Principles of Physics I (PHY111)

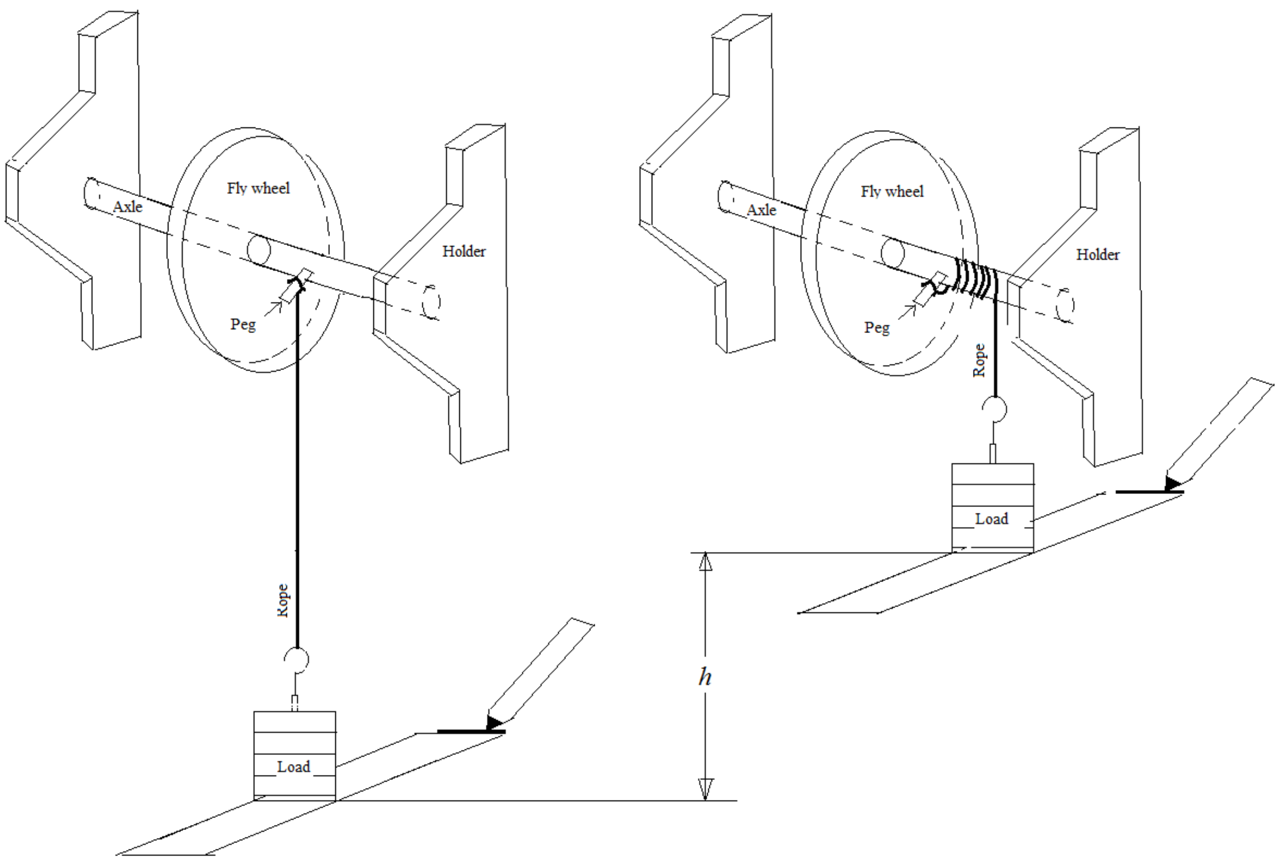
Lab

Experiment no: 3

Name of the experiment: Determination of moment of inertia of a flywheel about its axis of rotation

Theory

The flywheel is a big sized wheel. Most of its mass is distributed over the peripheral region. A thick cylindrical rod, called the axle, passes through the centre of mass of the wheel. The axis of the axle is perpendicular to the circular surface of the flywheel. The axle is kept horizontally by means of a holder hung on the wall. The wheel with the axle can rotate about the axis of the axle. There is a peg joined with axle. Objective of this experiment is to determine the moment of inertia of the flywheel about the axis of rotation, i.e., the axis of the axle.



