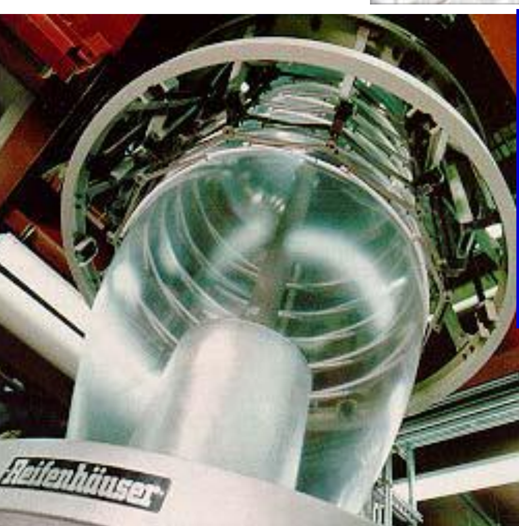
Basic concepts in Soft Matter

Raw material → *processing* → *Final product*

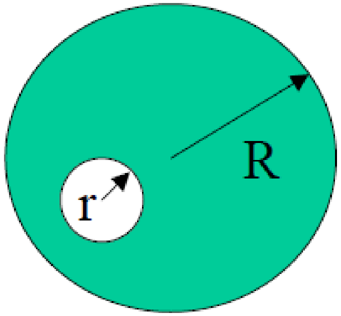


Establish the relationship between deformation-rate and stress

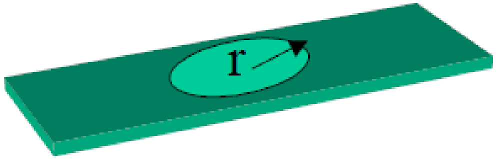
Important scales

Mass
Length
Time
Energy (modulus)

