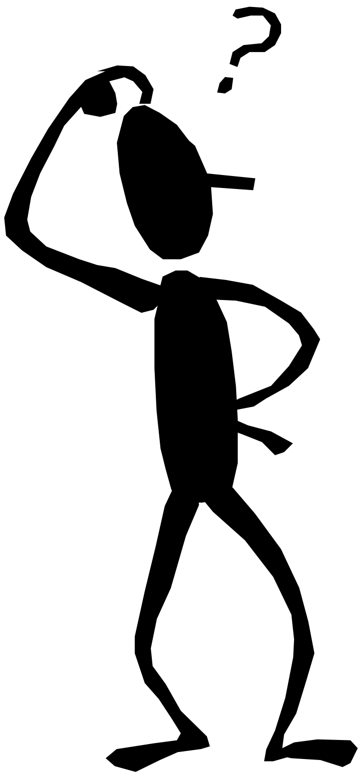
Rheology,

What for?

Definition



- Rheology (Darby 1978):

  Science of deformation and flow of matter.

  Specifically concerned with those properties of matter which determine how matter will deform or flow when subjected to an external force or system of forces

Let's first dissect the definition:

* ***matter*** ("gas", "liquid", "solid"**?**)
* ***deformation of a "solid"***
* ***flow of a "liquid"***

Cause

Matter

"reacts" according to its intimate nature (properties)

Effect

Quantitative Relation

Causes

Strain

Stress

Effects

Stress

Strain

then:

Rheology looks for a quantitative relation between the force applied and the resulting deformation or flow

(or between the deformation or flow applied and the induced force)

Such relation is called a modulus

“SOLIDS”

Deformation of a solid

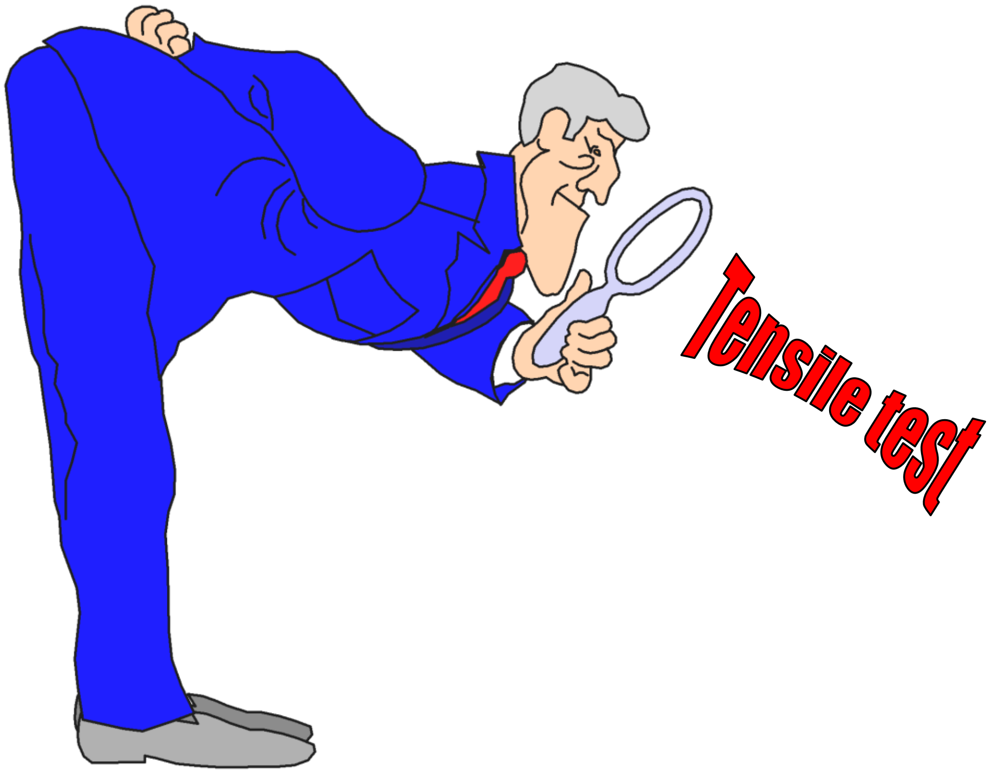
- Pulling it apart (tension test)
  - how much force is required to deform the solid by 1, 2, 3, etc.. % ?
- Bending (BBT test)
  - how much the solid deflects when a force is applied ?
- Squeezing (compression)

Concept of modulus for a solid

How is a modulus determined?

How is it called?

How many moduli exist?


Tensile test

How a tensile test is done

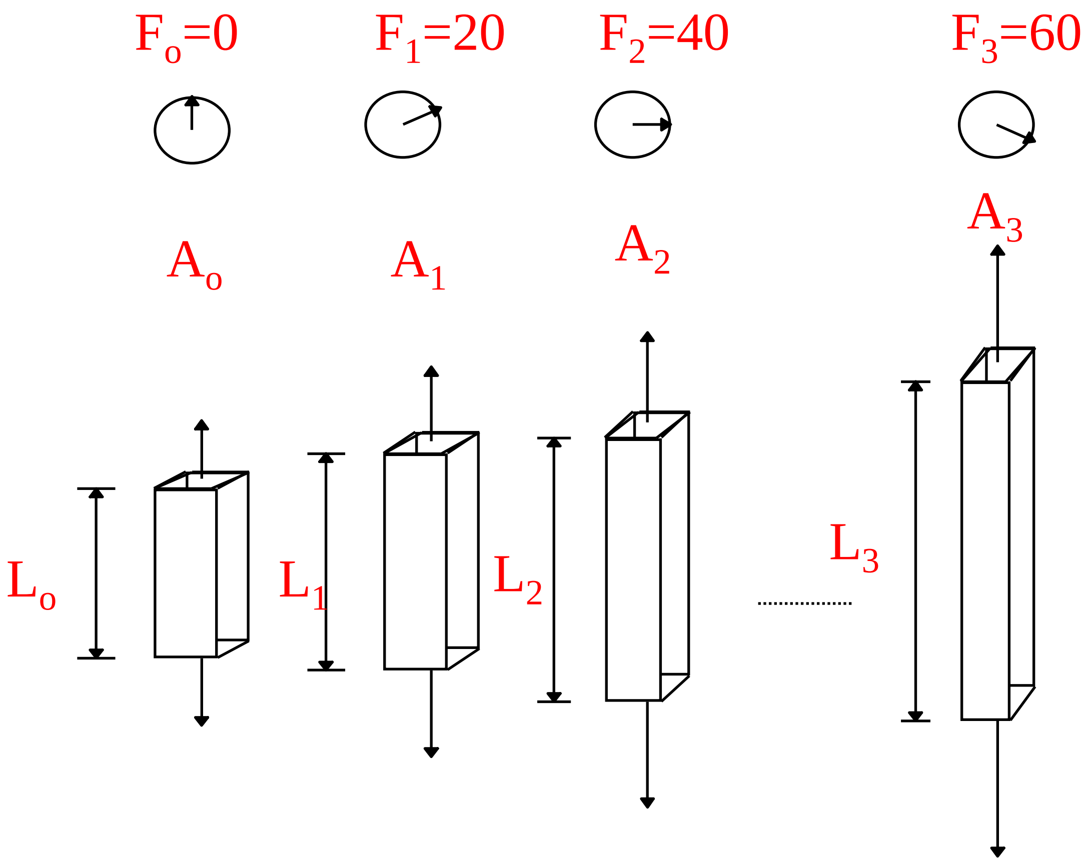
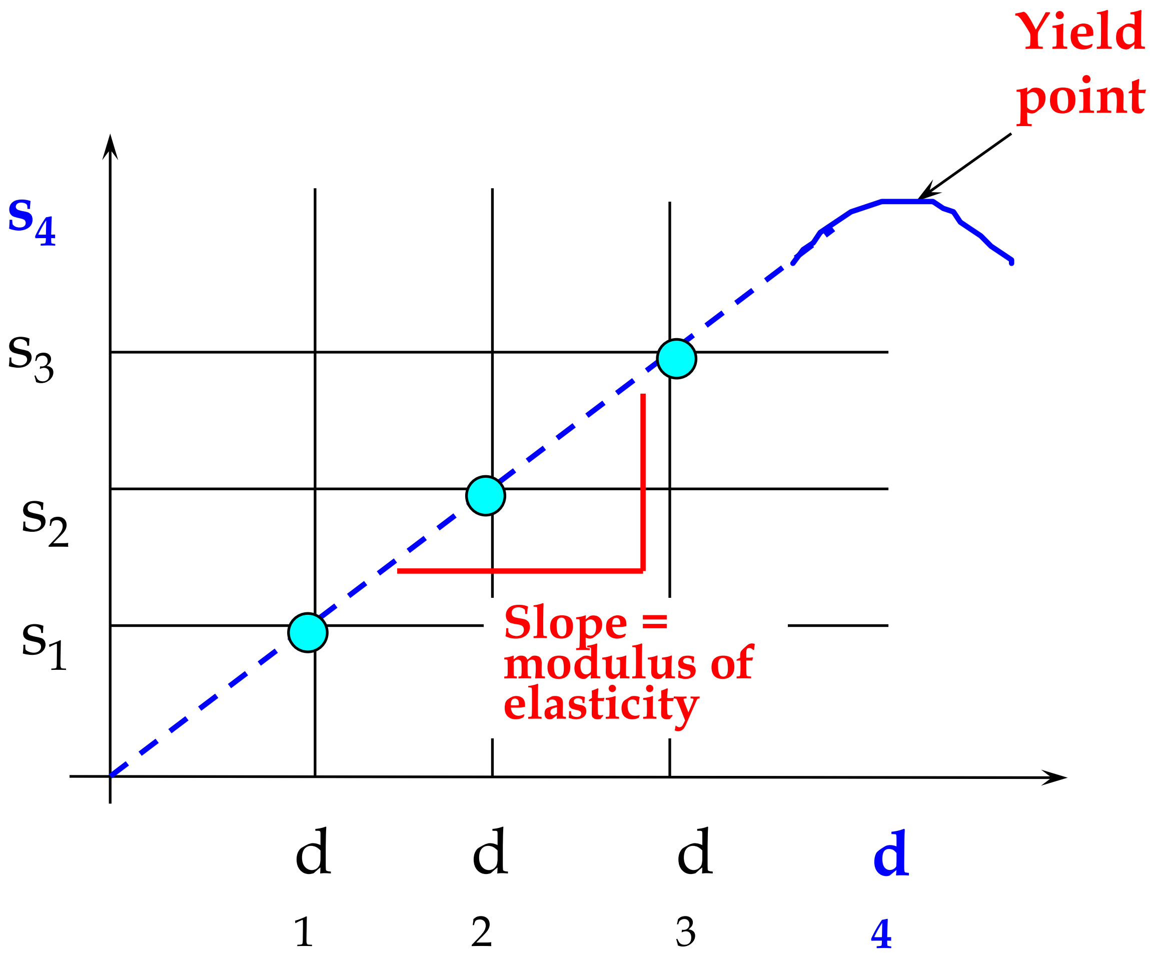