(a) **(b)**

Figure1: (a) Flywheel when the rope and load is about to be detached from the axle. (b) The same flywheel after rotating it for n_l number of times (here n_1 is 6)

There is a small peg on the axle, as shown in figure 1. We make a loop on one end of a rope round this peg. A load of mass, *M*, is connected to the other end of the rope. We hold the flywheel in such a way that the load is about to be detached from the axle (figure 1 a). Then we keep a straight meter scale at the bottom surface of the load, see where on the wall the end of the meter scale touches and put a mark over there. Next, we rotate the flywheel for n_1 times. Consequently the load moves upward. Again, we keep the straight meter scale at the bottom surface of the load; we see where on the wall the end of the meter scale touches and put a mark over there. The separation between the two marks is h.

Now, if the flywheel is made free to rotate, then its angular speed increases uniformly and the linear velocity of the load also increases uniformly. The flywheel completes n_1 revolutions after the release of the load and the load traverses a distance h vertically.

The work done by gravity on the load = M g h

A part of this work is used to increase rotational kinetic energy of the flywheel, and part of it supplies the linear kinetic energy to the load and the rest is used to work against the friction between the flywheel and the holder.

Let, I is the moment of inertia of the flywheel about its axis of rotation.

When the load is just detached from the axle, the angular speed of the flywheel be ω and the linear velocity of the load is v. So the rotational kinetic energy of the flywheel = $\frac{1}{2}I\omega^2$, and the kinetic energy of the load = $\frac{1}{2}Mv^2$

Let, the work done against friction to complete a single revolution = W_f , therefore, the work done against friction to complete n_1 revolutions = $n_1 W_f$

So, we can write,

$$Mgh = \frac{1}{2}I\omega^2 + \frac{1}{2}Mv^2 + n_1 W_f \qquad (1)$$

Neglecting the thickness of the rope the ω , v and the radius of axle, r, are related by:

$$v = \omega\ r$$

Hence, from equation (1)

$$Mgh = \frac{1}{2}I\omega^2 + \frac{1}{2}M\omega^2 r^2 + n_1 W_f \qquad (2)$$

Let, t is the time between the moment of detachment of the load from the axle and the moment when the flywheel comes into rest. In time t the flywheel completes n_2 revolutions.

During this second part of the motion of the flywheel, all of the rotational kinetic energy will be used to work against the friction which is $n_2 W_f$, and hence

$$\frac{1}{2}I\omega^2 = n_2 W_f \tag{3}$$

Since in one complete revolution the angular displacement is 2π radian, in n_2 revolutions, total angular displacement is $2\pi n_2$ radian. The average angular speed, $\overline{\omega} = \frac{2\pi n_2}{t}$

Now, during this second part of the motion, the angular speed decreases uniformly form $\omega_{initial} = \omega$ to $\omega_{final} = 0$

So, average angular speed, $\overline{\omega} = \frac{\omega_{initial} + \omega_{final}}{2} = \frac{\omega + 0}{2} = \frac{\omega}{2}$

Therefore, $\frac{\omega}{2} = \frac{2\pi n_2}{t}$

$$\Rightarrow \quad \omega = \frac{4\pi n_2}{t} \tag{4}$$

From equations (2) and (3) it follows that

$$I = \frac{2Mgh - M\omega^2 r^2}{\omega^2\left(1 + \frac{n_1}{n_2}\right)} \tag{5}$$

By using equations (4) and (5) we can determine the moment of inertia of the flywheel about its axis of rotation by measuring *M*, *h*, *r*, n_1 and n_2.

Apparatus

Fly-wheel, load, rope, stop-watch, meter scale, slide calipers and a piece of foam (most probably the upper portion of a broken seat) where the load will fall down

Procedure

1. Put the loop at one end of the rope round the peg (Figure 1 a) on the axle and a load of mass *M*=800 gm at other end.

