Gels

Gels consist of a three-dimensional structure formed by solid particles suspended in a liquid medium. The solid particles are usually some type of polymer. Polymers are most commonly compared to a chain. They are formed of a repeating monomer; a unit composed of a specific molecular structure. These different polymers can be connected through both physical and chemical bonds. The structure of the polymers allow for expansion once immersed in a solvent due to the relatively large voids in the structure as depicted in Figure 1.

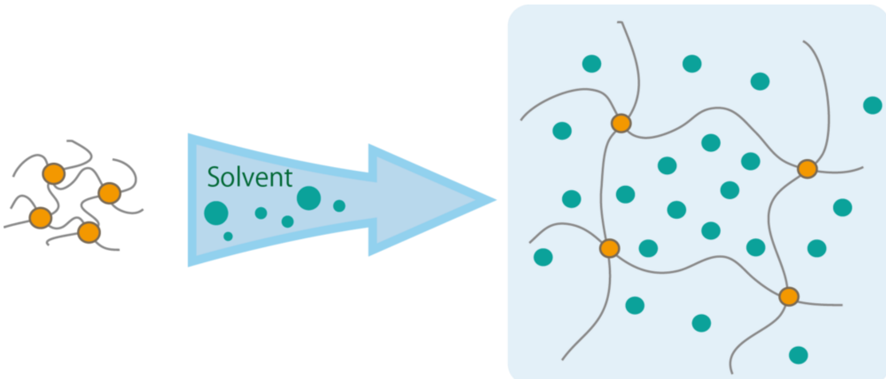


Figure 1: Structure of polymers in a gel

Gels have many different uses depending on their individual material properties. The most important properties are modulus of elasticity, Poisson's ratio, and viscosity which are discussed in more depth later in the handout.

Properties of Gels:

Modulus of Elasticity

Elasticity is a very important characteristic of a gel. Hooke's law relates the modulus of elasticity, or Young's modulus, to the stress and strain that the material experiences.

$$\sigma = E\varepsilon$$

A typical stress-strain diagram for ductile and brittle materials is shown in Figure 2.

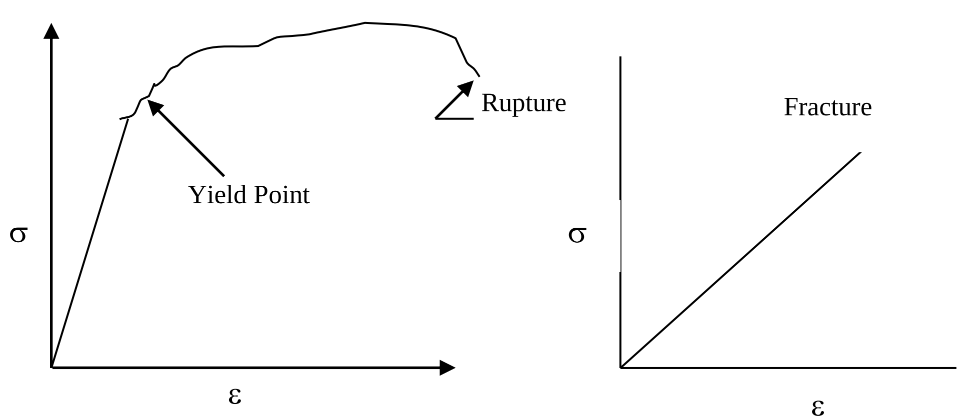


Figure 2: Typical Stress-Strain Diagram for a Ductile and Brittle Material

Stress-strain diagrams of various materials vary widely. It is possible however to distinguish materials into *brittle* and *ductile* on the basis of the characteristics of their stress strain diagrams. Since strain is a dimensionless quantity, the modulus of elasticity E has the same units as stress. The linear portion of the stress-strain diagram is known as the elastic region as deformation is not permanent. The more elastic the material the larger the elastic region and the lower the elastic modulus.