Fractal concepts and self-similarity

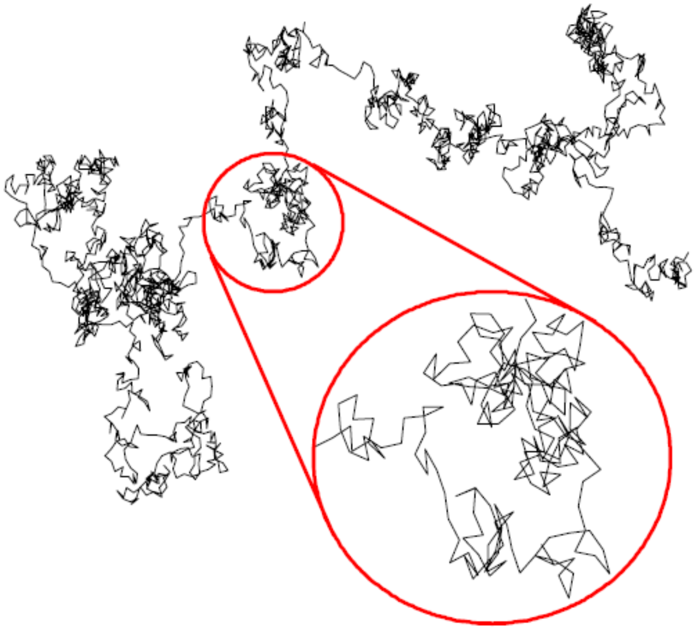


3-dimensional ball



2-dimensional sheet of paper

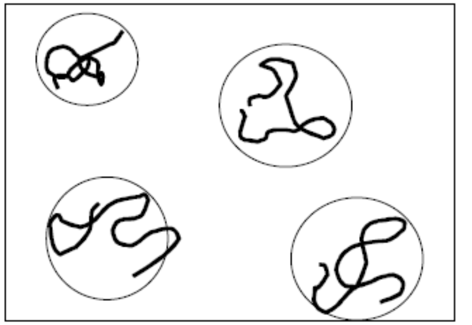
$m \sim r^3$ $m \sim r^{\mathcal{D}}$



$$N \sim \langle R^2 \rangle$$

Volume fraction

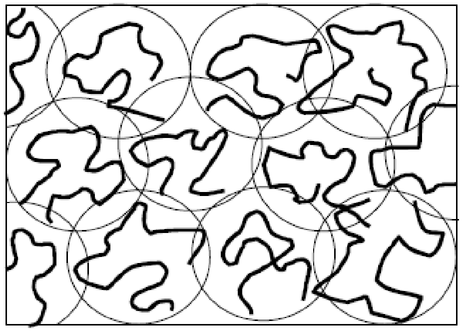
$$\phi = \frac{c}{\rho} = c\frac{v_{mon}N_{Av}}{M_{mon}}$$



dilute ($\phi < \phi^*$)

Pervaded volume

$$V \approx R^3$$

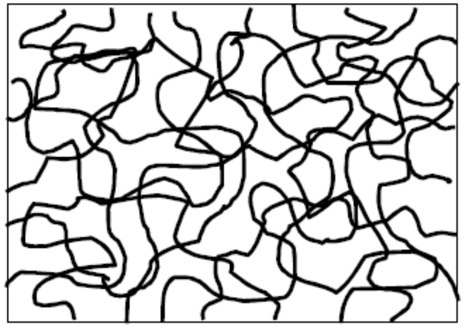


$\phi = \phi^*$

Overlap volume fraction
(volume of single molecule inside its pervaded volume)

$$\phi^* = \frac{N v_{mon}}{V}$$

Overlap parameter
(number of chains in a pervaded volume)



semidilute ($\phi > \phi^*$)

$$P = \frac{\phi V}{N v_{mon}}$$

Molar mass

$$M_N = M_{mon} N$$

number-average M_n

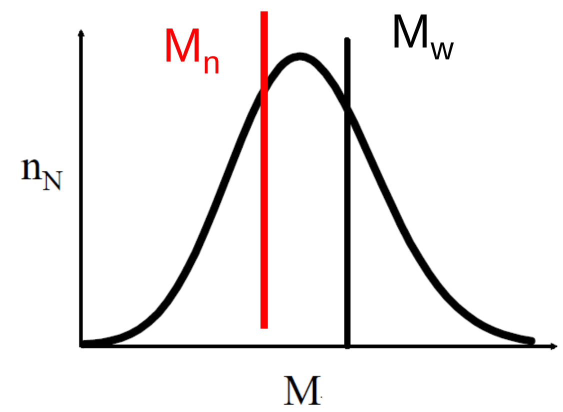
weight-average M_w

$$w_N = \frac{n_N M_N}{\sum_N n_N M_N} \qquad w_N = \frac{c_N}{c}$$

$$M_n = \sum_N n_N M_N = \frac{1}{\sum_N \frac{w_N}{M_N}}$$

$$M_w = \frac{\sum_N n_N {M_N}^2}{M_n} = \sum_N w_N M_N = \sum_N \frac{c_N}{c} M_N$$

$$PDI = \frac{M_w}{M_n}$$



Molecular Weight

You have:

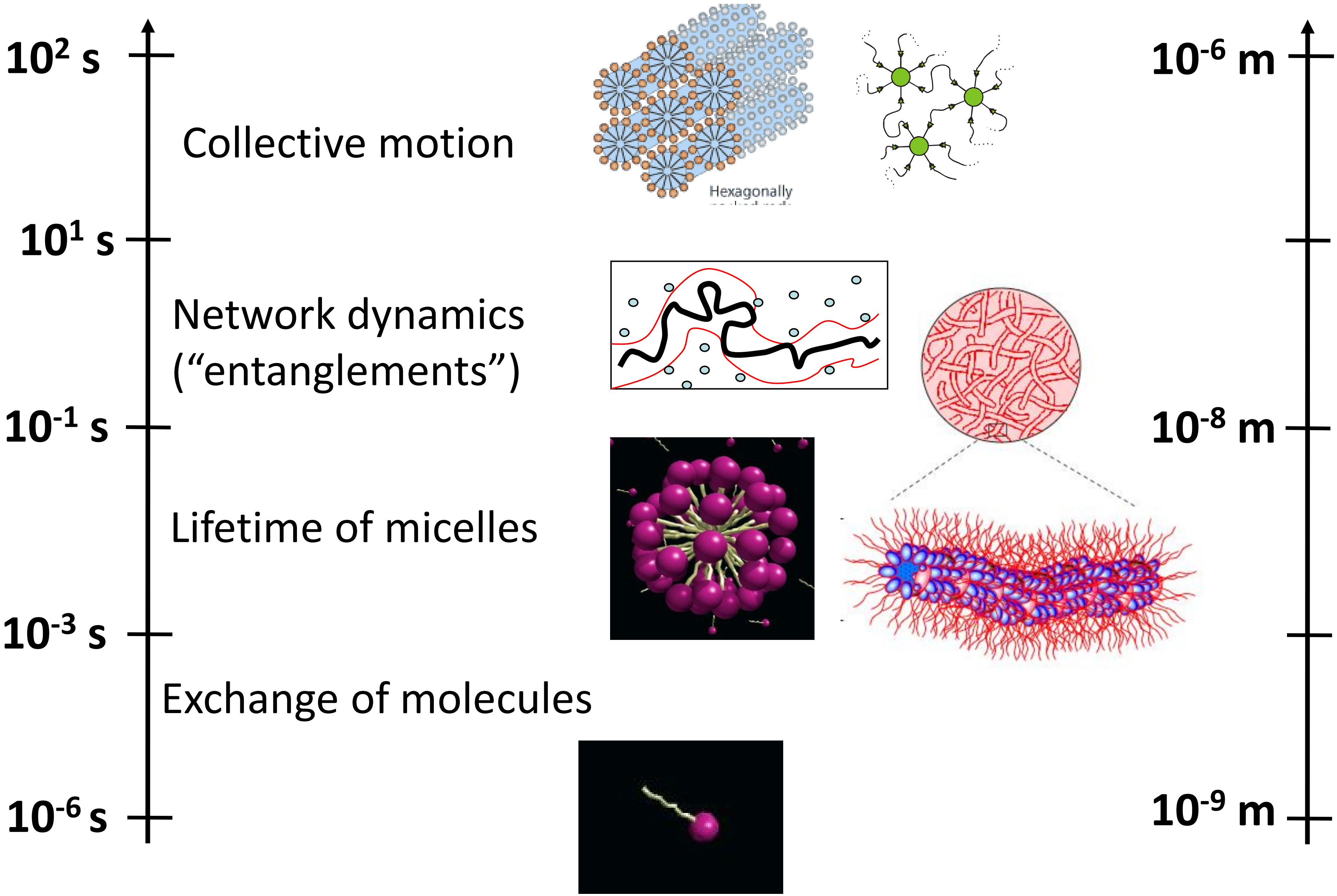
100 cherries at 9 g (each)

