Principles of Physics I (PHY111)

Lab

Experiment no: 5

Name of the experiment: Determination of the coefficient of viscosity of a given liquid by using Stoke's law

YOU HAVE TO BRING A GRAPH PAPER (cm scale) TO DO THIS EXPERIMENT.

Theory

In this experiment we determine the coefficient of viscosity of a liquid (glycerin) by using Stoke's law.

We gently place a ball on the surface of the liquid. As the ball is immersed into the liquid three different forces act on the ball. These are:

i) Weight of the ball, F_w which acts vertically downward

ii) Buoyancy force of the liquid on the ball, F_b which acts vertically upward and

iii) Drag force on the ball due to viscosity of the liquid, F_d which always acts against the direction of motion, in this case vertically upward since the ball moves downward.

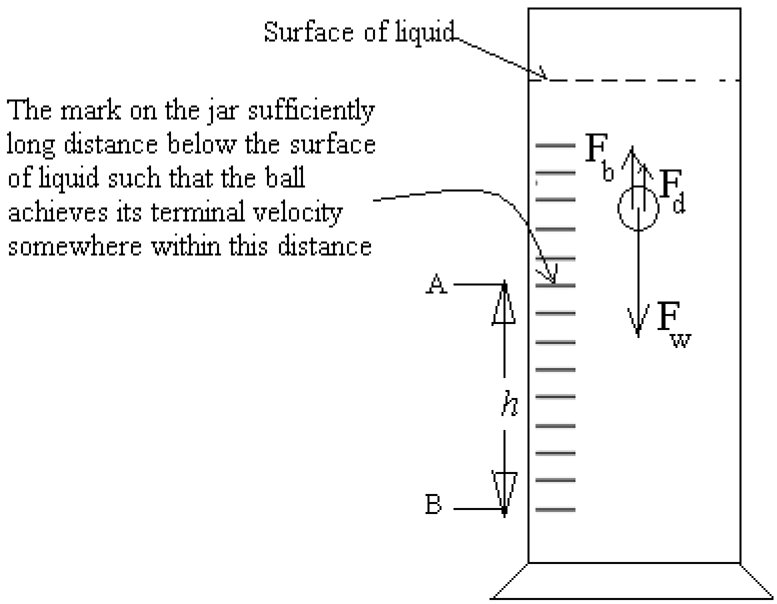

Figure 1: Arrangement for the experiment

Let the radius of the ball = r, then the volume of the ball is $V = \frac{4}{3}\pi r^3$ and the mass of the ball is $m = \rho V$, where ρ is the density of the ball's material.

So, the weight of the ball is $F_w = m g = \rho V g = \rho\left(\frac{4}{3}\pi r^3\right) g$ (1)

Let, the density of liquid is σ. Using Archimedes principle buoyancy force of liquid on the ball is given by, $F_b = \sigma \left(\frac{4}{3} \pi r^3 \right) g$ (2)

If v is the velocity of the ball and η is the coefficient of viscosity of the liquid, then according to Stoke's law the drag force due to viscosity, $F_d = 6 \pi r \eta v$ (3)

When the ball attains terminal velocity, the net force is zero. So upward force must be equal to the downward force, i.e.,

$$F_w = F_b + F_d \quad (4)$$

Using (1), (2), (3) and (4) we can show that

$$\eta = \frac{2}{9} \frac{r^2}{v_t} (\rho - \sigma) g \quad (5)$$

In this experiment we used different balls of different radii, r but made of same material (ρ is same) and for each of them we measure v_t. Then we draw a graph by plotting r^2 along x –axis and corresponding v_t along y-axis. It should be a straight line passing through the origin. The slopes of the line gives us the value of $\frac{v_t}{r^2}$. So from (5)

$$\eta = \frac{2}{9} \frac{(\rho - \sigma) g}{slope} \quad (6)$$

After drawing the v_t vs. r^2 graph and working out its slope we can deduce the coefficient of viscosity of glycerin by using equation (6)

Apparatus

A jar of glycerin, balls of different radii, screw gauge, stop watch and a meter scale.