2. Hold the flywheel in such a way that the load is about to be detached from the peg (figure 1 b). Then keep a straight meter scale at the bottom surface of the load, see where on the wall the end of the meter scale touches and put a mark over there. Next rotate the flywheel for a certain number of times (say for 6 times). It is the value of n_1. Write it down in the Table 1 of data sheet. The load moves upward. Again keep a straight meter scale at the bottom surface of the load, see where on the wall the end of the meter scale touches and put a mark over there. The separation between the two marks is *h*. Measure *h* by using a meter scale. Write it down in the Table 1 of data sheet.

3. Take the stop watch in your hand. Make the flywheel free to rotate. At the moment when the rope is just detached from the axle's peg, then turn on the stopwatch and begin counting the number of revolutions the flywheel makes until it comes to rest.

4. When the flywheel comes to rest, then turn off the stopwatch. The time recorded in the stopwatch is the value of, *t*. Write it down in the Table 1 of the data sheet. The number of revolutions what you have counted is n_2. Write it down in the Table 1.

5. Now repeat the whole process for the mass of the load, M = 700 gm and M = 600 gm

6. Measure the diameter of the axle by using a slide calipers. Use Table 2 to record the data. Find out the radius, *r* of the axle. Write it down in the data table. To know how to use a slide calipers please see the Appendix A (provided in the soft copy available in the server).

7. Find out the value of *I* for each case.

8. Take the average value of *I* for the final result.

Read carefully and follow the following instructions:

- **Please READ the theory carefully, TAKE printout of the 'Questions on Theory' and ANSWER the questions in the specified space BEFORE you go to the lab class.**
- **To get full marks for the 'Questions on Theory' portion, you must answer ALL of these questions CORRECTLY and with PROPER UNDERSTANDING, BEFORE you go to the lab class. However, to ATTEND the lab class you are REQUIRED to answer AT LEAST the questions with asterisk mark.**
- **Write down your NAME, ID, THEORY SECTION, GROUP, DATE, EXPERIMENT NO AND NAME OF THE EXPERIMENT on the top of the first paper.**
- **If you face difficulties to understand the theory, please meet us BEFORE the lab class. However, you must read the theory first.**
- **DO NOT PLAGIARIZE. Plagiarism will bring ZERO marks in this WHOLE EXPERIMENT. Be sure that you have understood the questions and the answers what you have written, and all of these are your own works. You WILL BE asked questions on these tasks in the class. If you plagiarize for more than once, WHOLE lab marks will be ZERO.**
- **After entering the class, please submit this portion before you start the experiment.**

Name: ______________________ ID: _______________ Sec: ___ Group: __ Date: ___________

Experiment no: ___

Name of the Experiment: ____

____

Questions on Theory

Questions on Theory

*1) What is a flywheel? [0.25]

Ans:

*2) What is the moment of inertia of a body? Is it a constant for a body? [0.25]

Ans:

*3) When the flywheel is set free and the load of mass M moves downward for distance h until it gets detached from the flywheel, then what is the work-done by gravity on the load? [0.25]

Ans:

*4) At the moment when the load is detached from the flywheel the angular speed of the flywheel is ω. The moment of inertia of the flywheel about its axis of rotation is I. What is the rotational kinetic energy of the flywheel? [0.25]

Ans:

*5) At the moment when the load is detached from the flywheel the speed of the load of mass M is v. What is the linear kinetic energy of the load? [0.25]

Ans:

*6) The flywheel makes n_1 revolutions during the period when the load moves downward for distance h. If W_f is the work done against friction per revolution then what is the Energy loss due to friction for n_1 revolutions? [0.25]

Ans:

*7) The amount of work done by gravity which you wrote in the answer of question 3 provides the kinetic energy to the load, rotational kinetic energy to the flywheel and the energy to work against the friction between the flywheel's axle and its holder. Write down the equation relating them according to the law of conservation of energy. [0.25]

Ans:

*8) If r is the radius of cross section of the axle then what is the relationship between the speed of the load v and the angular speed of the flywheel ω at the moment when the load is about to get detached from the flywheel? [0.25]

Ans:

*9) After the load is detached from the flywheel the flywheel slows down due to the friction between the axle and its holder. From the moment of detachment the flywheel makes n_2 number of revolutions until it stops rotating. If W_f is the frictional energy loss per revolution then what is the total frictional energy loss for making n_2 revolutions? [0.25]