6 bananas at 180 g

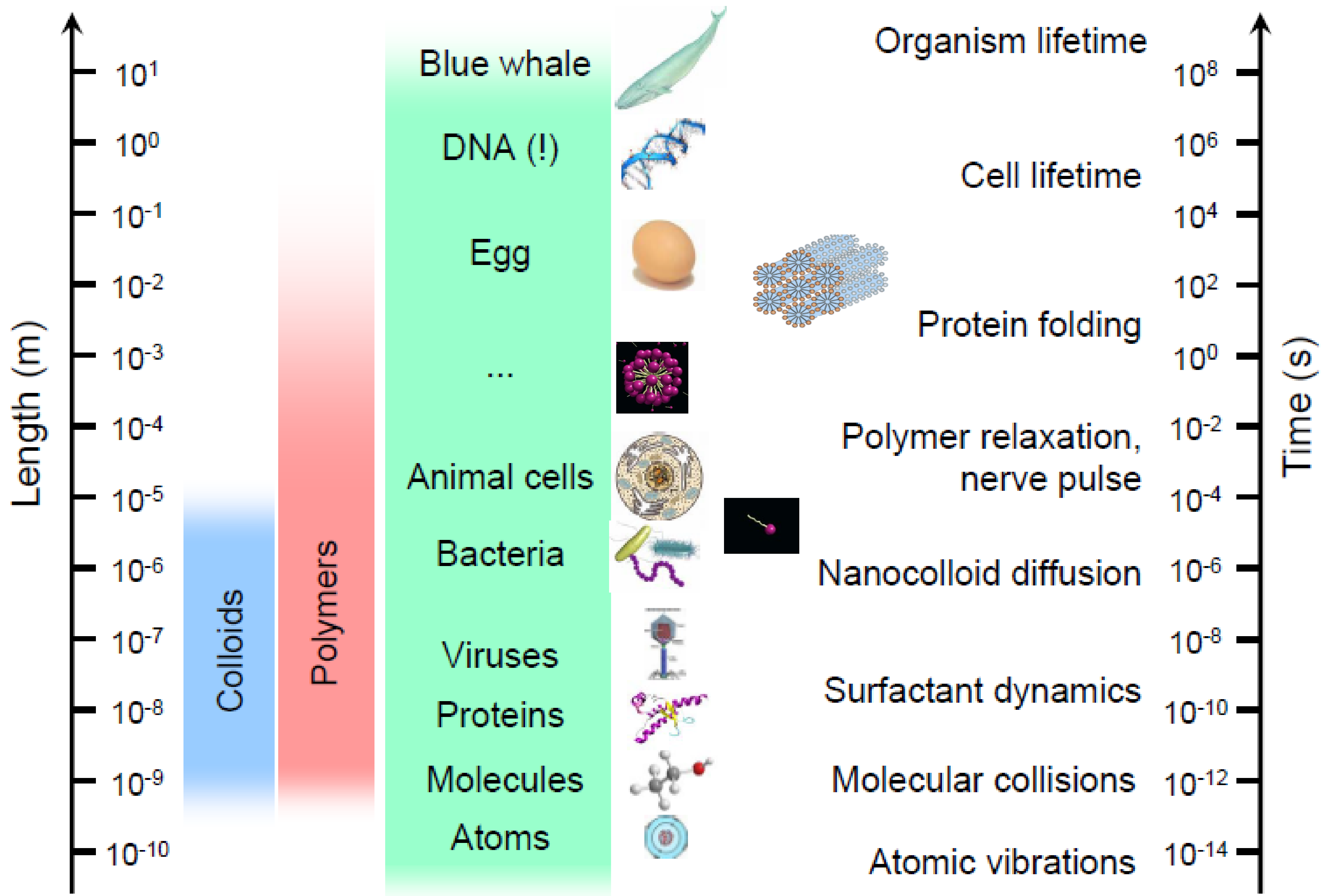
4 watermelons at 1.2 kg

What is the average weight of a piece of fruit?