Procedure

1. Write down the density of glycerin, σ and density of the ball's material, ρ in section A and B of the data sheet respectively.

2. Fix a mark, A (as shown in figure 1) on the jar sufficiently long distance below the surface of glycerin such that the ball achieves its terminal velocity while passing this mark (say, it is the mark specifying 600 ml). Fix another mark, B (as shown in figure 1) near the bottom of the jar (say, it is the mark specifying 100 ml). Measure the distance, h between two marks and write it down in the table 1 of section C of data sheet.

3. Take a ball and measure its diameter by using a screw-gauge. Please see to know how the use a screw-gauge appendix A (given in the softcopy of this script which is available in the server). Find out its radius and write it down in the table-1 of section C.

4. Take the stop watch in one hand and with other hand gently place the ball at the middle of the top surface of the liquid. Make sure that the ball does not touch the wall while it is moving downward.

5. When the ball passes the mark A, then turn on the stop watch. When the ball passes the mark B, then turn off the stop-watch. Time recorded in the stop watch is, t. Write it down in table-1 of section C.

6. Find out the terminal velocity, $v_t = h/t$

7. Repeat steps 2, 3 and 4 for other balls.

8. Draw v_t vs. r^2 graph and work out the slope of the graph.

9. Determine the value of η.

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: ____

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Questions on Theory

*1) When the ball falls downward in the liquid then what are the major forces which act on the ball? Draw the free body diagram. [0.5]

Ans:

*2) State the law of Archimedes to find out the buoyancy force acting on the ball. [0.5]

Ans:

*3) Find an expression of the weight of the ball in terms of the density of ball’s material and its radius. [0.5]

Ans:

*4) Find an expression of the buoyancy force on the ball by the liquid in terms of the density of liquid and the radius of the ball. [0.5]

Ans:

*5) If v is the velocity of the ball, η is the coefficient of viscosity of the liquid and r is the radius of the ball, then according to Stoke's law what is the drag force on the ball due to viscosity? [0.5]

Ans:

*6) What is the terminal velocity of the ball? [0.25]

Ans:

*7) When the terminal velocity is achieved by the ball then write down the equation relating the major forces acting on the ball. [0.25]

Ans:

8) Starting from this equation show that, $\eta = \frac{2}{9}\frac{r^2}{v_t}(\rho - \sigma)g$ [Use additional page(s) if you require]

[2]

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.**
- **DO NOT forget to bring a GRAPH PAPER.**

Data

Density of glycerin, σ = ___________________gm/cm^3

Density of ball's material (steel), ρ =__________________gm/cm^3

Table 1: Data of r^2 and corresponding v_t

Distance between to marks, AB h (cm)	Radius of the ball, r (cm)	r^2 (cm^2)	Time taken by the ball to pass distance AB, t (s)	Terminal velocity of the ball, v_t=h/t (cm/s)

Please attach a v_t vs. r^2 graph here.

- **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, Graph, 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) If we use balls of different materials will the v_t vs. r^2 graph be a straight line? If v_t vs. r^2 is not found to be a straight line what can be the possible reason, explain. [1]

Ans:

2) In this experiment you have assumed that every ball consists of a same material. How will you perform the experiment if different balls consist of different materials? [1]