Figure 1. Deformation of a solid by applying an uniaxial force.

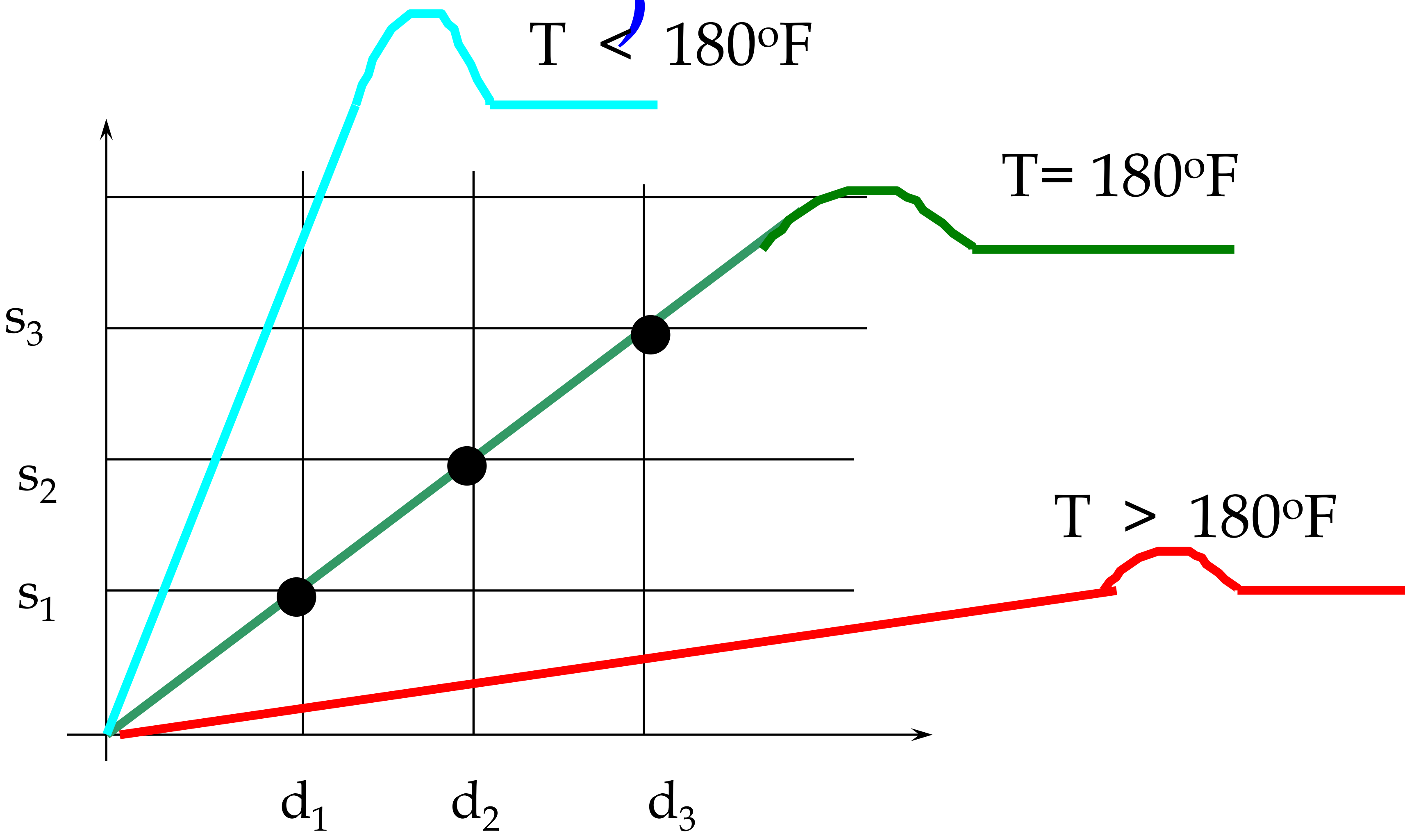
What do we do with these data?

Datum	Force	Area	Length	Stress = F/ A	Strain = $\frac{L_0 - L_i}{L_0}$
0	F_0	A_0	L_0	**0**	**0**
1	F_1	A_1	L_1	s_1	d_1
2	F_2	A_2	L_2	s_2	d_2
3	F_3	A_3	L_3	s_3	d_3