Ans:

*10) The rotational kinetic energy which the flywheel attains at the moment when the load gets detached is used to work against friction to make n_2 revolutions. Write down the equation relating this rotational kinetic energy attained by the flywheel and the frictional energy loss after the load gets detached. [0.25]

Ans:

*11) At the moment the load gets detached the flywheel's angular speed is ω. It slows down due to friction and finally stops. We assume that this negative angular acceleration is constant. The angular displacement of the flywheel during this period is θ and the measured time is t. What is the relationship among θ, ω and t? [0.25]

Ans:

*12) What is θ in terms of n_2? [0.25]

Ans:

13) Using equations (2), (3) and (4) show that, $I = \frac{\left(ght^2 - 8\pi^2 n_2^2 r^2\right)M}{8\pi^2\left(n_2^2 + n_1 n_2\right)}$

[2]

[Use additional page(s) to answer this question]

Ans:

- **Draw the data table(s) and write down the variables to be measured shown below (in the 'Data' section), using pencil and ruler BEFORE you go to the lab class.**
- **Write down your NAME and ID on the top of the page.**
- **This part should be separated from your Answers of "Questions on Theory" part.**
- **Keep it with yourself after coming to the lab.**

Data

Table 1: Table for determination of n_1, h, n_2 and t

Mass, M (gm)	Path traversed by the load since the moment when the flywheel is made free to rotate, until the load is just detached from the peg, h (cm)	Number of revolutions of flywheel since the moment when the flywheel is made free to rotate, until the load is just detached from the peg, n_1	Number of revolutions of flywheel since the moment when the load is just detached from the peg until the flywheel comes to rest, n_2	Duration of time since the moment when the load is just detached from the peg until the flywheel comes to rest, t (s)	Moment of inertia of the flywheel about its axis of rotation, $I = \frac{(ght^2 - 8\pi^2 n_2^2 r^2)M}{8\pi^2 (n_2^2 + n_1 n_2)}$ (gm cm^2)

Table 2: Data for the measurement of the radius of axle, r

Linear scale reading L. S. R (cm)	Vernier scale reading V. S. R (cm)	Mechanical Error M.E. (cm)	Diameter of axle = LSR+VSR $\pm$ M.E (cm)	Average value of the diameter of the axle, d (cm)

- **READ the PROCEDURE carefully and perform the experiment by YOURSELVES. If you need help to understand any specific point draw attention of the instructors.**
- **DO NOT PLAGIARIZE data from other group and/or DO NOT hand in your data to other group. It will bring ZERO mark in this experiment. Repetition of such activities will bring zero mark for the whole lab.**
- **Perform calculations by following the PROCEDURE . Show every step in the Calculations section.**
- **Write down the final result(s).**

Calculations

Result:

- **TAKE printout of the ‘Questions for Discussions’ BEFORE you go to the lab class. Keep this printout with you during the experiment. ANSWER the questions in the specified space AFTER you have performed the experiment.**
- **Attach Data, Calculations, Results and the Answers of ‘Questions for Discussions’ parts to your previously submitted Answers of ‘Questions on Theory’ part to make the whole lab report.**
- **Finally, submit the lab report before you leave the lab.**

Name: ___________________________ ID: ___________________

Questions for Discussions

1) What type of difficulties did you face while counting the number of revolutions of the flywheel? Please mention. [1]
Ans:

2) What is the physical significance of the moment of inertia? [0.5]

Ans:

3) Why does a flywheel have most of its mass distributed around its rim? [0.5]

Ans:

APPENDIX A: How to measure length with a slide calipers

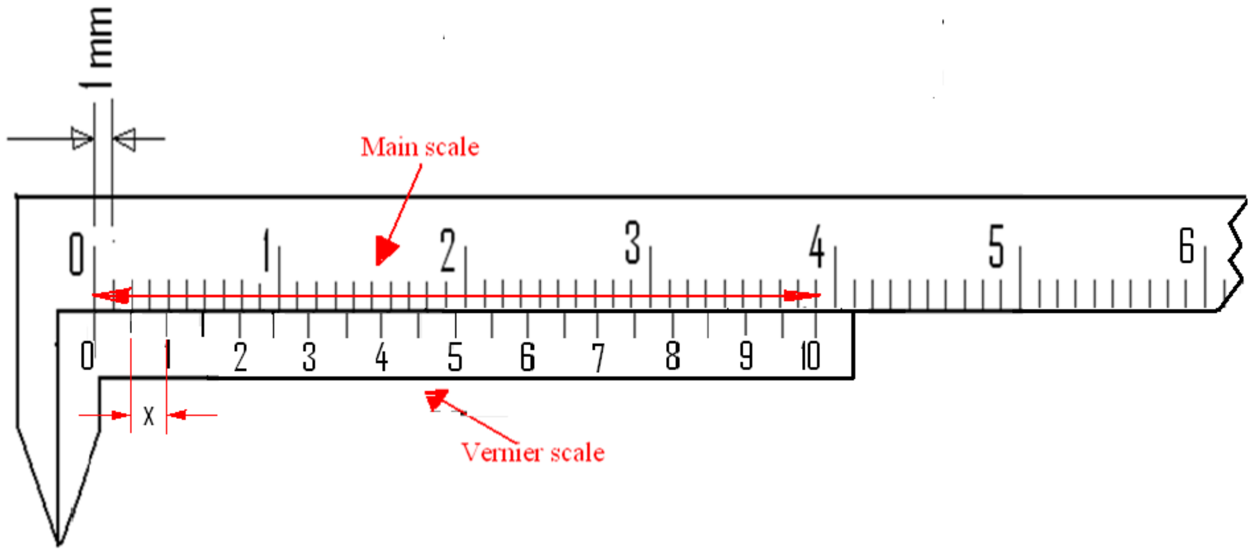


Figure 1: A slide calipers when its two jaws touch each other.

Figure 1 shows you the magnified view of the slide calipers what you are using in the laboratory. When the two jaws touch each other the 0 mark of main scale coincides the 0 mark of the Vernier scale, if the slide calipers is free from mechanical error.

Step 1: Notice what the length of smallest division of the main scale is.

It is 1 mm, for the slide calipers shown above

Step 2: Count the number of the smallest divisions of the Vernier scale.

Here, it is 20.

Step 3: Measure the length of the all 20 divisions of the Vernier scale by using the main scale (If your vernier scale had 40 divisions instead of 20, then you would measure the length of all 40 divisions in this step).

Here, it is 39 mm.

Step 4: Work out the length of the smallest division of the Vernier scale.

If x is the length of the smallest division of the Vernier scale then we can write,