APPENDIX A: How to measure length with a screw gauge

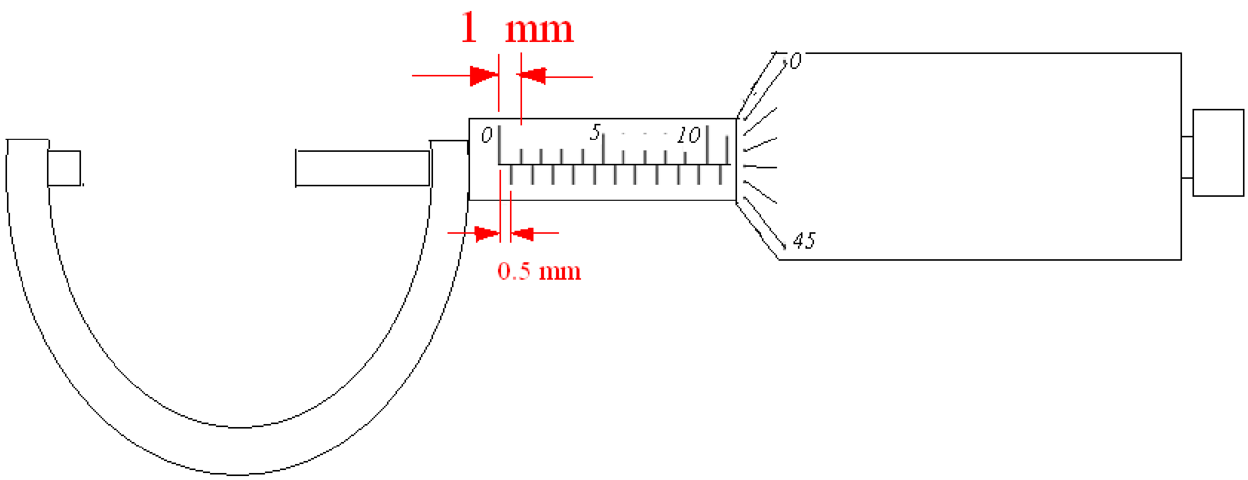

Figure 1: A screw gauge

Figure 1 shows the magnified view of the screw gauge what you are using in the lab.

Step 1: First notice the length of the smallest division of the linear scale.

You can see the separation between the two consecutive lines of the upper portion of the linear scale is 1 mm. Each of the line of the lower portion of linear scale has divided this 1mm segment equally. So the gap between a line of the upper scale and the next line of the lower scale is 0.5 mm.

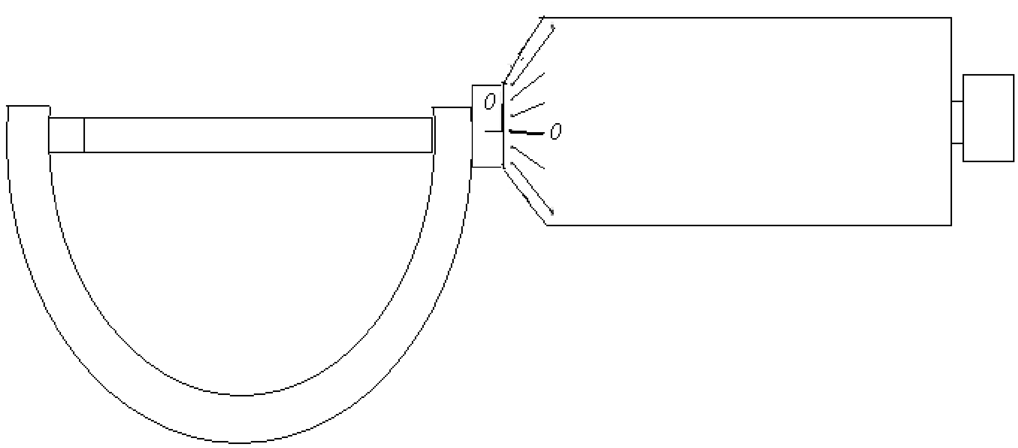

Figure 2: If the screw gauge is free from mechanical error, when the screw touches the left end of the frame of screw gauge, then 0 of circular scale coincides with the linear scale