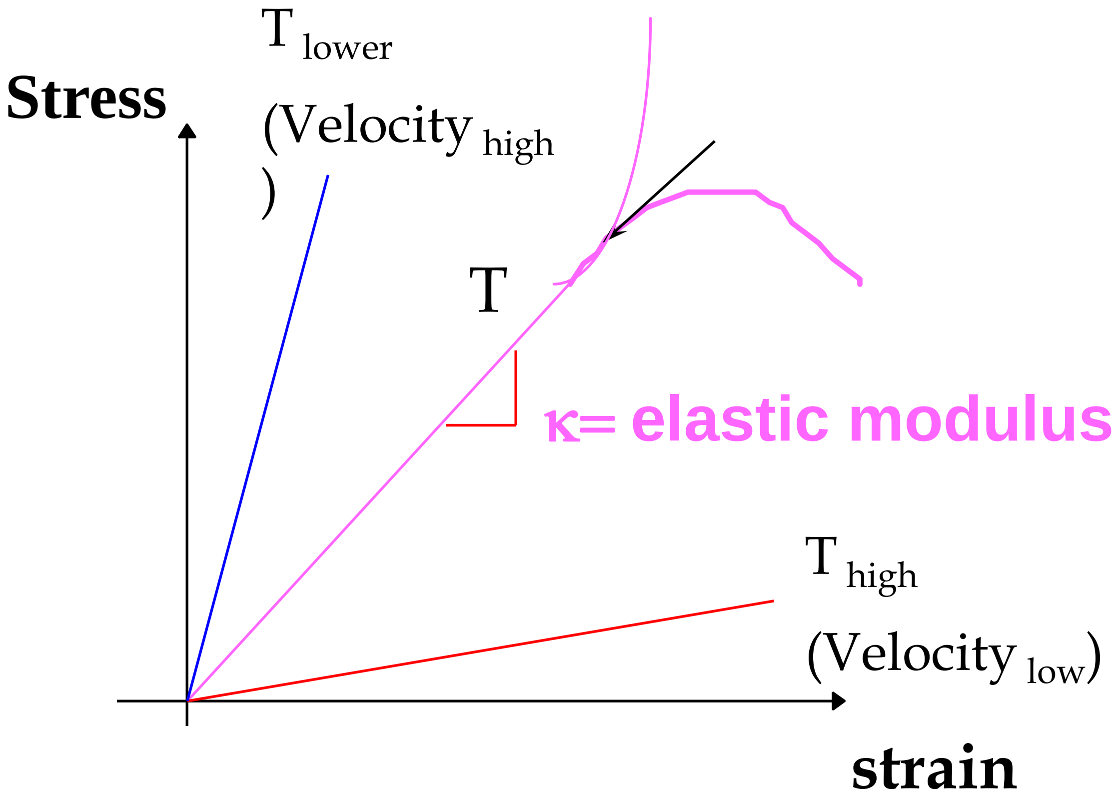
Tensile test



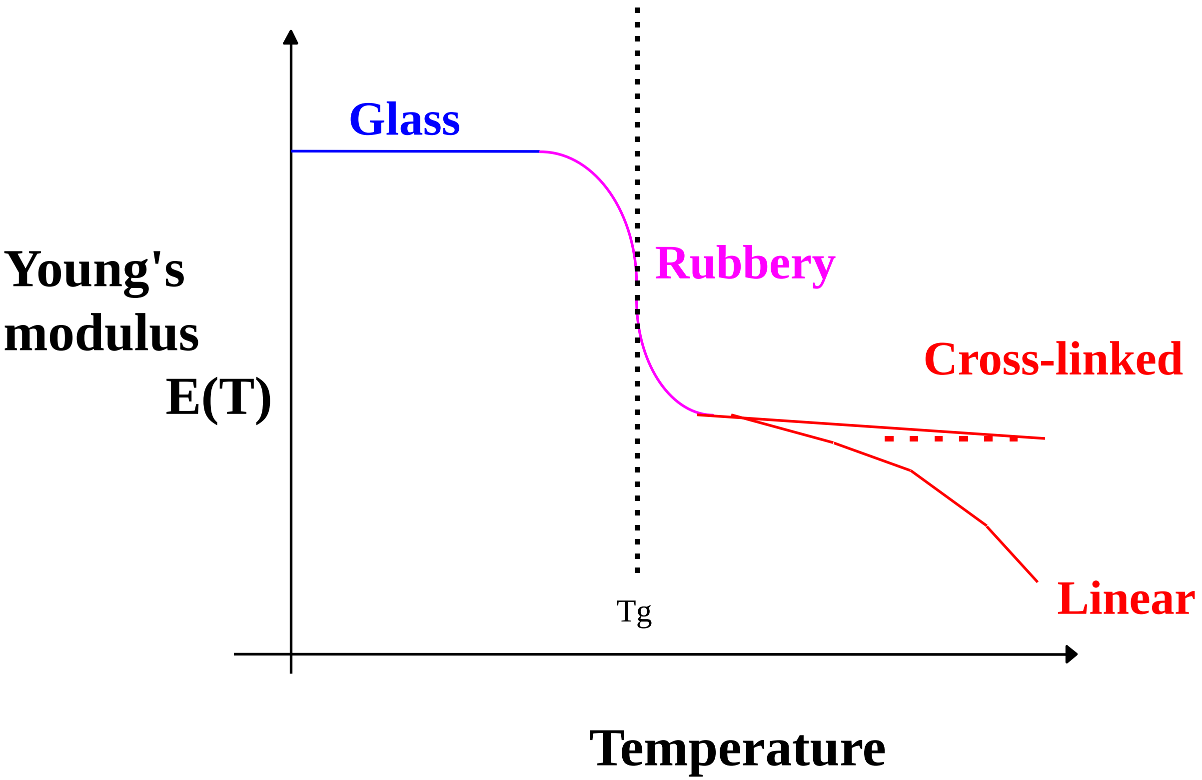
Temperature (velocity effects)



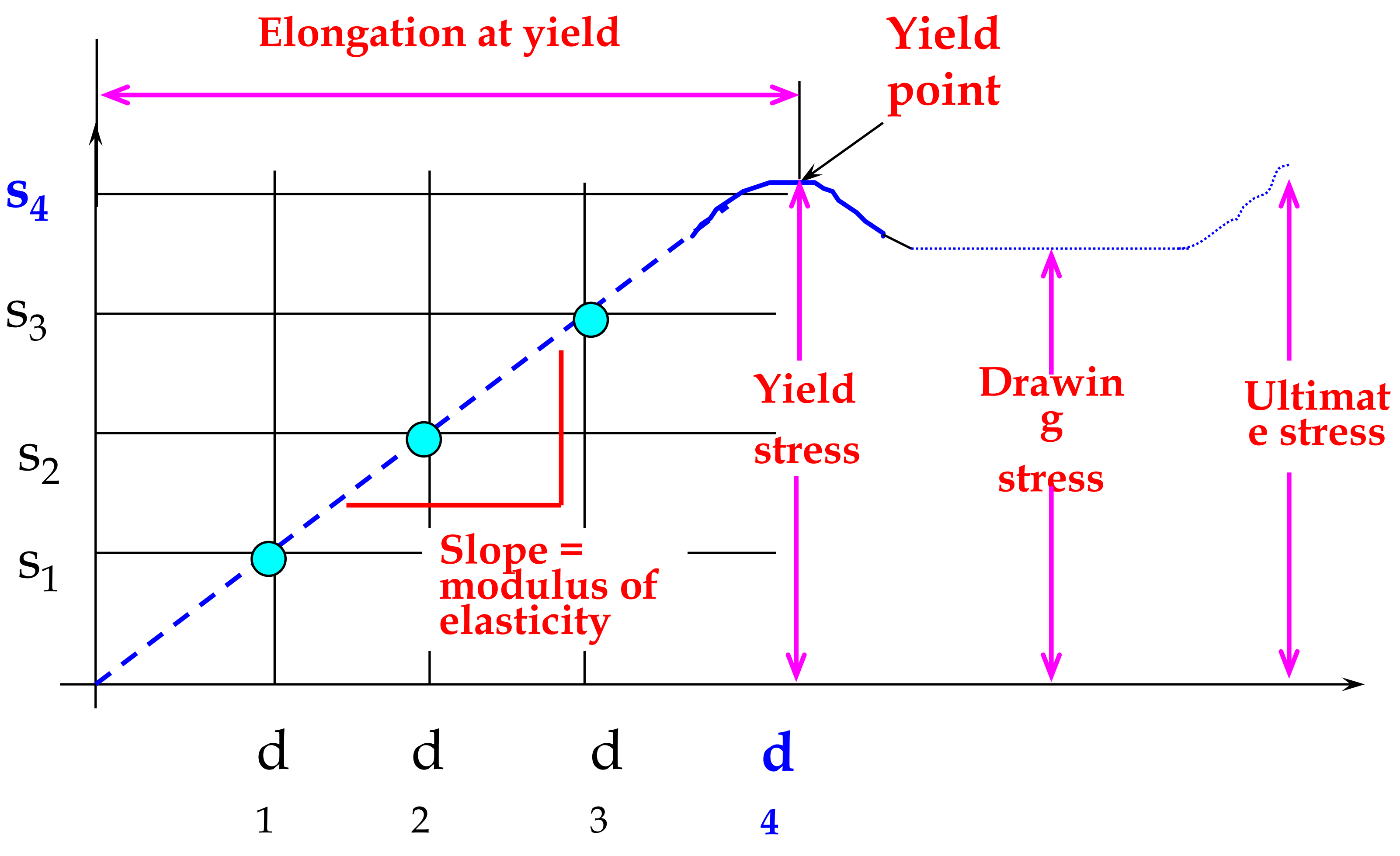
Therefore, for a "solid" if the temperature or the velocity (at which the deformation occurs) changes, then the elastic modulus :



Young's modulus vs. temperature (for a polymer)



