Stokes' Law

In class we have talked about the efficiency of air, water and ice to transport sediment. The main difference of the three transport media is their density ρ and viscosity μ. Air has both, the lowest density and viscosity and is the least efficient transport medium. Ice, on the other hand, has the highest values of ρ and μ, and is most efficient in transporting sediment.
The transport efficiency of a substance depends on how fast bodies fall through the medium. Things fall very fast through air, slower through water and extremely slowly through ice. The free fall velocity is given by **Stokes' Law**, which describes how fast spherical bodies fall through viscous liquids, assuming laminar flow. For spherical Stokes' law can be written as:

$$v = \frac{1}{18}\left[\frac{(\rho_s - \rho_F)gd^2}{\mu}\right]$$

where	v	= settling velocity	
	g	= gravitational acceleration	$g = 9.80\ m/s^2$
	ρ_s	= density of dropped object	
	d	= diameter of dropped object	
	ρ_F	= density of fluid	
	μ	= viscosity of fluid	

Remember that this relationship only holds for laminar flow, that means the fluid moves around the object in an orderly, non-turbulent way. The Reynolds Number R_e describes whether flow conditions around a sphere are laminar or turbulent. R_e can be calculated from:

$$R_e = \frac{d\,v\,\rho_F}{\mu}$$

Flow conditions are

- **laminar** for $R_e < 500$
- **turbulent** for $R_e > 500$
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The exact values depend on the flow conditions and the geometry of the setup. The point top remember is that low Reynolds numbers are more likely to translate into laminar flow conditions. Stokes' Law is only valid for "low Reynolds numbers.

In this homework problem you are measuring settling velocities for steel balls dropped in glycerine as a function of particle diameter. The experimental setup is in the physics lab right next to the Rock of the Week, so you can do both exercises in one day.

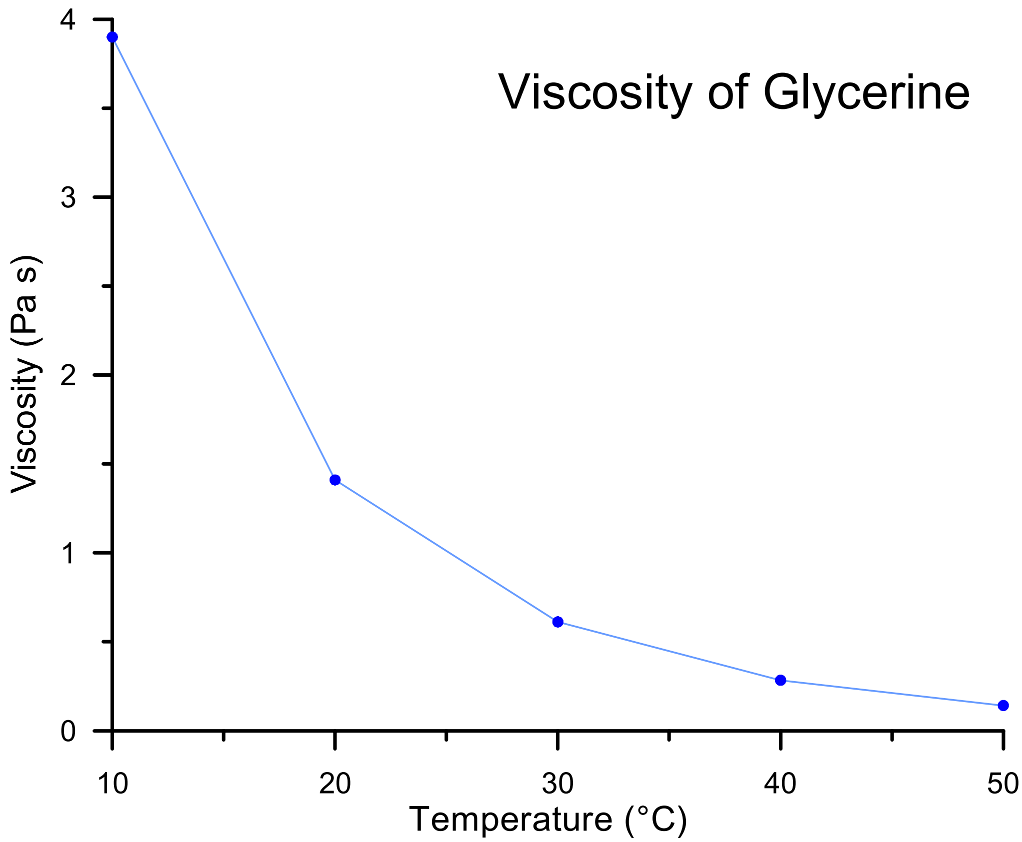
What to do:

In this homework exercise you will measure settling velocities for steel balls dropped into glycerine and compare your experimental results with the theoretical predictions made by Stokes' Law. The two graphs at the end of the handout give you the viscosity and density of glycerine as a function of temperature. As you can see they vary quite a bit.