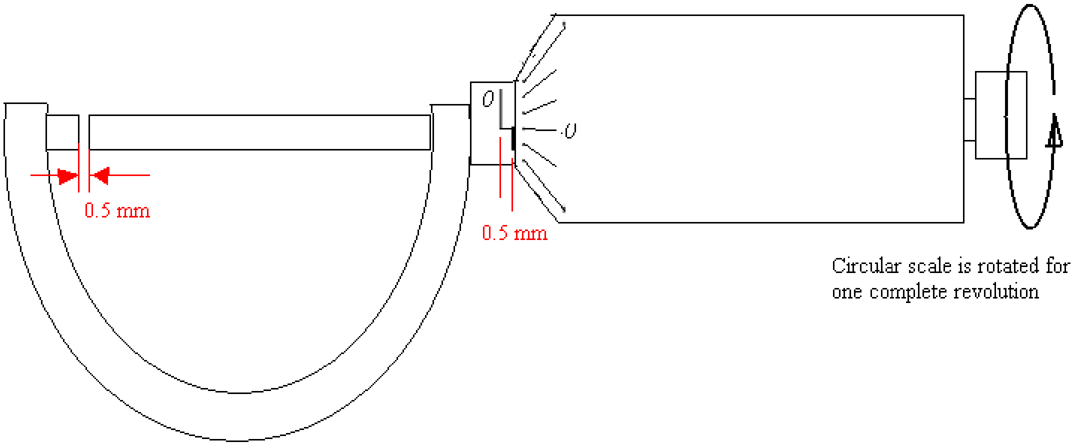

Figure 3: The position of the circular scale on the linear scale when it is rotated for one complete revolution

Step 2: Rotate the circular scale for one complete revolution and notice the displacement of the circular scale along the linear scale. This is the pitch of the screw gauge

To do so suppose initially 0 mark of circular scale coincided with the linear scale (figure 2) and then the position of the circular scale on linear scale was at 0. Now the circular scale is rotated for one complete revolution and 0 of circular scale has been brought back to coincide with the linear scale (figure 3). Here we see circular scale is displaced for 0.5 mm along the linear scale.

So the Pitch = 0.5 mm

Step 3: Now see how many number of divisions are there in the circular scale.

Here, it is 50.

Step 4: Find the Least Count.

Least Count = Pitch/ number of division of circular scale

Least Count = (0.5/50) mm = 0.01 mm

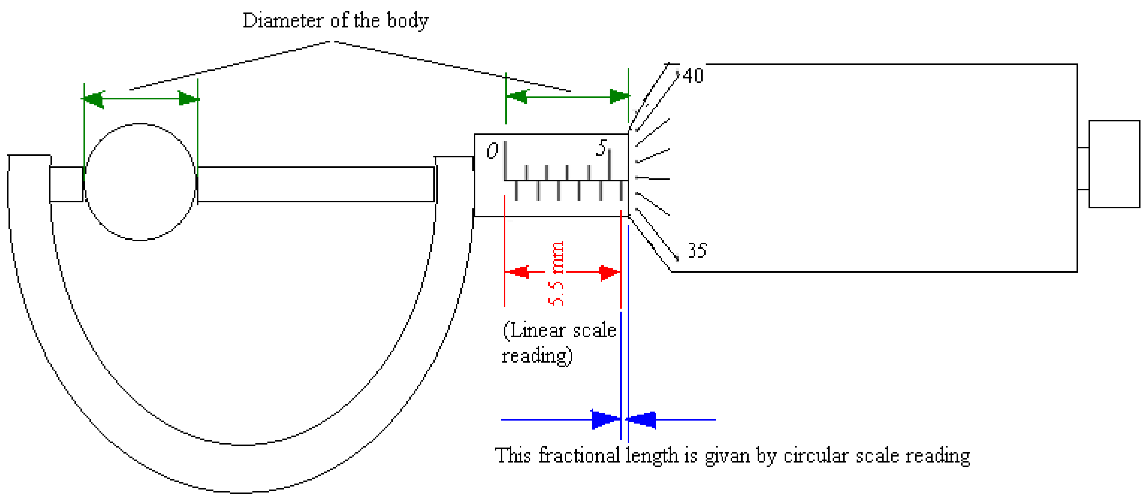

Figure 4: Measuring diameter of a ball.

Step 5: Now keep the body whose diameter or length is supposed to be measured between the left end point and the screw of the screw gauge. Rotate the circular scale until left end point and the screw both touch the body (figure 4)

Step 6: See which division of the linear scale the circular scale just crosses. That will be the linear scale reading.

In this case we see it is 5.5 mm (= linear scale reading)

Step 7: See which line of the circular scale coincides with the linear scale.

In this case it is 37

Step 8: By multiplying it by least count find the circular scale reading

37×0.01 mm = 0.37 mm (= Circular scale reading)

Step 9: Find the total reading of the diameter of the body by adding linear scale reading and the circular scale reading.