Tensile test

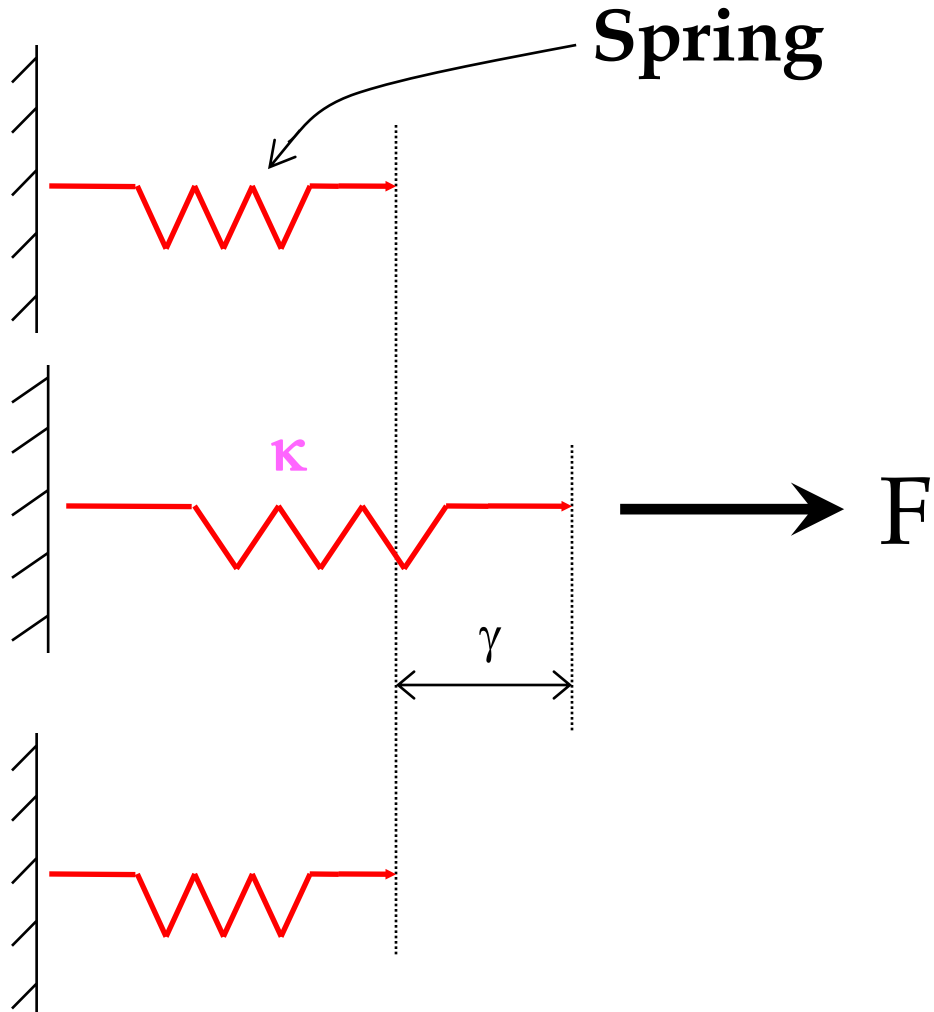


A Model for the Hookean Region

At rest

Force is applied

Force is released

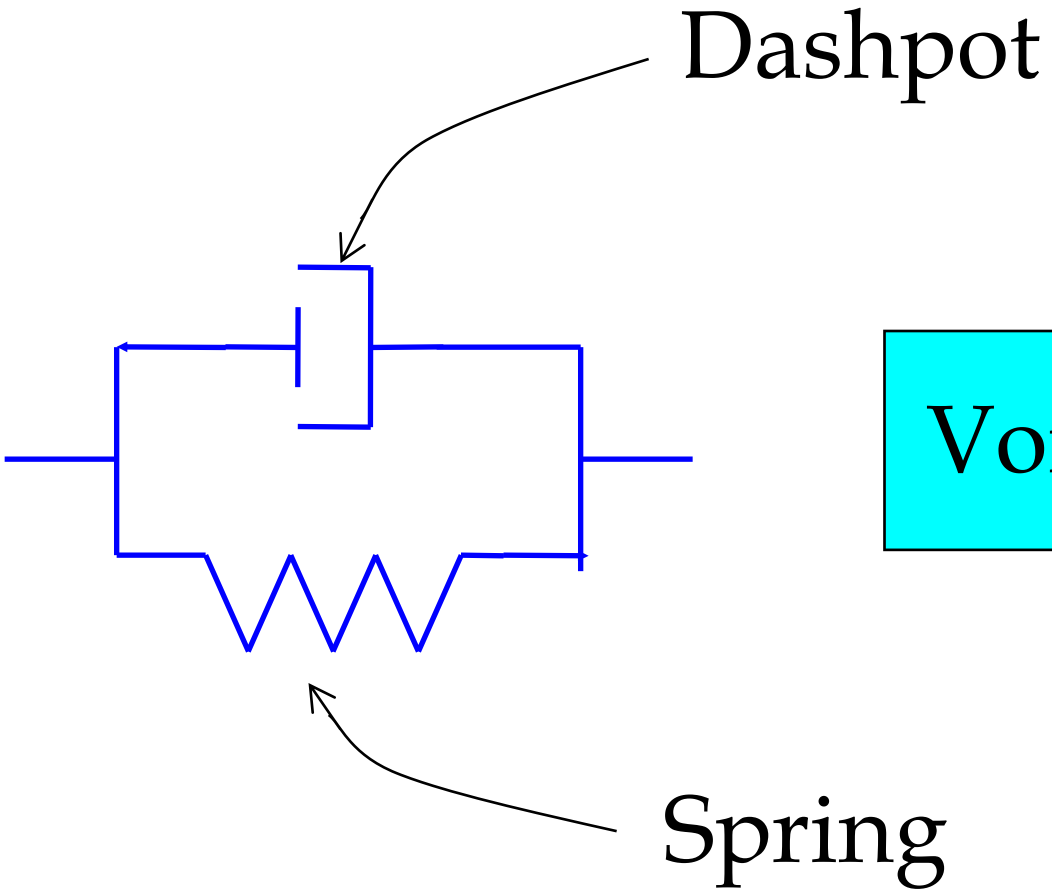


Once the force is released the material recovers its original shape (recoils)

$F \propto \gamma$

$F = \kappa \gamma$

A Model for the Non-Hookean Region



Voight Element

"LIQUIDS"

Flow of a liquid

- Pushing it through a cylinder (capillary test)
  - how much force is required to make it flow at a given flow rate (for example 1, 2, 3, etc. gallons/min ?)

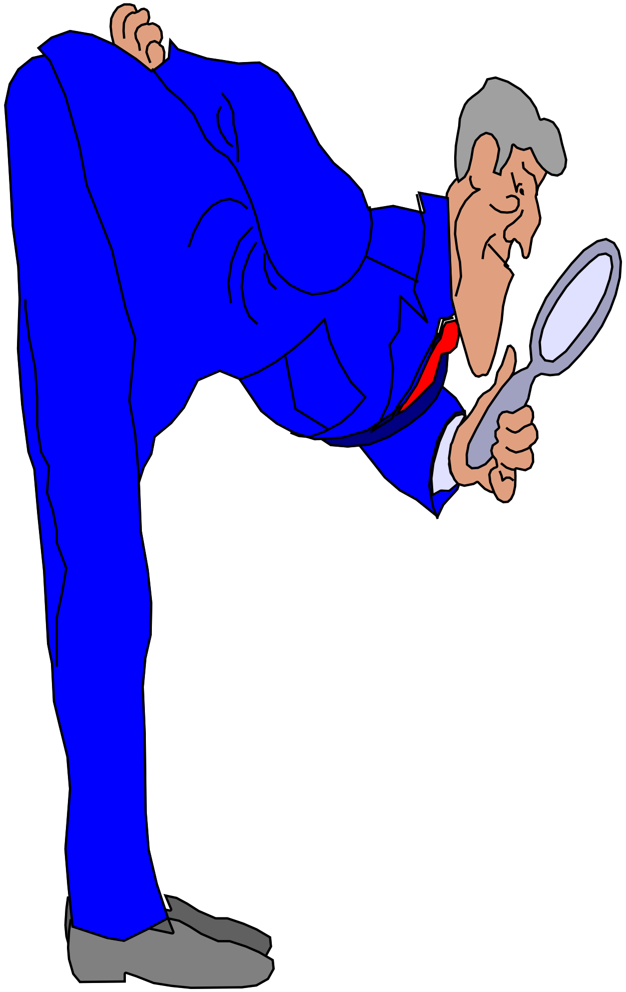
- Deforming the material between two plates

Concept of modulus for "liquids"

How a is the modulus determined?