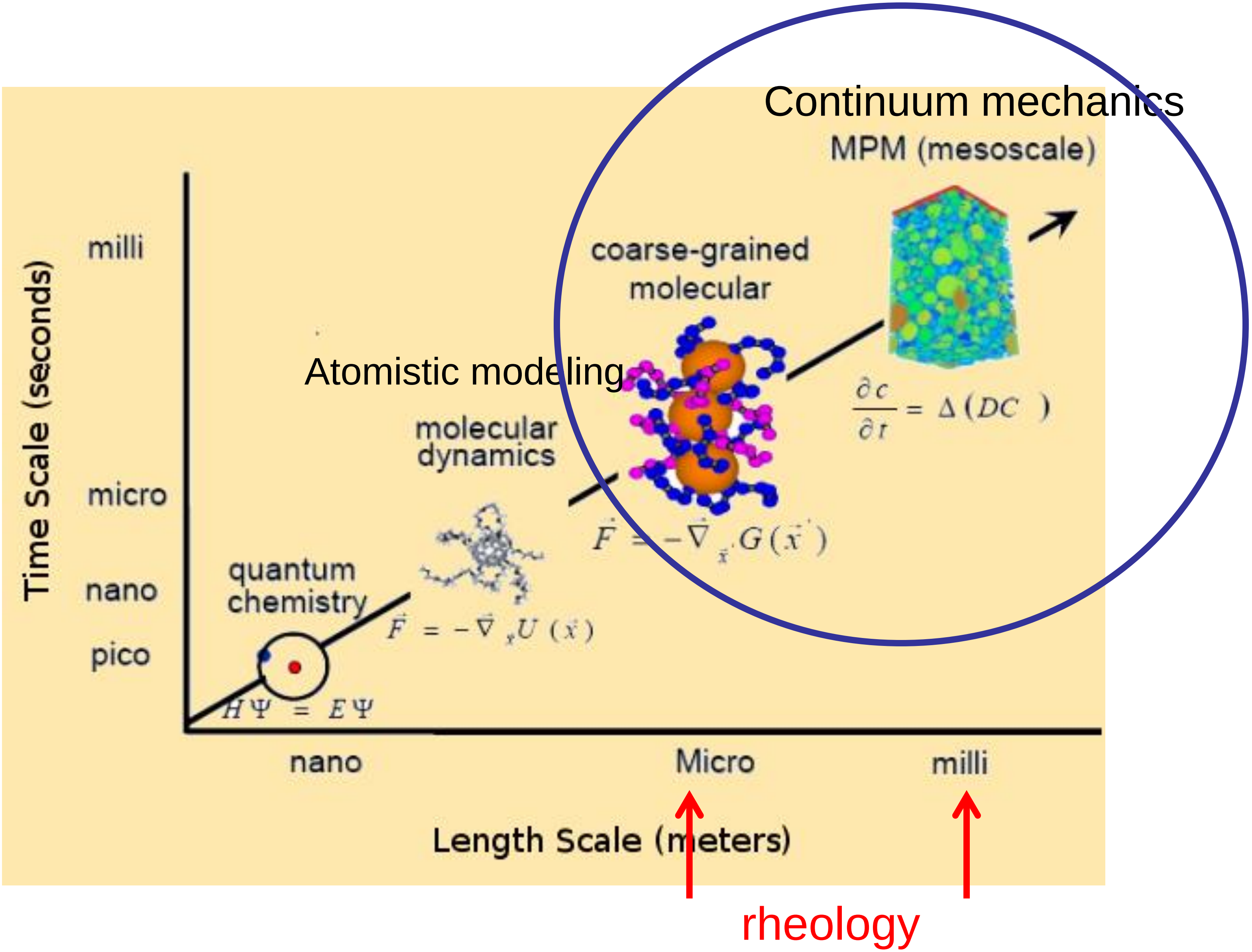
Time and length scales: Collective response + Self-Assembly



Examples of length and time scales



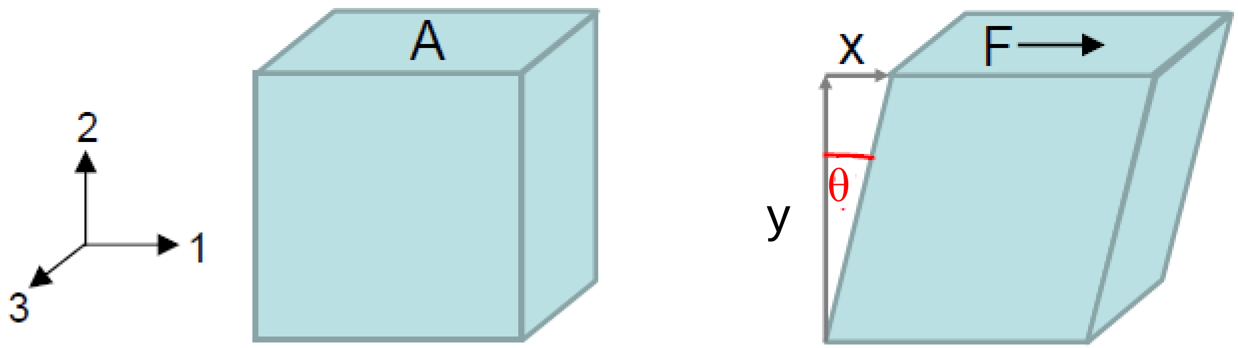
Description polymers: Coarse graining and the Importance of the length scales