$20\,x = 39$ mm
So, $x = (39/\ 20)$ mm $= 1.95$ mm

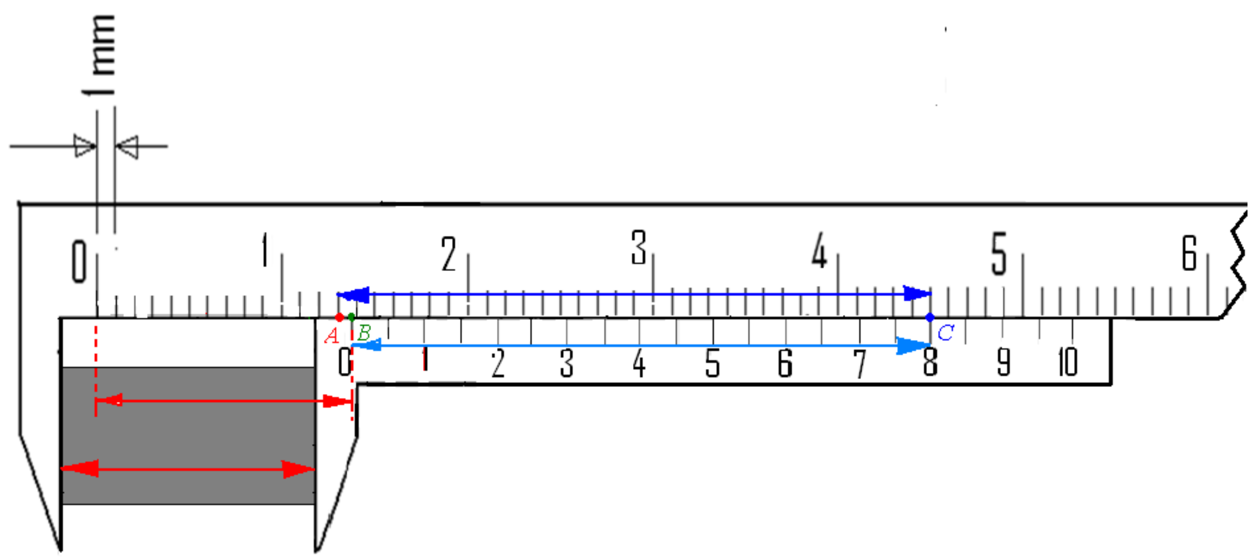


Figure 2: Same slide calipers containing a body between its two jaws.

<u>Step 5</u>: Now keep the body between the jaws of the slide calipers. So the 0 mark of the Vernier scale is displaced. Separation between the 0 mark of the main scale and the 0 mark of the Verinier scale is equal to the length of the body. Which mark of the main scale does the 0 of Vernier scale (B) just cross?

We can see, for this body it the mark of 13 mm. Let's denote it by A (figure 2)and the 0 of Vernier by B.

So, the length of the body = 13 mm + AB

Main scale reading = 13 mm

<u>Step 6:</u> Now, see which mark of the Vernier scale coincides with any mark of the main scale.

We can see it is the mark of 16th division of the Vernier scale. In the Vernier scale this mark is denoted by 8. Let's call it point C.

<u>Step 7:</u> Measure AC by using main scale.

AC = 32 mm

<u>Step 8</u>: Measure BC by using Vernier scale.

BC = 16 x = 16×1.95 mm = 31.2 mm

<u>Step 9</u>: Find AB.

AB = AC – BC = (32-31.2) mm = 0.8 mm
So Vernier scale reading = 0.8 mm

<u>Step 10</u>: Now find the total length of the body

Length of the body = Main scale reading + Vernier scale reading
= (13 + 0.8) mm

Vernier constant:

Go back at step 9. Look how we find AB (Excess by Vernier scale)

AB = (32 – 31.2) = 16 (2-1.95) mm = 16 $\times$ 0.05 mm

Here 16 was the mark-number of Vernier which coincided with a mark of main scale. This is called “vernier coincident”. By multiplying it by 0.05 mm we get the Vernier scale reading.

We say 0.05 mm is the Vernier constant of the slide calipers. You must have noticed that 0.05 mm is written at the top left corner of the Vernier scale of the slide calipers what you are using.

So, to find the Vernier scale reading, you can just notice the Vernier scale division which coincides with a mark of main scale and then multiply it by Vernier constant.

Mechanical Error:

If 0 of Vernier scale does not coincide with the 0 of main scale when the two jaws touch each other, then there is mechanical error.

