MECHANICAL PROPERTIES
Rheology

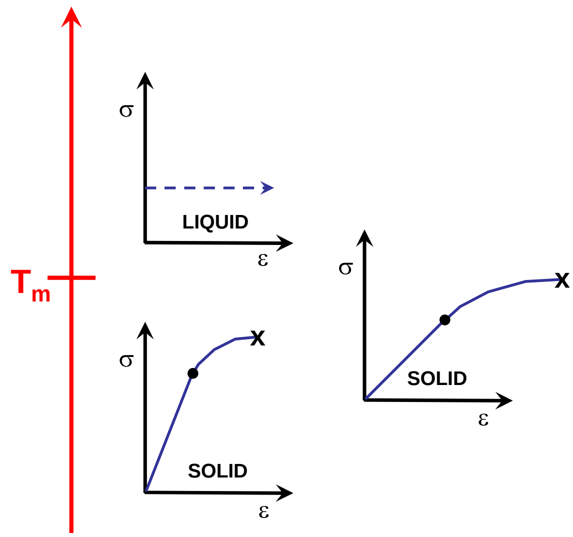
S.C. BAYNE,[1]
J.Y. Thompson[2]

[1]University of Michigan
School of Dentistry,
Ann Arbor, MI 48109-1078
sbayne@umich.edu

[2]Nova Southeastern
College of Dental Medicine,
Ft. Lauderdale, FL 33328-2018
jeffthom@nova.edu

INTRODUCTION

Rheology = mechanical properties of liquids



Thus far we have focused on the mechanical properties of solids. However, liquids have mechanical properties as well. Consider the transition in stress-strain behavior as you heat up a material and go through its melting temperature. Let's start in the solid state (below Tm) and then follow a material as it melts.

[CLICK] At first you have a stress-strain curve that looks fairly typical. **[CLICK]** However, at higher and higher temperatures, the modulus is lower, with decreasing elastic limit, and much more plastic deformation prior to fracture. **[CLICK]** At the melting temperature, traditional elastic behavior disappears. Only plastic deformation remains. Any stress produces continual flow. Higher stresses produce faster flow rates, but at all stresses there is flow. In a moment, you will see how we must modify our approach to analyzing stress-strain to arrive a meaningful graphical representation.

TERMINOLOGY

Viscosity and fluidity – and flow.

RHEOLOGY = measurement of flow

(1) Viscosity = resistance to flow
(2) Fluidity = tendency of liquid to flow = 1/(viscosity)

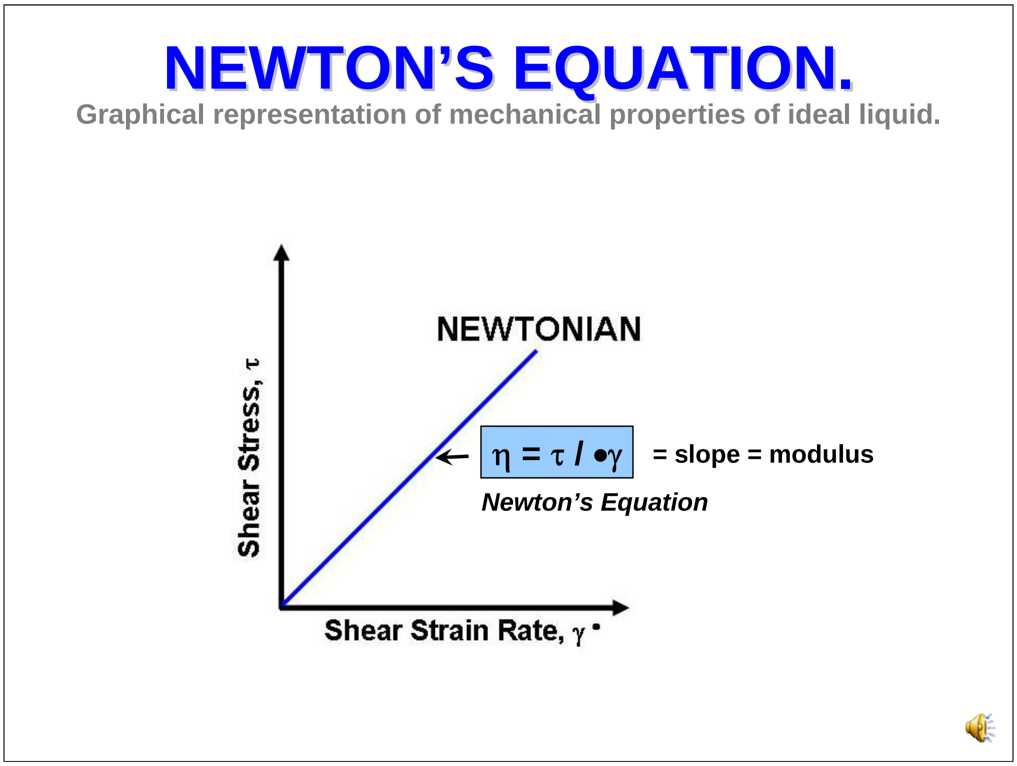
Modes of FLOW:

(1) Laminar Flow = uniform force within fluid in motion

(2) Turbulent Flow = widely varying force within moving fluid

[CLICK] The science of or study of or measurement of FLOW is called RHEOLOGY. **[CLICK]** Viscosity is the resistance to flow. **[CLICK]** Fluidity is the tendency to flow.

[CLICK] The simplest model for envisioning fluid flow is watching a liquid flow through a tube. If the fluid is moving in a uniform fashion it is described as LAMINAR FLOW. **[CLICK]** In more cases than not, fluids do not move uniformly and are best described as TURBULENT.



Just as we normalized load-deformation for mechanical properties of solids, we will do the same for liquids. Since most liquids involve shear, we will represent the stress as shear stress, τ (tau). The shear strain is constant. Rather, we are interested in the shear strain rate. We will represent that as gamma dot, or $\bullet\gamma$. **[CLICK]** Viscosity, or η (nu), is the ratio of shear stress to shear strain rate, or $\eta = \tau / \bullet\gamma$, which is called Newton's equation, and represents an ideal liquid. **[CLICK]** The relationship is a straight line as graphed.

There are disturbances that will affect the measurement of viscosity and so you often encounter a series of qualifying adjectives. One might talk about the real, true, absolute, or instantaneous viscosity. A partially corrected measurement may be called the apparent viscosity. An uncorrected value may be called false viscosity.

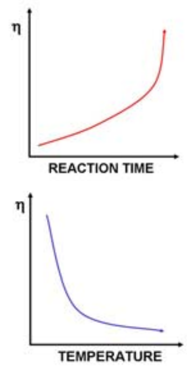
Viscosity is measured in gm/cm/sec of flow and called a POISE. 100 centipoises are 1 poise. Water at 20C has a viscosity of 1 centipoise. Very thick dental materials such as dental cements have viscosities in the range of 100,000-200,000 cp.

VISCOSITY MEASUREMENT

Units, measurement approaches, and applications of concepts.

Simple measurement systems for viscosity:

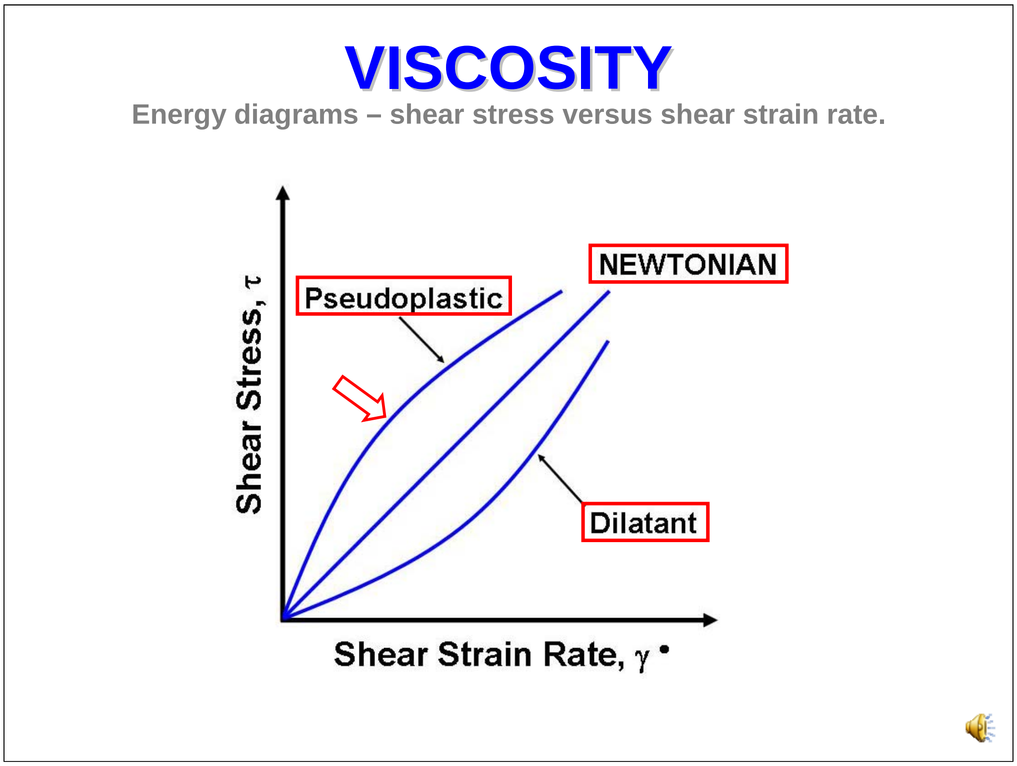
(1) Orifice rheometer: gravity flow of a fluid through an opening.
(2) Falling ball or rising bubble: gravity flow of an object in the fluid.
(3) Capillary rheometer: pressure flow of a fluid.
(4) Parallel plate, cone-and-plate, or spindle: frictional drag of surface against a fluid.



There are a number of ingenious and simple methods for measuring viscosity, as listed in the table. **[CLICK]** One of the simplest of all is the measurement of a bubble rising through a fluid-filled tube. **[CLICK]** One measures the seconds for the bubble to rise 10 cm in a standard tube at room temperature. Water takes 1 second in the standard tube. Dilute polymer solution might take seconds to minutes. Honey might take many minutes to hours. For most dental materials, low viscosities are required for flow and wetting to occur in reasonable clinical working times.

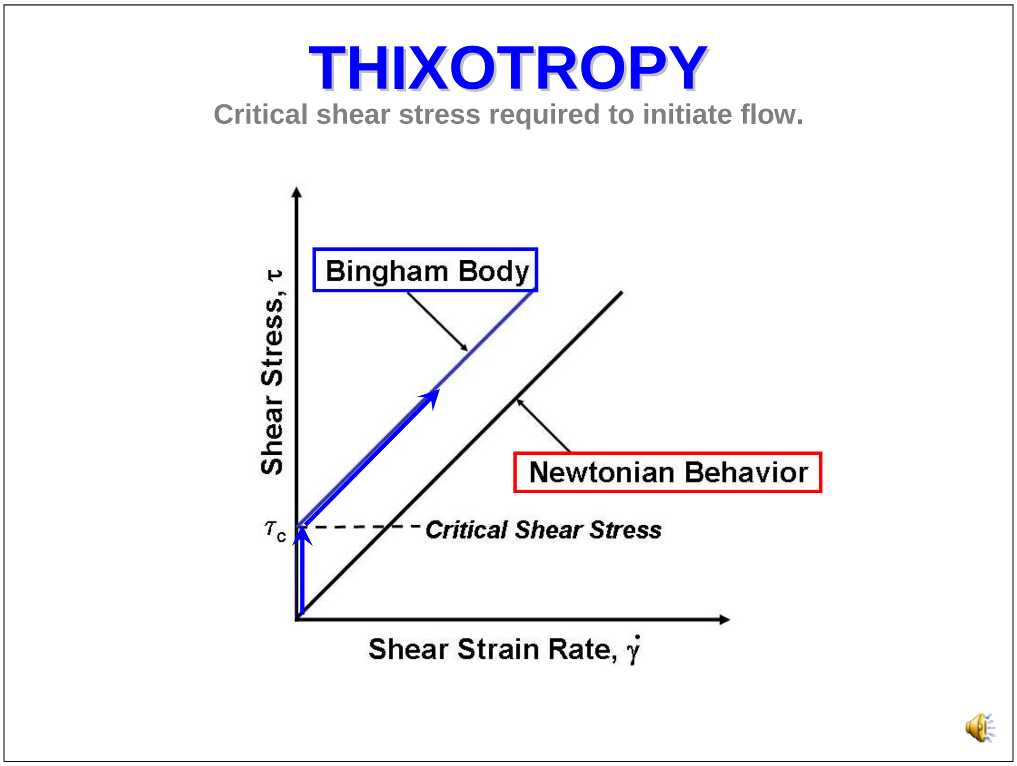
Parallel plate, cone-and-plate, and spindle rheometers also are capable of monitoring viscosity continually and using it as an indication of events such as dental material setting reactions or effects of temperature. **[CLICK]** When a material changes from liquid to solid, the viscosity essentially becomes infinite. It no longer is capable of significant flow.