Mesoscopic world → interpretation measurement

Shear

Elementary continuum definitions:



shear stress

$$\sigma_{21} = \frac{F_1}{A_2} = \sigma_{12}$$

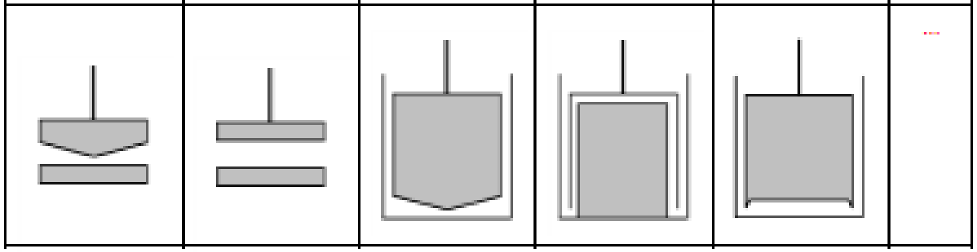
shear deformation strain

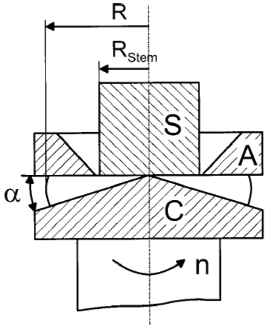
$$\gamma = \frac{x}{y} = \tan\theta$$

shear rate rate of strain

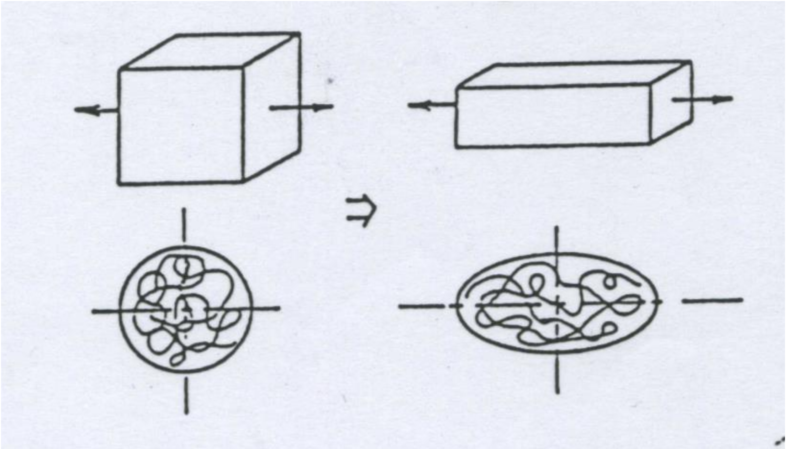
$$\dot{\gamma} \equiv \frac{d\gamma}{dt} = \frac{d}{dt}\left(\frac{dx}{dy}\right) = \frac{du}{dy}$$

Cone-Plate	Plate-Plate	Coaxial Cylinder	Double Gap Cell	Mooney Cell	...