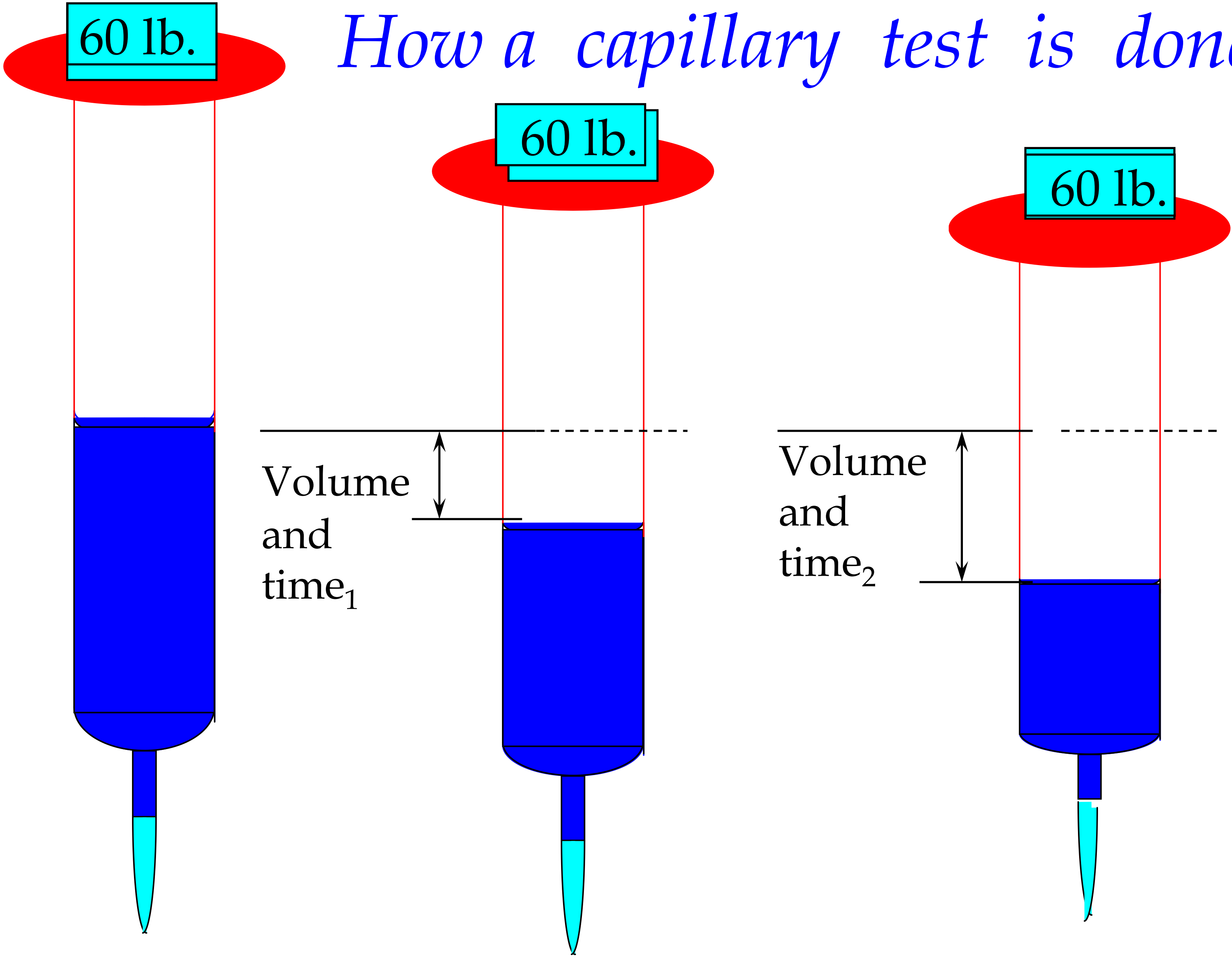
How is it called?

How many moduli exist?



CAPILLARY TEST

How a capillary test is done?

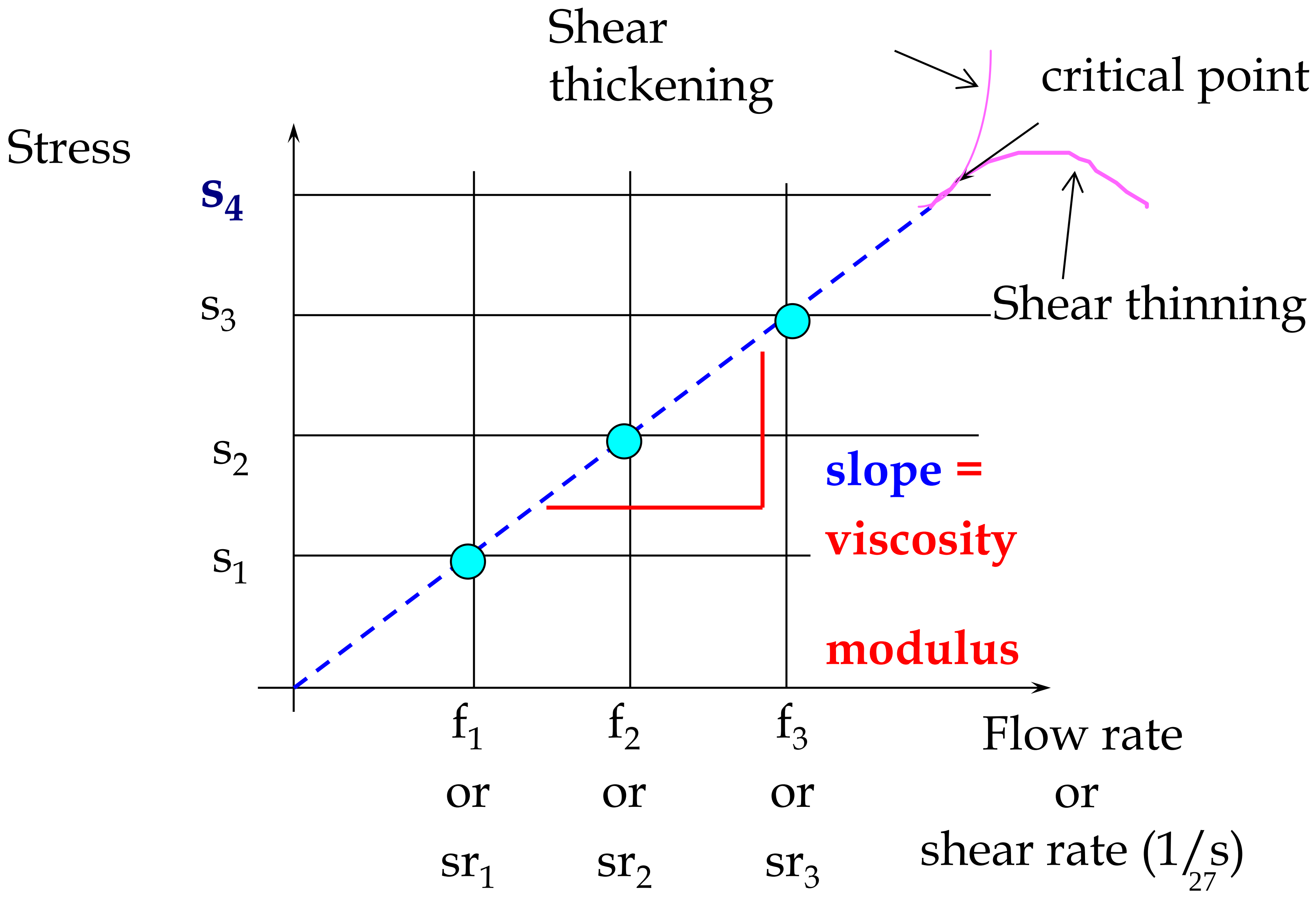


What do we do with these data?

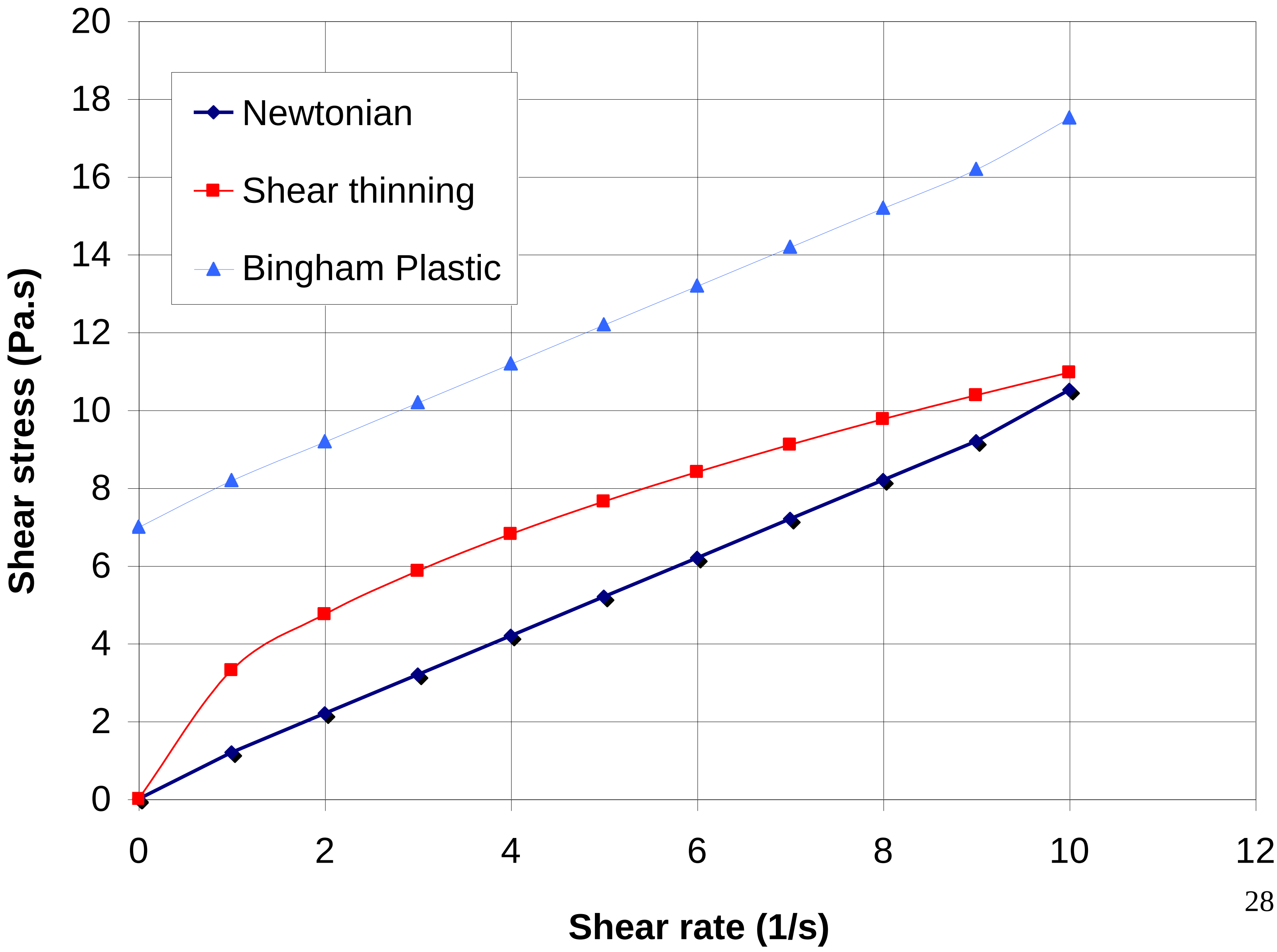
Datum	Force	Area	Volume	Stress = F/ A	Flow rate = $\frac{\text{Volume}}{\text{time}}$
0	$\mathbf{F_0}$	$\mathbf{A_0}$	$\mathbf{V_0}$	**0**	**0**
1	$\mathbf{F_1}$	$\mathbf{A_1}$	$\mathbf{V_1}$	$\mathbf{s_1}$	$\mathbf{f_1}$
2	$\mathbf{F_2}$	$\mathbf{A_2}$	$\mathbf{V_2}$	$\mathbf{s_2}$	$\mathbf{f_2}$
3	$\mathbf{F_3}$	$\mathbf{A_3}$	$\mathbf{V_3}$	$\mathbf{s_3}$	$\mathbf{f_3}$

