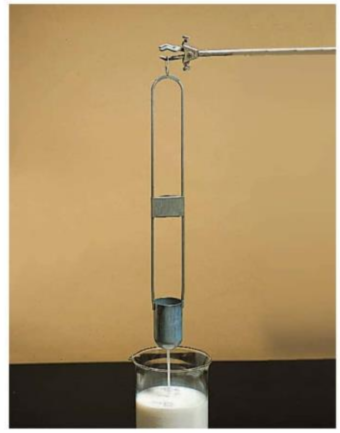
Lab 1D: Viscosity
In this lab experiment, you will measure the viscosity of different liquids using multiple methods. Informally, viscosity is a fluid property that quantifies its resistance to flowing. Large (small) values of viscosity imply strong (weak) resistance to flow. More formally, it relates shear stress and the rate of fluid strain.



Learning outcomes:
- Employ a Zahn cup and the falling spheres method to measure the viscosity of multiple fluids
- Identify potential sources of error and uncertainty in measurements of fluid viscosity

Part A: Zahn cup
Objective:
Measure the viscosity of motor oil using Zahn cup

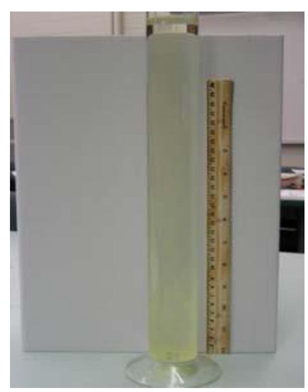
Procedure:
(1) Fill the Zahn cup with motor oil (SG =0.86)
(2) Let the fluid fall through the cup
(3) Record the time it takes for the cup to empty; time from completely full to empty (i.e., when stream breaks)

Questions and analysis:
(1) The Zahn cup determines viscosity with the following equation: $\nu = 10.09T - 587/T$, where ν is kinematic viscosity (in centistokes, 1 centistoke = $1\text{x}10^{-6}$ m^2/s) and $\boldsymbol{T = 1.0177t}$ where t is the time (in seconds) it takes for the cup to empty. Here 1.0177 is a calibration coefficient. Fill the table below to calculate the dynamic viscosity μ and the kinematic viscosity ν. Recall that $\nu = \mu/\rho$. (4 pts)

Time t (sec)	$\boldsymbol{T = 1.0177t}$	Kinematic Viscosity, ν (m^2/s)	Density ρ (kg/m^3)	Dynamic Viscosity, μ ($N*s/m^2$)

(2) How does your estimated value of dynamic viscosity compare to the published value of μ=0.17 $N*s/m^2$? (1pt)

Part B: Falling Sphere
Objective:
Measure fluid viscosity from the terminal speed of a falling sphere (BB).



Procedure:
(1) Set up a graduated cylinder filled with corn syrup (SG of light corn syrup = 1.39)
(2) Determine the mass of a few BB balls using a scale and calculate the BB's density (diameter = 4.7 mm)

BB_{Mass} = ___________ *g* ρ_{BB} = ____________ kg/m^3

(3) Release a BB at the syrup surface, instantaneously begin a stopwatch, and record elapsed time as the ball passes each marked distance along the cylinder (every 5 cm from the top of the cylinder). (5 pts)

Corn syrup

Distance from surface (cm)	0 cm	5 cm	10 cm	15 cm	20 cm
Elapsed Time (sec)					
Mean Velocity	xx				

Questions and analysis:

When the ball reaches terminal velocity ($V_{terminal}$), the vertical force balance is $F_D + F_B = F_W$

Drag Force (from Stoke's Law): $F_D = 6\pi r \mu V_{terminal}$

Buoyancy Force: $F_B = \frac{4}{3}\pi r^3 \rho_{fluid} \cdot g$

Weight: $F_W = \frac{4}{3}\pi r^3 \rho_{particle} \cdot g$

(1) Using equations provided above, derive an equation for dynamic viscosity μ. (5 pts)

(2) Calculate the mean velocities in the table as distance/time. Choose the largest velocity as $V_{terminal}$. (2 pts)

(3) Calculate the corn syrup viscosity using the equation derived above. (3 pts)

(4) Compare your estimation of the viscosity of corn syrup with a published value of 15 N-s/m^2. Suggest the most important sources of experimental uncertainty that might explain the differences between your measurement and the given value. (5 pts)