PRACTICAL 1.1

SIMPLE MEASUREMENTS

Objective: measurement of linear dimensions and masses of various objects, data processing and error analysis.

References: Lab Manual, Penn State University (Error analysis)

Equipment: various objects for measurements, micrometer, scales, vernier caliper.

INTRODUCTION

Measuring instruments and our senses are imperfect, so all the measurements can only be done with a certain degree of accuracy, and an experimental error cannot be less than that determined by the measuring equipment. Therefore, the measurement task is not only to obtain the values, but also to estimate the degree of the measurement uncertainty, referred to as “error analysis”. When an indirect measurement is being performed (which is often the case in science), the total error not only depends on the errors of individual measurements, but also on the functional relation between the calculated value A and directly measured quantities, say x, y, x: $A = f(x,y,z)$.

Here are two practical rules which allow estimation of the absolute measurement error of a single direct measurement:

1. the absolute error of a single direct measurement equals one half of the smallest division of the scale if the pointer is between two divisions;
2. the absolute error of a single direct measurement equals the smallest division of the scale if the pointer is digital, i.e. it lacks the ability to provide any values which are between its scale divisions.

<u>In this Practical you will learn how to:</u>

- make direct measurements of the linear dimensions and the mass of an object,
- make indirect measurements (calculations) of a physical value;
- perform statistical analysis and error analysis of the measurements and calculations.

DESCRIPTION OF THE MEASURING TOOLS

<u>Vernier caliper</u>

The vernier caliper is an instrument that measures internal or external dimensions and distances. It allows more precise measurements than could be performed with a regular ruler.

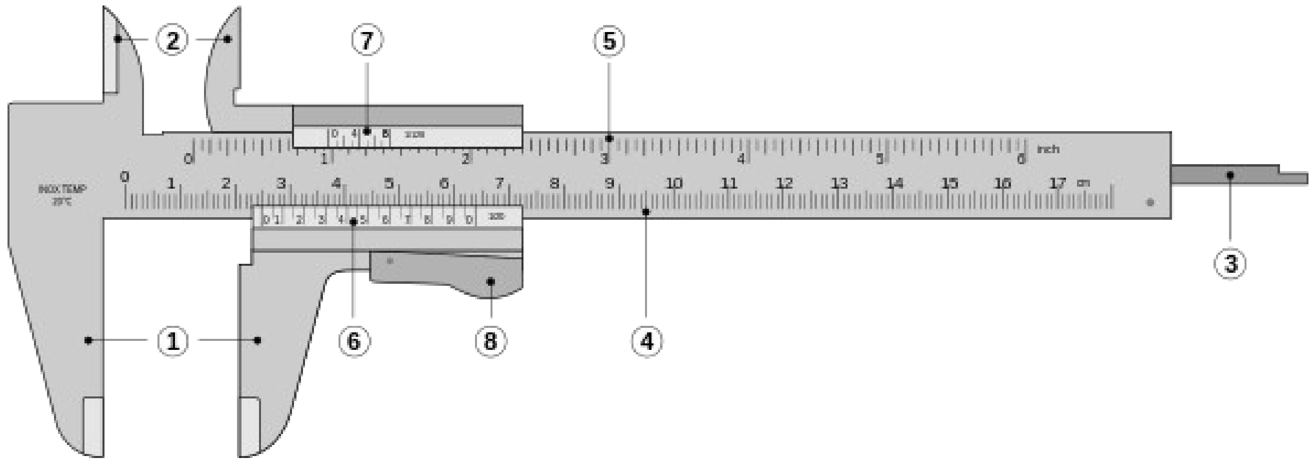

Fig. 1. A diagram of a vernier caliper. Indicated in the diagram are:

1 – outside large jaws: used to measure external diameter or width of an object

2 – inside small jaws: used to measure internal diameter of an object

3 – depth gauge: used to measure depths of an object or a hole

4 – main scale: scale marked every mm

5 – main scale: scale marked in inches and fractions

6 – vernier scale gives interpolated measurements to 0.1 mm or better

7 – vernier scale gives interpolated measurements in fractions of an inch

8 – retainer: used to block movable part to allow the easy transferring of a measurement

Referring to Fig. 1, the vernier caliper has outside large jaws that are used for measuring external diameters, as well as inside small jaws that are used for measuring internal diameters of objects. Some models also have a depth probe. The main scale is fixed in place, while the vernier scale slides thus opening and closing the jaws.