Total reading = (5.5 + 0.37) mm = 5.87 mm

Mechanical Error

When the screw touches the left end point of the screw gauge, then if the 0 of circular scale does not coincide with the linear scale then there is mechanical error.

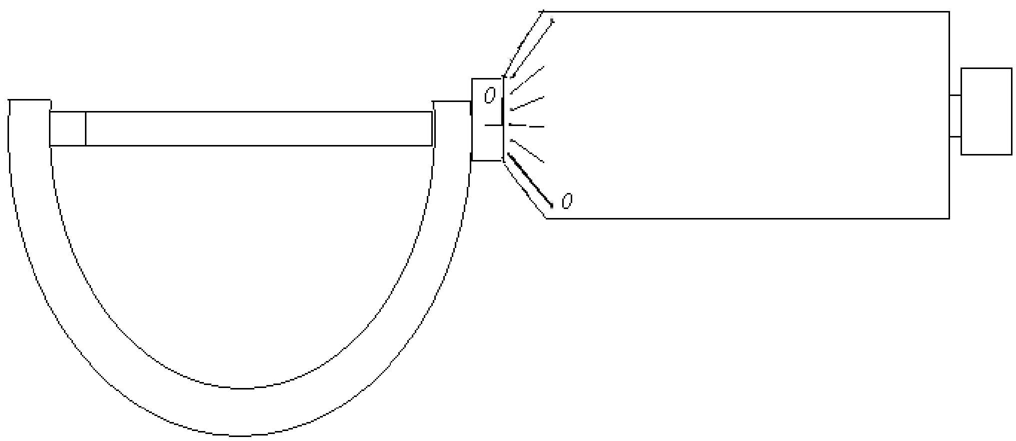

Figure 5: Screw gauge with mechanical error where 0 of circular scale lies below the linear scale when the screw touches the left end point.

Case 1: Where 0 of circular scale lies below the linear scale when the screw touches the left end point.

- See how many number of divisions 0 of circular scale lies below linear scale.

  Here it is 2 (figure 5)

- Multiply it by least count. 2×0.01 mm = 0.02 mm
- Subtract it from the total reading to correct the measurement.

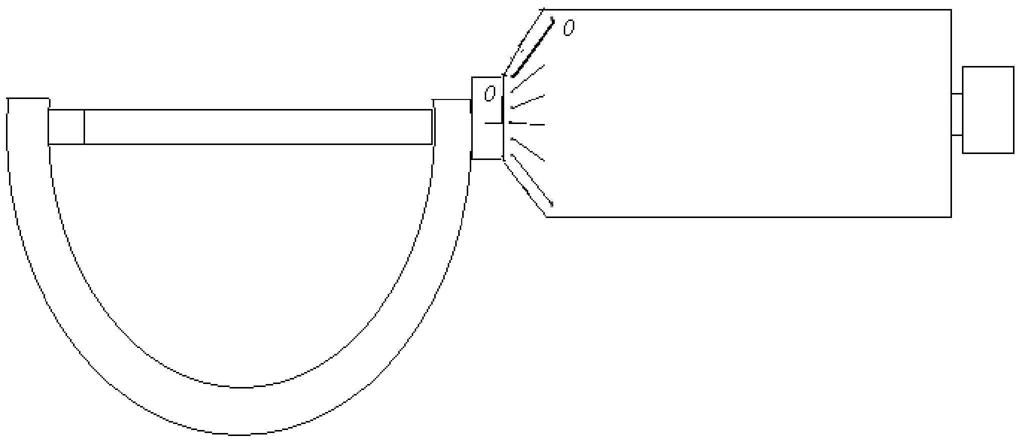

Figure 6: Screw gauge with mechanical error where 0 of circular scale lies above the linear scale when the screw touches the left end point.

Case 2: Where 0 of circular scale lies above the linear scale when the screw touches the left end point.

- See how many number of divisions 0 of circular scale lies above the linear scale.

  Here it is 3 (figure 6)

- Multiply it by least count. 3×0.01 mm = 0.03 mm

- Add it with the total reading to correct the measurement.