are four variables to obtain the density, and each variable gets uncertainty. Therefore, to obtain the uncertainty of density, you have to combine each standard deviation, which needs more consideration than one variable measurement. It also depends on the equation to obtain the final quantity. (⇨ Refer to the lab sheet for "Experimental Uncertainty.")

Idea of the Least Squares Fit

Even though you expect a straight line from a set of data, you likely have scattered plots. To obtain the expected line from the data, you use the method of the least squares.

Look at the graphs below. You can draw a line as in Fig. 1, and as in Fig. 2. Which is the best fitted line with the raw data points? To figure it out, you will take the following procedure: you have to find the line which is determined so that the sum of difference squared between each point and the line can have the minimum value. For example, from Figs. 1 and 2, you can find y values from the data and estimated lines.





Look at this table.

Fig. 1			Fig. 2		
y	y'	$\|y-y'\|^2$	y	y'	$\|y-y'\|^2$
6	6	0	6	5	1
3	7	16	3	6	9
8	8	0	8	7	1
	Total error	16		Total error	11

The values of y and y' denote raw and estimated data respectively. The total error is the sum of each difference squared. According to the errors, the line in Fig. 2 has less error, which means that it is closer to the best fit line. This is the concept of method of the least squares. However, this way is tedious to keep finding the less error to get the slope, so usually people use a systematic way to calculate the least fit line. (⇨ Refer to “About the Least Squares Fit” from Useful Handouts.)