Each scale of the caliper reads like an ordinary ruler. Typically, a caliper has a main scale marked in millimetres and inches. The vernier scale has a label engraved on it to tell what it represents. If the sliding scale doesn't have a label, this means that the numbered divisions represent 1/10 of the smallest division on the main scale.

Below are the steps for making a measurement with a caliper (see Fig. 2):

- Clean the object you are measuring; Wipe it off to make sure there's no grease on it, and that there's nothing in the way that will interfere with an accurate measurement.

- Unlock the retainer; if your caliper has a locking screw, loosen it before you begin.

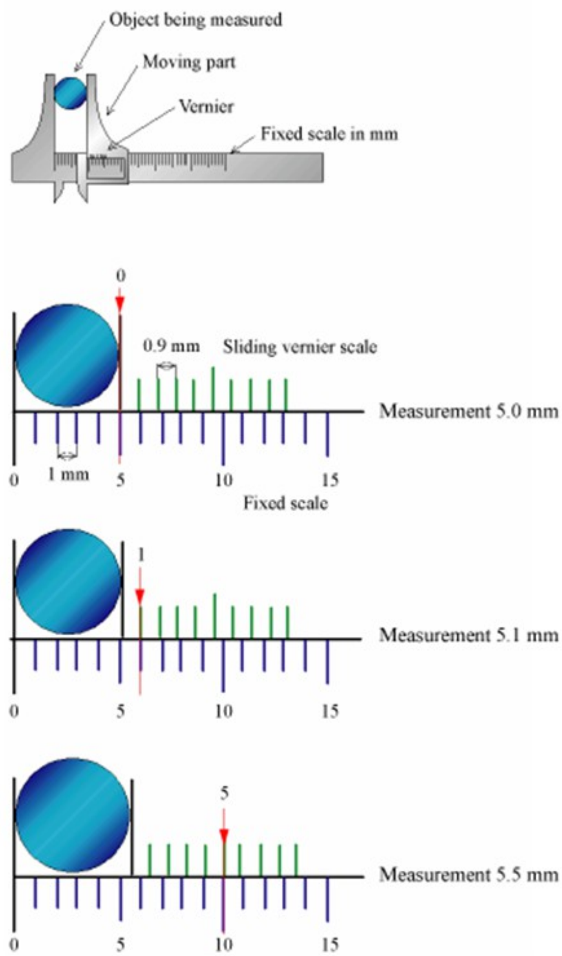

Fig. 2: Making a measurement with a vernier caliper.

- Close the jaws. Before measuring anything, close the jaws to zero out the reading so that you get a precise measurement. If you don't do this, you won't start with your scales lined up at zero when you take your measurement, and you will have to correct for the zero error.

- Slide one of the jaws against the object. The caliper has two types of jaws. The larger ones tighten around an object, to measure the distance across it. The smaller jaws fit into an opening, and can then be pushed outward to measure its internal diameter. You can adjust either pair of jaws by sliding the smaller scale. Once you've got one of the jaws in position, tighten the locking screw if there is one.

- Read the main scale where it lines up with the sliding scale's zero. The main scale on a Vernier caliper typically tells you the whole number plus the first decimal. Read this just as you would a ruler, measuring to the zero mark on the sliding (Vernier) scale.

- Read the Vernier scale. Find the first mark on the Vernier scale that lines up perfectly with any line on the main scale. That mark tells you the value of the additional digits.

- Add the numbers together. Add the main scale and Vernier scale results together to get the final answer. Make sure you use the correct units as labelled on each scale, or you won't get the right answer.

Using a micrometer

The micrometer is a precision measuring instrument used by engineers. Each revolution of the ratchet moves the spindle face 0.5 mm towards the anvil face. The object to be measured is placed between the anvil face and the spindle face. The ratchet is turned clockwise until the object is ‘trapped’ between these two surfaces and the ratchet makes a ‘clicking’ noise. This means that the ratchet cannot be tightened any more and the measurement can be read.

A diagram of a micrometer is shown in Fig. 3. The measurement procedure is the following:

- Clean the anvil and spindle before beginning. Use either a clean sheet of paper or soft cloth, and hold it between the anvil and the spindle. Gently twist and close on the sheet or cloth. Slowly, pull out the sheet or the cloth.

- Check if a “zero” reading is obtained by gentle moving of the spindle towards the anvil by turning the ratchet knob until a “click”.

- Hold the object in your left hand and place it against the anvil. The anvil is stationary and can withstand more pressure than the spindle. Make sure the object doesn't move or scratch the surface of the anvil. Move the spindle inwards until a “click”.