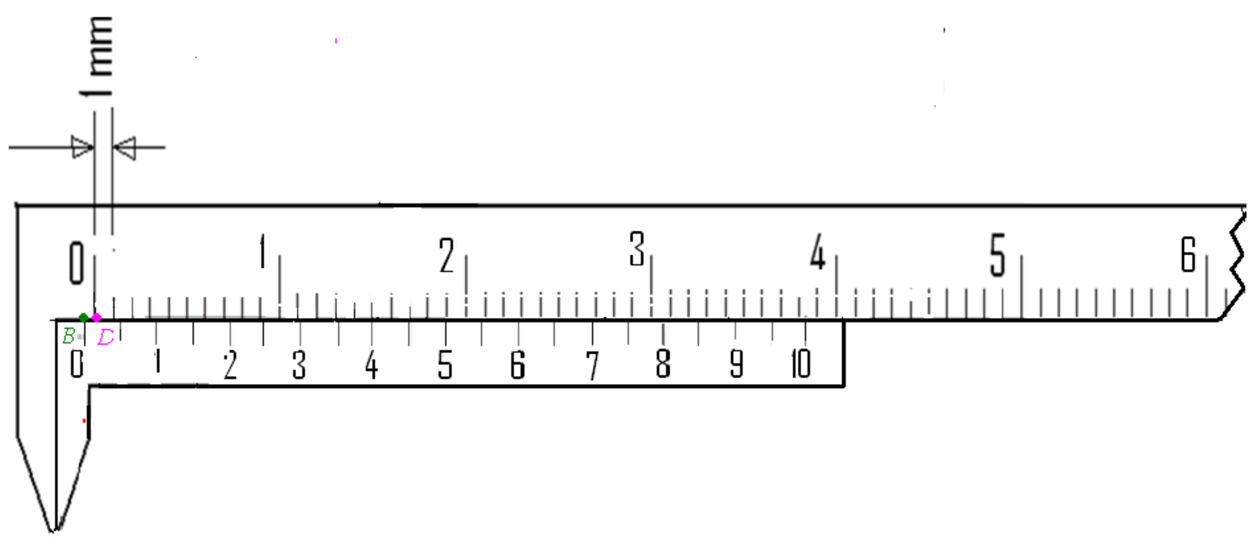


Figure 3: A slide calipers with mechanical error, where 0 of Vernier scale lies at left of the 0 or main scale.

In figure 3 we see the 0 of Vernier scale (B) lies at left of the 0 of main scale (D). We have to add this distance BD with the measured length of any body to correct it.

We can see the mark of 8th division (denoted by 4 in the Vernier scale) coincides with a line of the main scale.

So BD = 8×0.05 mm = 0.40 mm

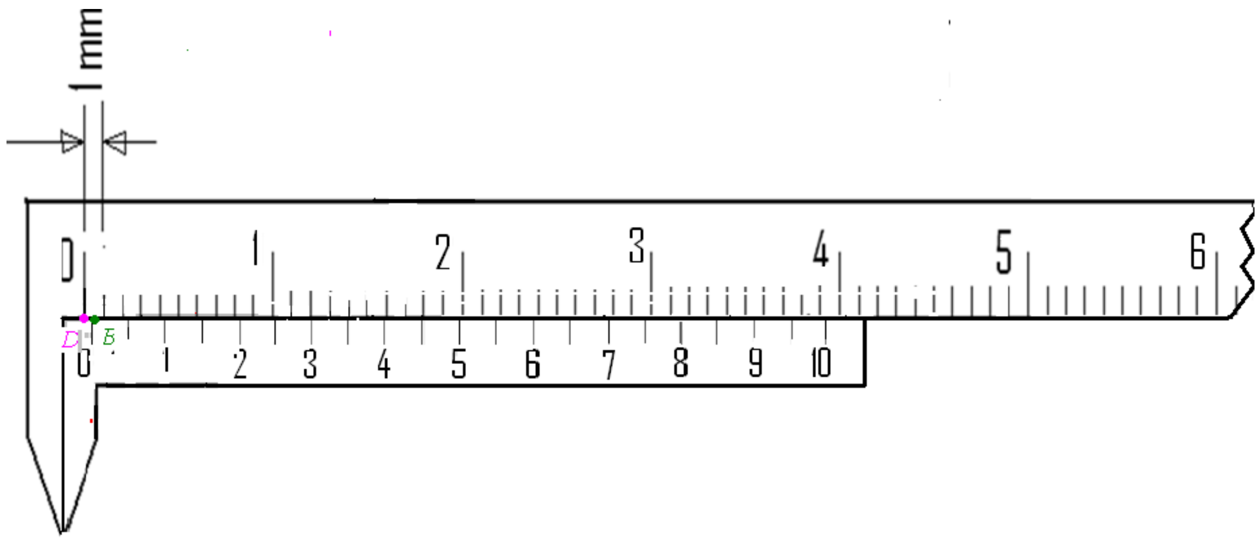


Figure 4: A slide calipers with mechanical error, where 0 of Vernier scale lies at right of the 0 or main scale.

In figure 4 we see the 0 of Vernier scale (B) lies at left of the 0 of main scale (D). We have to subtract this distance BD from the measured length of a body to correct it.

We can see the mark of 6^{th} division (denoted by 3) in the Vernier scale coincides with a line of the main scale.

So BD = 6×0.05 mm = 0.30 mm