Note: flow rate can be converted to shear rate by multiplying it by geometric factors.

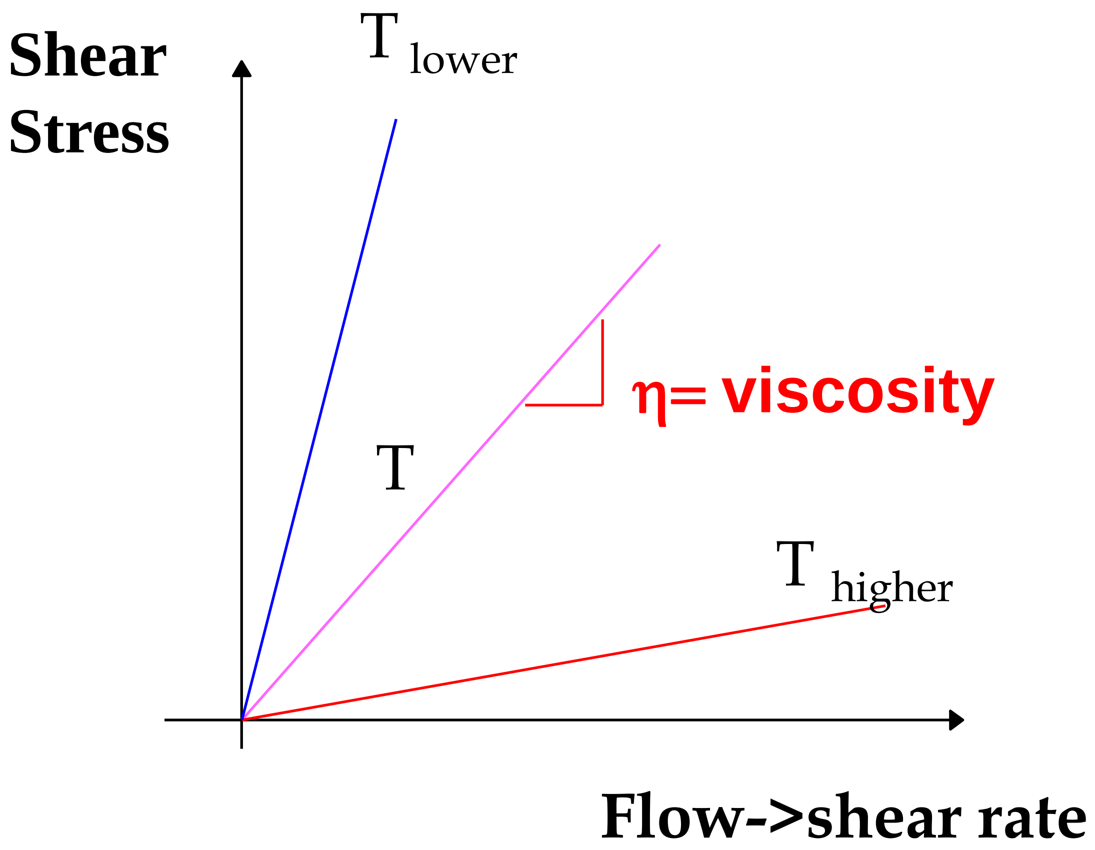
Plot data


Shear thickening
critical point
Stress
s_4
s_3
s_2
s_1
Shear thinning
slope =
viscosity
modulus
f_1 or sr_1
f_2 or sr_2
f_3 or sr_3
Flow rate or shear rate (1/s)

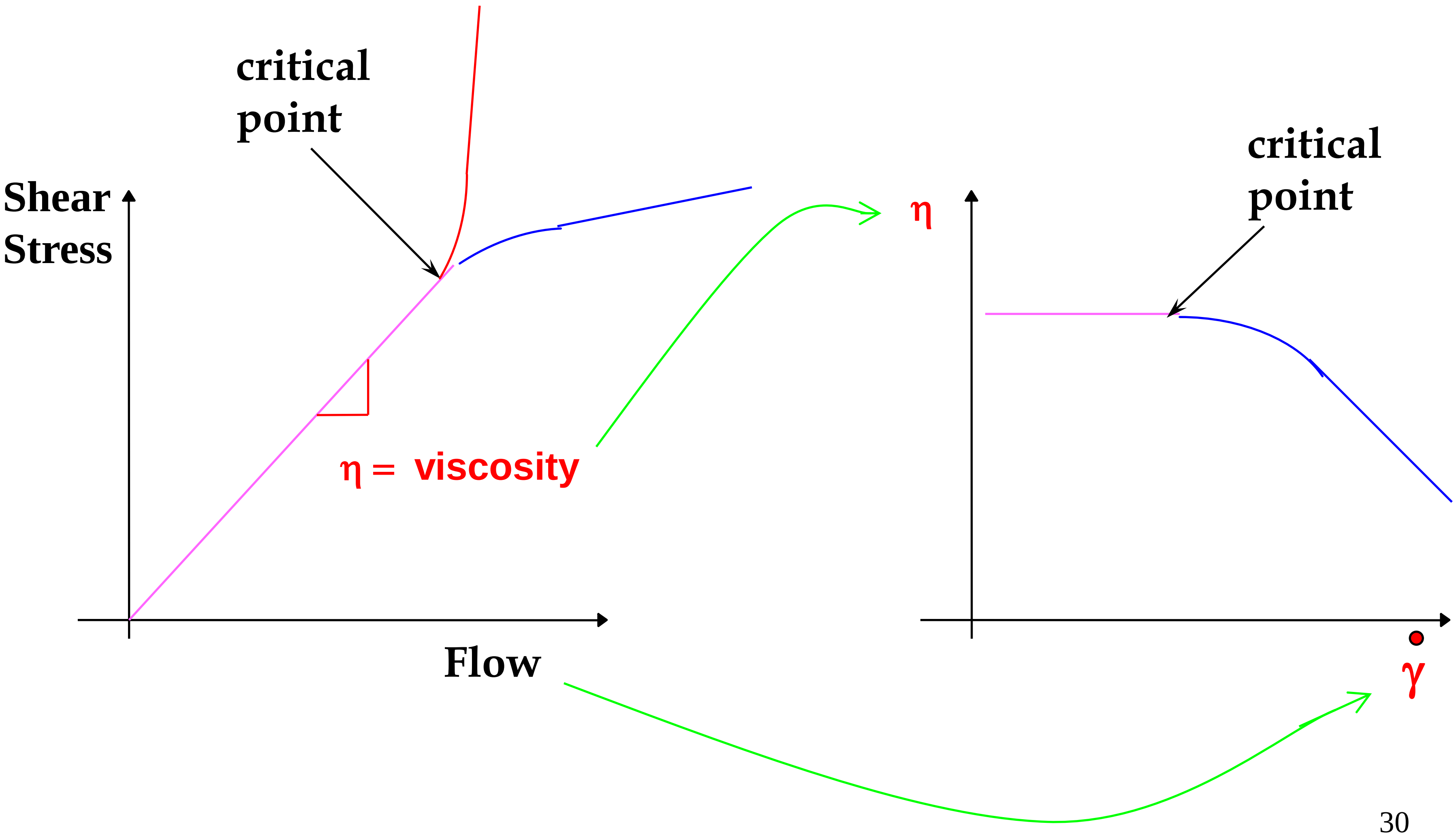
Steady State Behavior



For a “liquid”, if temperature changes



Transforming the shear stress-flow curve to a shear viscosity-shear rate curve



What information should be indicated whenever a capillary test is requested ?

