1. Experimental Contents

1) Measure time and speed of a moving object using a laser photoelectric sensor
2) Measure oil viscosity using falling ball method and Stokes formula
3) Understand the falling ball method and make proper corrections if necessary

2. Experimental Procedure

1) Set up the apparatus
   a) Level the base: hang a plumb bob under the middle of the beam while adjusting the screws on the base until the tip of the plumb points to the central circular point.
   b) Turn on the upper and the lower lasers on the post. Adjust the laser beams until they vertically hit the hanging wire of the plumb bob.
   c) Remove the plumb bob, and place the cylinder with liquid under test to the central portion of the base (the location of the cylinder must remain unchanged throughout the experiment).
   d) Place the guiding tube on the beam and clean the steel ball using dehydrated alcohol.
   e) Place the small ball into the guiding tube to see whether it can block the laser beam. If not, adjust laser position appropriately.
2) Measure the temperature of the liquid under test using a thermometer before and after all steel balls have fallen. Average two readings as the actual temperature of the liquid.
3) Use an electronic balance to measure the masses of 10~20 steel balls and then take the average as the mass of a ball m. Measure the volume of a steel ball using a pycnometer. Now the density of a steel ball, p', can be calculated. Measure the density of the liquid (castor oil), p, using a liquid density meter. Measure the inner diameter of the cylinder, D, using a caliper. Finally, measure the depth of oil column, H, using a ruler.
4) Measure the speed of ball falling at uniform motion using the electronic timer
   a) Measure the distance between the upper and lower laser beams.
   b) Measure the diameter of a ball using a caliper. Place the ball into the guiding tube. Record the time interval when the ball falls within the distance set by the two laser beams. Repeat 6 times or more. Finally, calculate the viscosity of castor oil.

3. Examples of Data Recording and Processing

Note: the following data are for reference purposes only, not the criteria for apparatus performance.

Liquid under test: castor oil

Oil temperature: 15.90 °C

Density of oil: p=0.960×10^3 kg/m^3

Full distance: 20.12 cm

Liquid depth: H=53.40 cm

Timing device: electronic timer

Density of steel ball: p'=7.90×10^3 kg/m^3

Diameter of cylinder: 6.72 cm

Approximate half-distance: 10.70 cm

Table 1 Averaged data

Ball diameter d (mm)	Half-distance time t_1 (s)	Full-distance time t_2 (s)	Half-distance speed ν_1 (cm/s)	Full-distance speed ν_2 (cm/s)
0.993	39.76	74.14	0.269	0.271

As seen in Table 1, ν_1 and ν_2 are almost identical indicating the steel ball indeed undertakes a uniform speed motion during the entire falling process.

Since the depth and the width of the cylinder are not infinite, the measured falling speed of the ball should be corrected as: $v = v_0(1+2.4d/D)(1+3.3d/2H)$.

By substituting *d, D* and *H* into Eq. (3), we get η=1.33 Pa·s, which is close to the reference value of 1.37 Pa·s (<2.8% error) as listed in Table 2. The relationship between the temperature and viscosity of castor oil is shown in Figure 3. **Note**: as the viscosity of a liquid is related to the temperature of the liquid, which must be measured precisely or significant error will occur.

Table 2 Viscosity of castor oil

Temperature θ (°C)	0	10.00	15.00	20.00	25.00	30.00	35.00	40.00
Viscosity η (Pa·s)	5.30	2.42	1.51	0.95	0.62	0.45	0.31	0.23

Note: 1 Poise (P)=0.1 Pascal·Second (Ps·s)

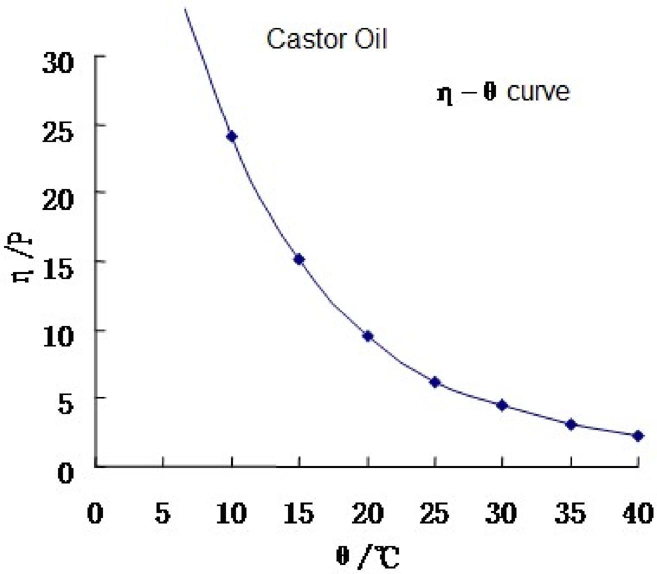

Figure 3 Relationship curve between temperature and viscosity of castor oil