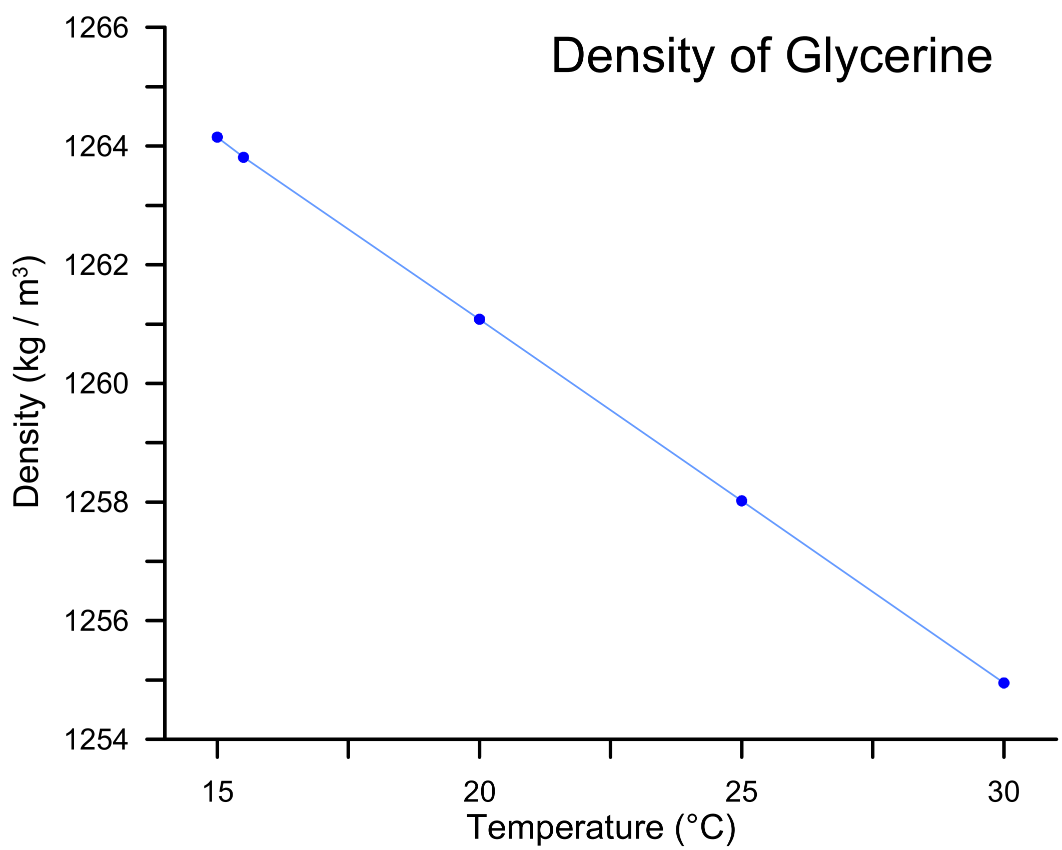
1. Measure the room temperature.
2. Familiarize yourself with the provided stopwatch. To measure the settling velocity of the steel balls, select a ball and note its diameter (you'll have to convert it from inches to mm later), then drop it down the tube. Let it settle for about 50 cm (this will assure that the ball reached a terminal settling velocity), then measure the time it takes the ball to sink another 50 cm through the glycerine. Record the time and distance traveled, as well as the diameter of the ball.
3. Repeat for steel balls with different diameters.

To evaluate your results:

4. **calculate the settling velocity** of the balls from your measurements:
   $v = s / t$, where s is the distance the ball fell during the time interval t
5. **draw a graph of settling velocity vs. ball diameter** - you can do this by hand (do it accurately, using a ruler and the graph paper provided), or use a computer program, such as Excel etc.
6. **Determine the viscosity and density of the glycerine** from the provided graphs.
7. **Calculate the Stokes' velocities** for each diameter. Compare the theoretical predictions (from step 7) with your experimental results (from step 4) by adding the theoretical velocities to your graph. Are the two values the same, are they close, or do they not match at all?
8. **Calculate the Reynolds number** for each diameter, using the theoretical velocity values, and decide whether the flow around the ball is laminar or turbulent. How does this affect the interpretation of your results?



Viscosity of Glycerine
Viscosity (Pa s)
4
3
2
1
0
10
20
30
40
50
Temperature (°C)



Density of Glycerine
Density (kg / m3)
1266
1264
1262
1260
1258
1256
1254
15
20
25
30
Temperature (°C)