Answers

1) ________________

2) ________________

3) ________________

and why?

Answers

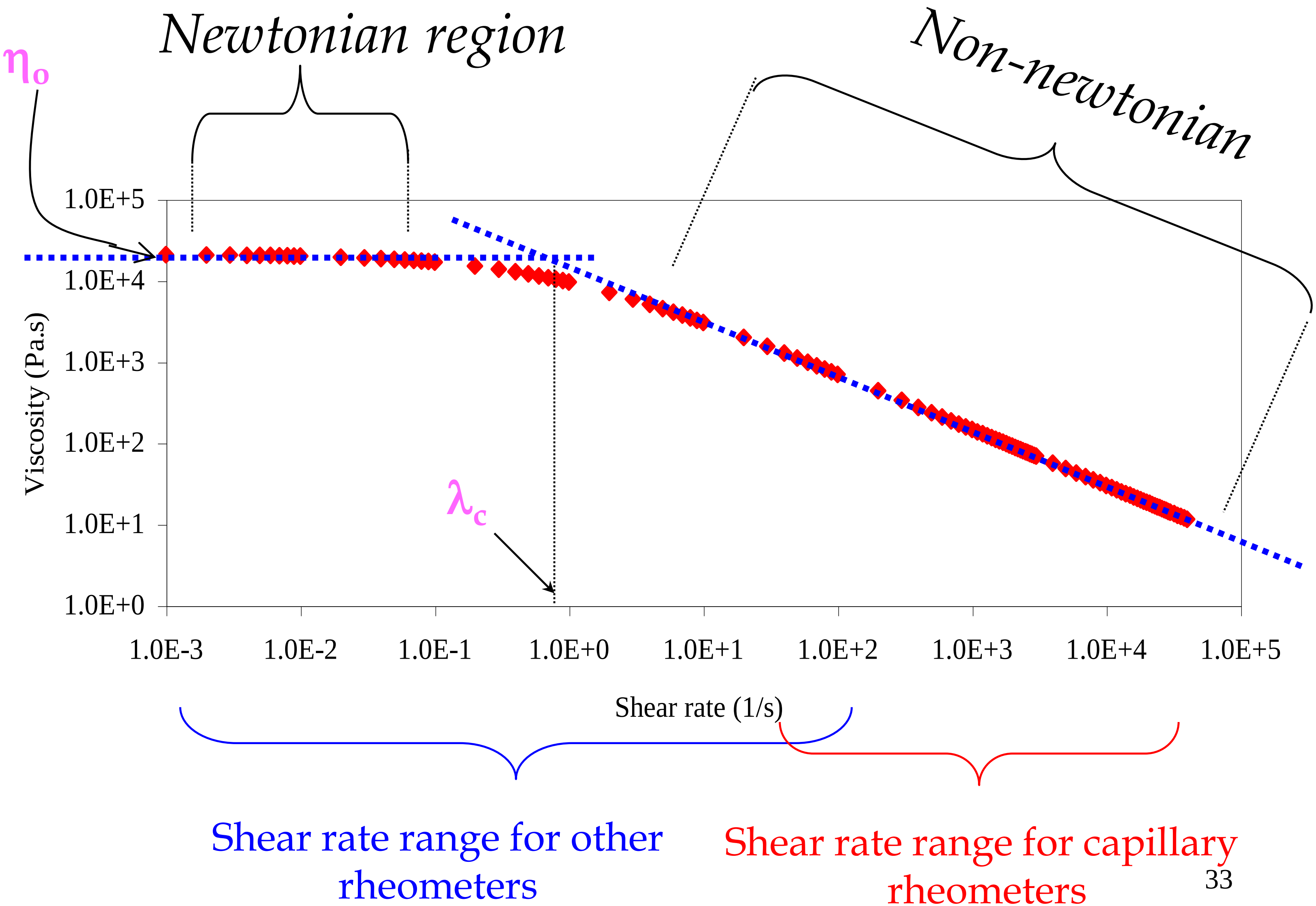
1) ________________

2) ________________

Then, what information can be obtained from a capillary test?

Answers	***Units***
1) The shear viscosity (η),	*1) ________________*
2) ________________	*2) ________________*
3) ________________	*3) ________________*
4) ________________	*4) ________________*
5) ________________	*5) ________________*

Typical viscosity curve

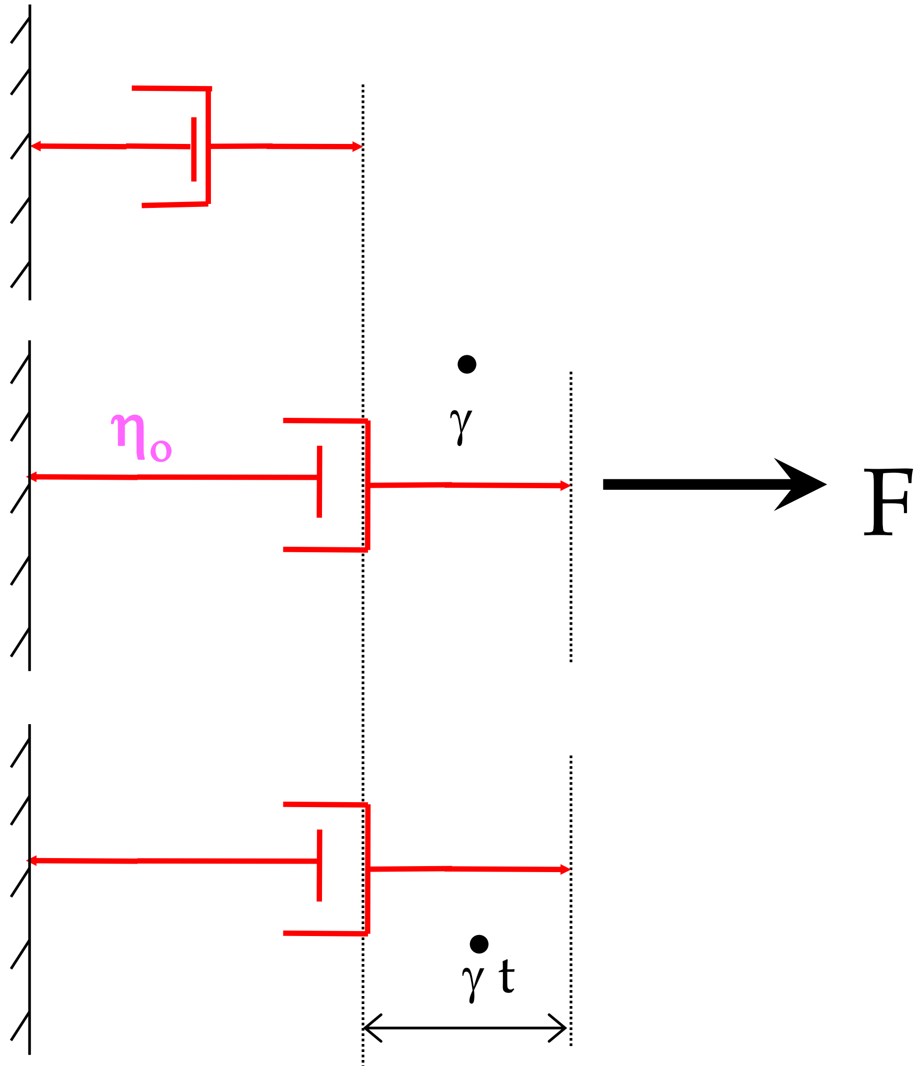


A Model for the Newtonian Region

At rest

Force is applied

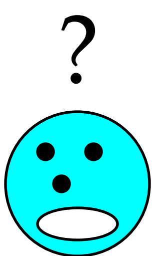
Force is released



Once the force is released the material stays deformed

$F \propto \dot{\gamma}$

$\tau = \eta_o \dot{\gamma}$



VIDEO

Beyond the critical point,
the relationship between stress and flow
IS NO LONGER LINEAR,

the materials are neither purely elastic
*nor purely viscous***,**
they are considered
visco-elastic materials

A Model for the Non-Newtonian Region (visco-elastic behavior)

Maxwell Element

Rheologically speaking the materials can be classified as

- Perfectly elastic solids
- Visco-elastic solids
- Visco-elastic liquids
- Perfectly viscous liquids