[CLICK] Decreasing the temperature, increases the viscosity of fluids. The standard viscosity for oil in your car's engine in the winter time would become too viscous at winter temperatures, so it is usually replaced with a lower viscosity version.



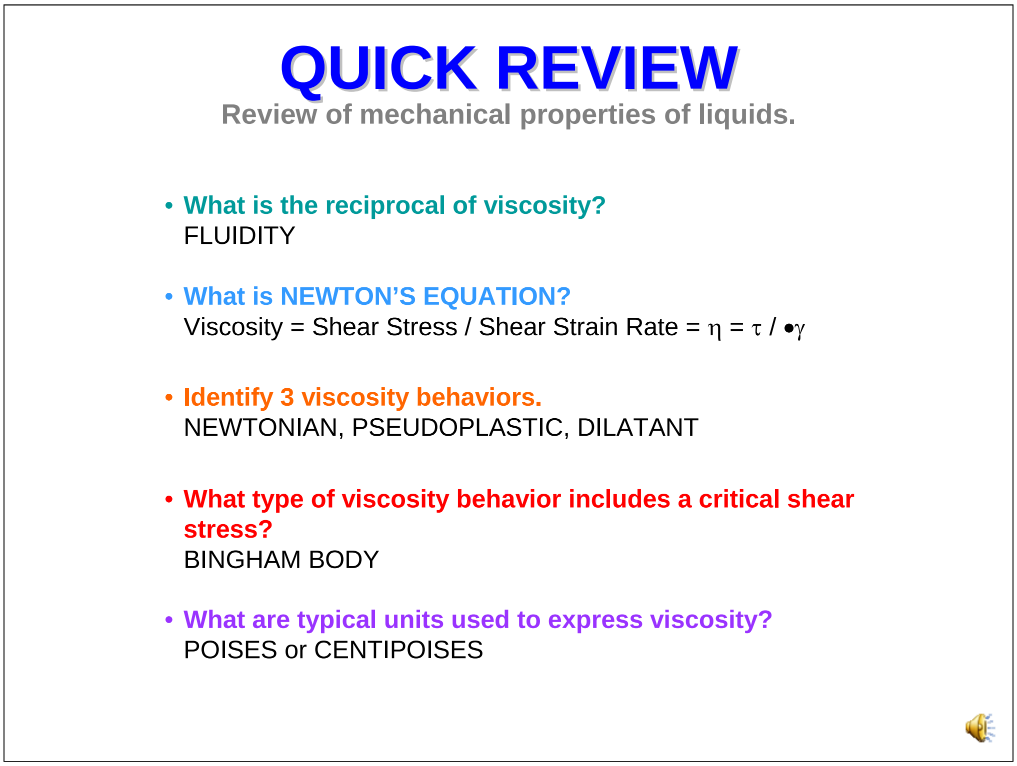
Ideal behavior of fluids is NEWTONIAN. **[CLICK]** The shear stress is linearly proportional to the shear strain rate. However, most real systems depart from ideal behavior. **[CLICK]** PSEUDOPLASTIC behavior is represented by a curve cupped downward. At higher shear stresses the fluid flows more easily. Materials like this are called shear thinning. **[CLICK]** DILATANT behavior is represented by a curve cupped upward. As the shear stress increases, the shear strain rate more than proportionally increases. Materials like this are called shear thickening.