The elastic modulus can also be calculated using a relationship between the shear modulus (G) and Poisson's ratio (ν).

$$\mathbf{E = 2G(1 + \nu)}$$

Where G = shear stress/ shear strain. Shear strain is depicted in Figure 3.

$$\boldsymbol{\gamma = \Delta x/l = \tan\theta}$$

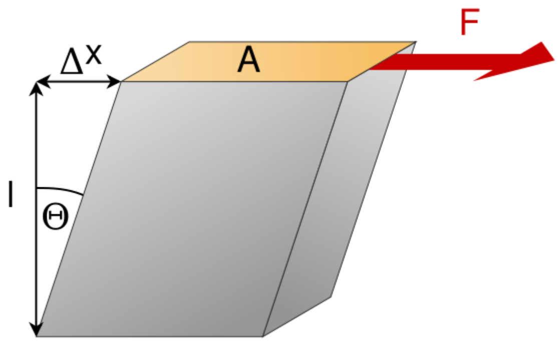


Figure 3: Shear strain

Poisson's ratio is a measure of the phenomenon of a material expanding/contracting in the direction perpendicular to the force applied. This is known as the Poisson effect. This is extremely visible in gels and that is why it is a prevalent topic and is related to the change in strain in the opposite directions of the applied force.

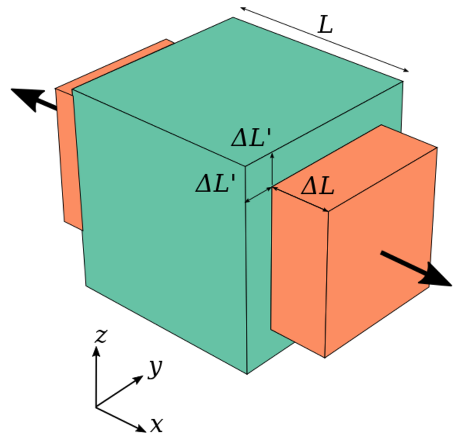


Figure 4: Poisson Effect

Viscosity

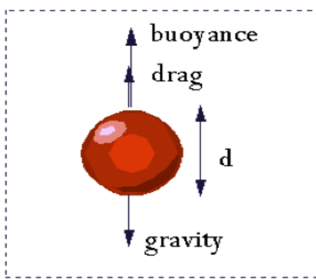
Viscosity is a result of the interaction between the different molecules in a fluid. This can be also understood as friction between the molecules in the fluid. There are two types of viscosities, kinematic viscosity and dynamic viscosity. Dynamic velocity is a measure of the force applied over a specific area for a specific time, shear rate (γ). Its units are Pa/s.

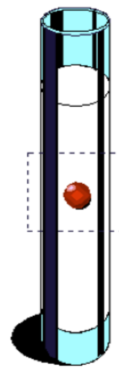
$$\eta = \frac{F/A}{\dot{\gamma}}$$

Kinematic viscosity is a measure of how fast does a fluid flow for a given force applied to it. And can be used to compare two different fluids to each other. The equation for it relates the dynamic velocity and the density of the fluid and produces the units m^2/s.

$$\nu = \frac{\eta}{\rho}$$

Viscosity can be measured using simple experiments. If a small stainless steel ball is dropped into a liquid and timed the data retrieved can be used to find the dynamic viscosity using the proof below.





Gravity = mg

$F_b = (4/3)\pi r^3 \rho_{fluid}\, g$

$F_d = 6\pi\mu V d$

$F_b + F_d = mg$

$(4/3)\pi r^3 \rho_{fluid}\, g + 6\pi\mu V d = m_{sphere}\, g$

$$\mu = \frac{4}{9}\frac{r^2 g(\rho_s - \rho_f)}{V_s}$$

r = measured radius of sphere (in cm)

ρ_{fluid} = density of fluid = m/Vol

g = convert 9.8 m/s2 to cm/s2 = 980cm/s 2

V = velocity of sphere in the water (cm/s)

d = measured diameter of sphere (cm)

m = mass of sphere (kg)

In-Class Activity

A sphere (ρ=2.5 g/cm^3, d=1.5 cm) is dropped into one of three 100 mL graduated cylinders that contain unknown liquids of different viscosities. Each of the cylinders has uniform height (L=50 cm). Using the data obtained below and the previous equations, identify the unknown liquids.

Unknown Fluid	Mass (g)	Time (s)
1	80	$1.4x10^{-3}$
2	90	.32
3	150	20.4

Unknown Fluid	Fluid Density (g/mL)	Velocity (cm/s)	Viscosity (g/cm s)
1			
2			
3			

Fluid	Viscosity (Pa-s)
Alcohol	.0012
Bleach	.0011
Corn Syrup	.075
Honey	10
Hydraulic Oil	.035
Motor Oil	.25

References:

http://furrowpump.com/comparative-viscosities-for-common-compounds/
https://web.stanford.edu/group/lpchscience/cgi-bin/wordpress/images/Viscosity-T.pdf
http://www.aip.nagoya-u.ac.jp/en/public/nu_research/highlights/detail/0001878.html
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