But before we go into more deatils...
why do you think that knowing the viscoelastic properties of a given material is considered so important in the industry?
A: ____________________________
____

Because…

The polymer industry is in the bussines of **producing** *and* **selling**

VISCO-ELASTIC MATERIALS

and to **give service** *to the costumers about the use of such materials* *a lot of work and research are oriented to* search for ***new catalysts, new blends, new additives, new processing conditions,***

and to use the rheological techniques to ***monitor and insure the production of materials with specific visco-elastic properties.***

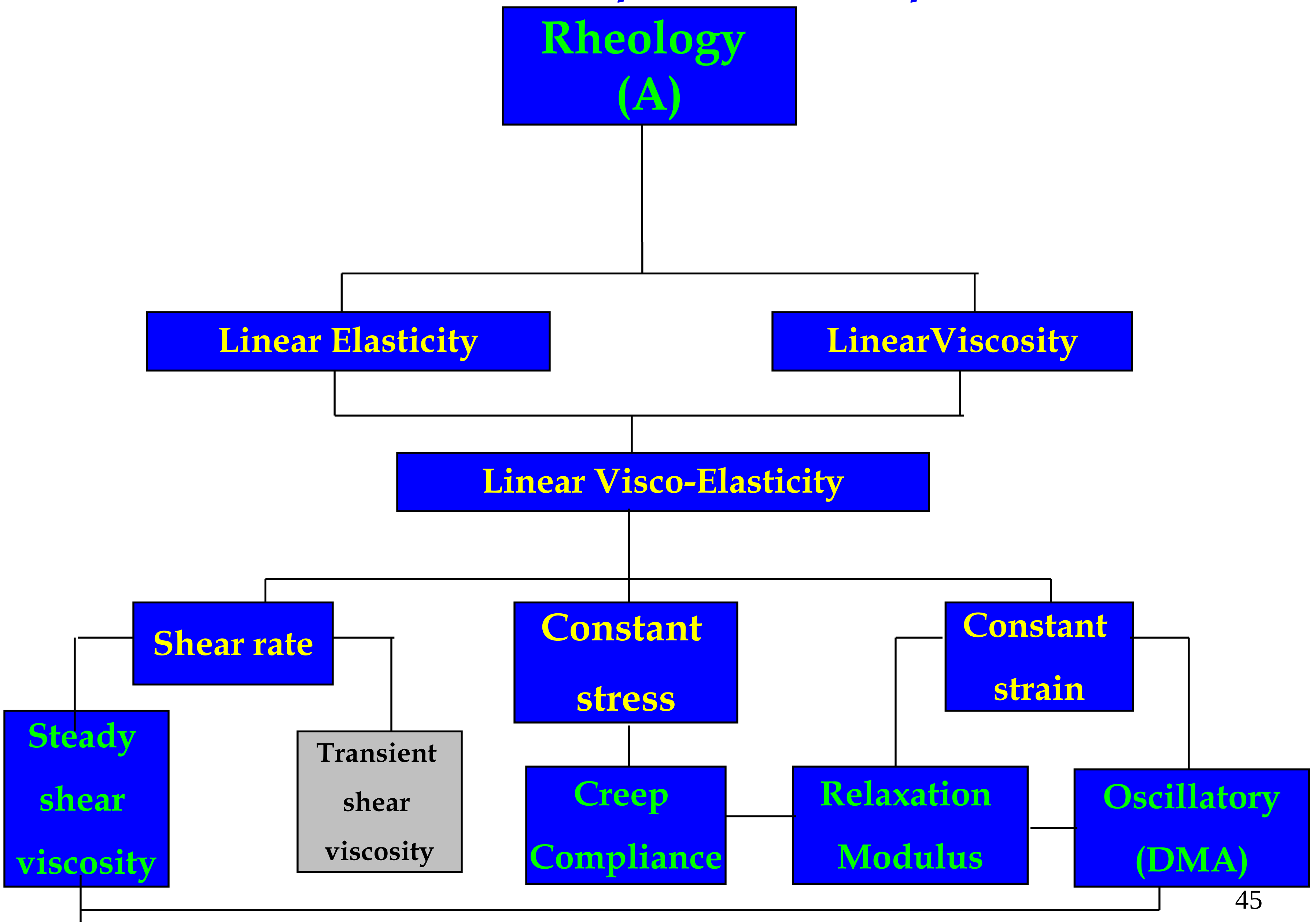
and...

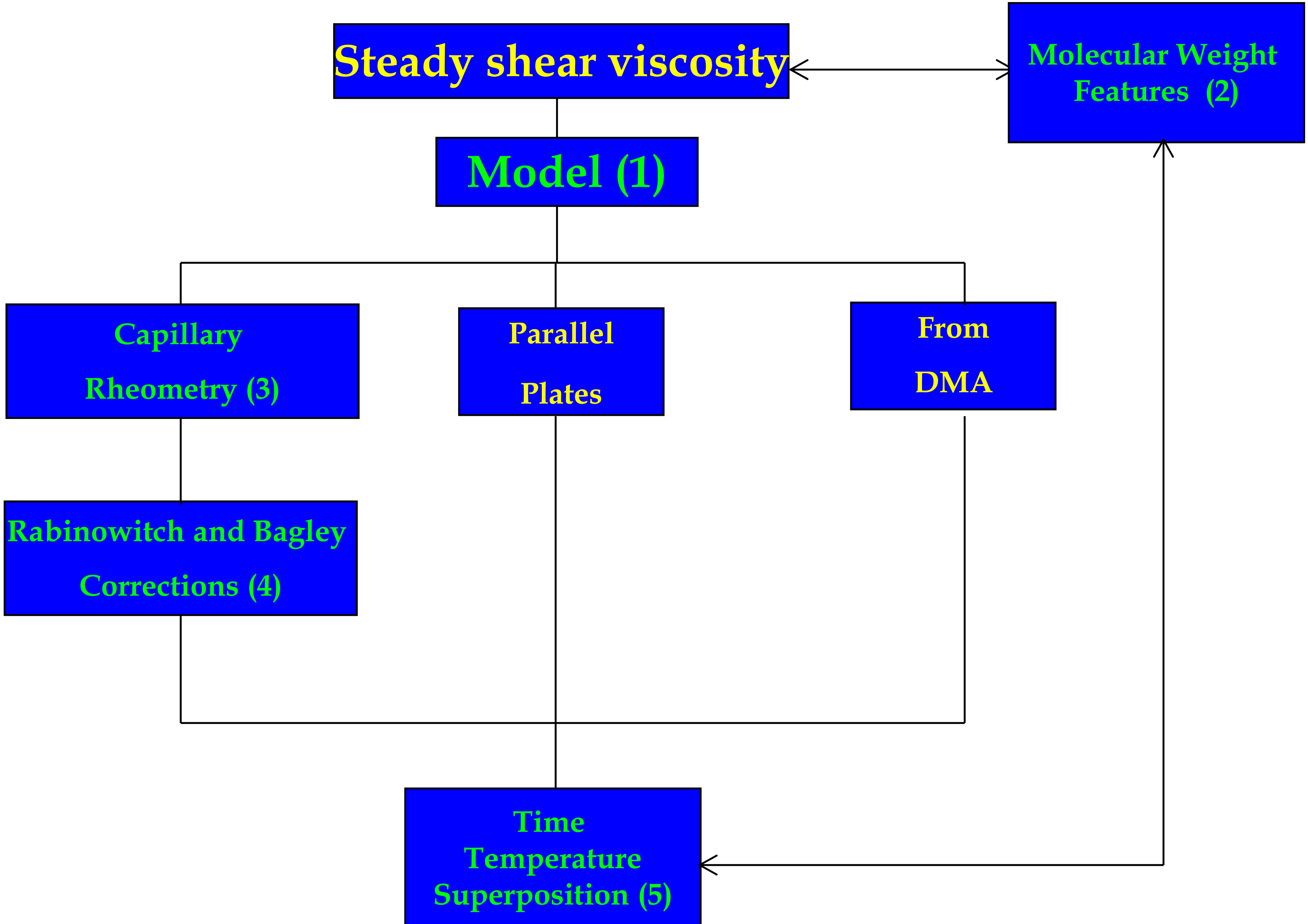
measuring, understanding, using and applying such visco-elastic properties is the realm of the Science called Rheology.

Questions and Reflections

- **Besides of the capillary test, are there some other ways to measure the viscosity?**
- **What other moduli exist for solid and liquids?**
- **Are those moduli dependent from each other?**
- **If they are dependent, how can a given moduli be calculated from another one?**

Conceptual Map




Steady shear viscosity
Molecular Weight Features (2)
Model (1)
Capillary Rheometry (3)
Parallel Plates
From DMA
Rabinowitch and Bagley Corrections (4)
Time Temperature Superposition (5)