[CLICK] Most dental materials display PSEUDOPLASTIC BEHAVIOR. Increasing the shear stress, helps the material to flow. An excellent example is cementation of a crown onto a prepared tooth. You ask the patient to bite down firmly and quickly. This creates a high shear stress and helps the material to flow.



Ideal behavior is represented by the NEWTONIAN curve **[CLICK]** that starts at zero shear stress and zero shear strain rate. However, it is possible for liquids to resist flow until a certain critical shear stress is exceeded. **[CLICK]** This is called BINGHAM BODY behavior. **[CLICK]**

There are many advantages for Bingham Body behavior in dentistry. You can design toothpaste so that it only flows out of the tube when you press hard enough. You can design dental sealant so that when it is painted onto an occlusal surface, it does not run off before it is cured.



Now, let's a quick review of the concepts from this module.

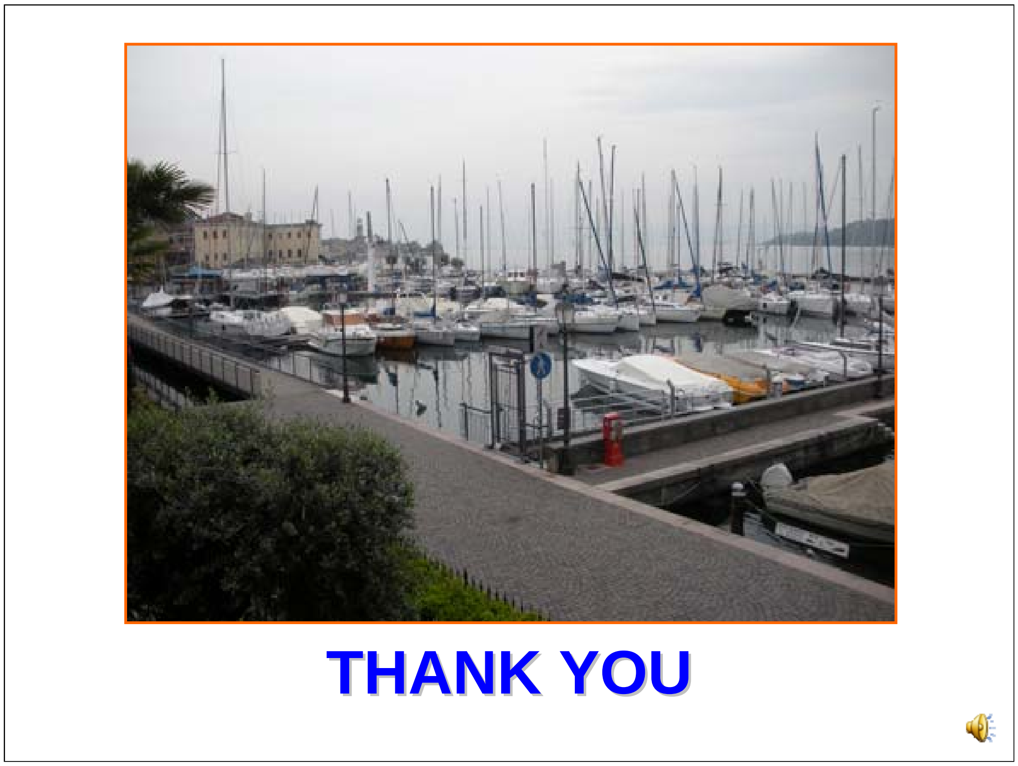
[CLICK] (1) What is the reciprocal of viscosity?
[CLICK]

[CLICK] (2) What is NEWTON's EQUATION?
[CLICK]

[CLICK] (3) Identify 3 viscosity behaviors?
[CLICK]

[CLICK] (4) What type of viscosity behavior includes a critical shear stress?
[CLICK]

[CLICK] (5) What are typical units used to express viscosity?
[CLICK]



THANK YOU.