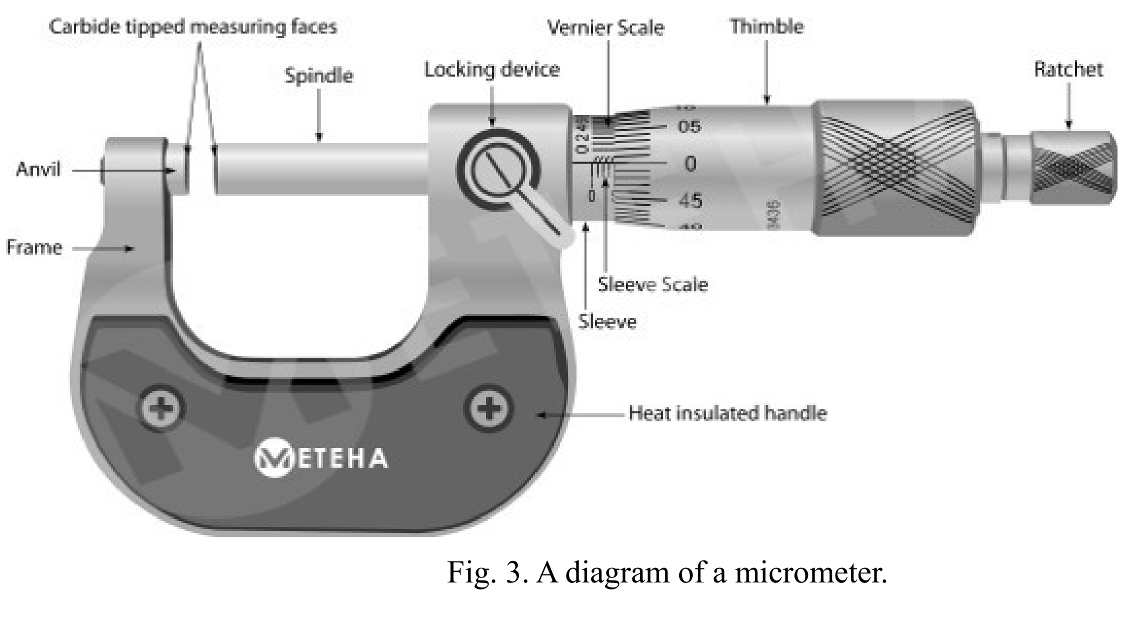

Fig. 3. A diagram of a micrometer.

- Read the measured value (see Fig. 4 for an example):

1. Read the scale on the sleeve. The example clearly shows 12 mm divisions.

2. Still reading the scale on the sleeve, you can see a further ½ mm (0.5) measurement on the bottom half of the scale. The measurement now reads 12.5mm.

3. Finally, the thimble scale shows 16 full divisions (these are hundredths of a mm). The final measurement is 12.5mm + 0.16mm = 12.66.

MEASUREMENTS AND DATA PROCESSING

T a s k . Calculate the density of a ring.

The density of a ring can be computed as

$$\rho = \frac{4m}{\pi (D^2 - d^2) h}, \tag{1}$$

where D and d are the outer and inner diameters, respectively; h is the thickness; and m is the mass of the ring.

- Measure D and d with the vernier caliper. Perform each measurement three times.
- Measure h with the micrometer. Perform each measurement three times.
- Measure m with the scales.
- Make a table which includes all the measured values and the averaged values.
- Compute the absolute and relative errors.
- Compute the mass density of the ring and find out what material it is made of.
- Repeat the above steps for another ring.

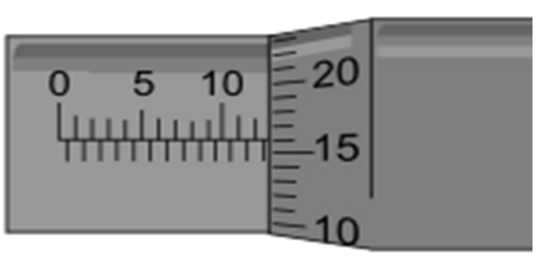

Fig. 4. Reading a micrometer.

QUESTIONS AND EXERCISES

1. How do you use the vernier caliper and the micrometer?

2. What are the absolute and relative errors of a measurement? How can they be calculated?

3. What is a nonius and how it works? How can one make a nonius which improves the measurement accuracy by a factor of n?

4. Which of your measurements was the least/most precise?

5. What accuracy would be enough for the mass measurement?