Cone –partitioned plate



Extension

$$v_x = -\frac{1}{2}\dot{\varepsilon}(1+b)x \quad \text{(with } 0 \le b \le 1\text{)}$$

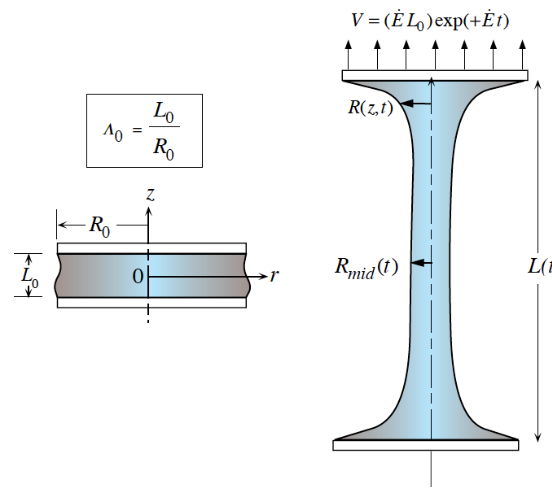
$$v_y = -\frac{1}{2}\dot{\varepsilon}(1+b)y$$

$$v_z = \dot{\varepsilon} z \quad \text{(Elongation rate)}$$

If b=0, constant rate (uniaxial elongation):

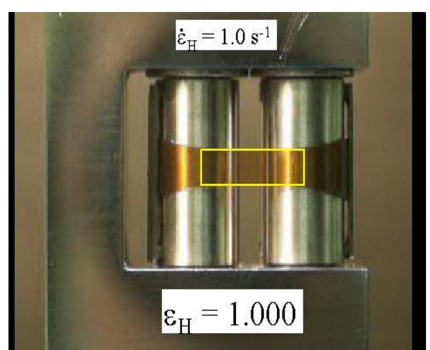
$$v_x = \frac{\partial x}{\partial t} = \frac{-1}{2}\dot{\varepsilon}x \;\Rightarrow x(t_2) = x(t_1)\exp\left(-\frac{\dot{\varepsilon}(t_2 - t_1)}{2}\right)$$

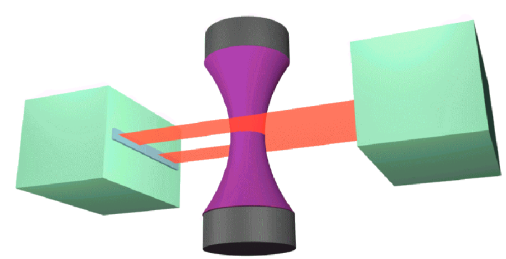
$$v_z = \dot{\varepsilon} z \;\Rightarrow z(t_2) = z(t_1)\exp\left(\dot{\varepsilon}(t_2 - t_1)\right)$$



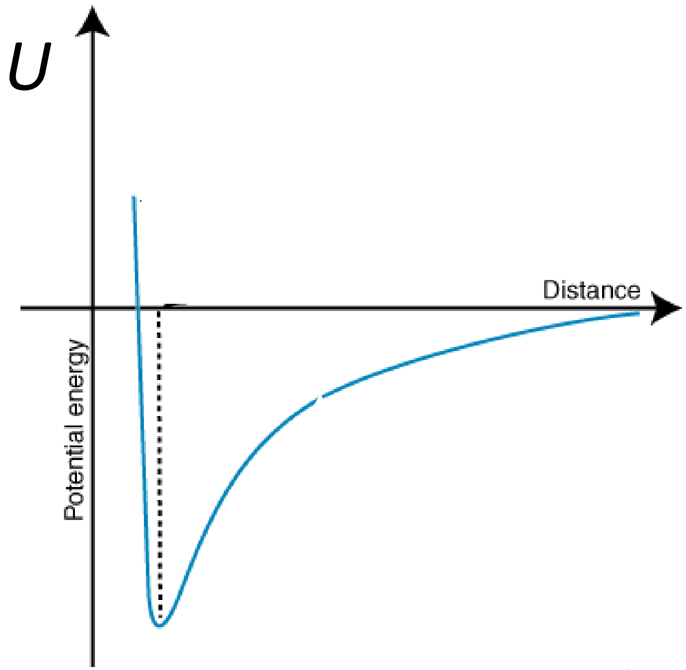
Henky strain

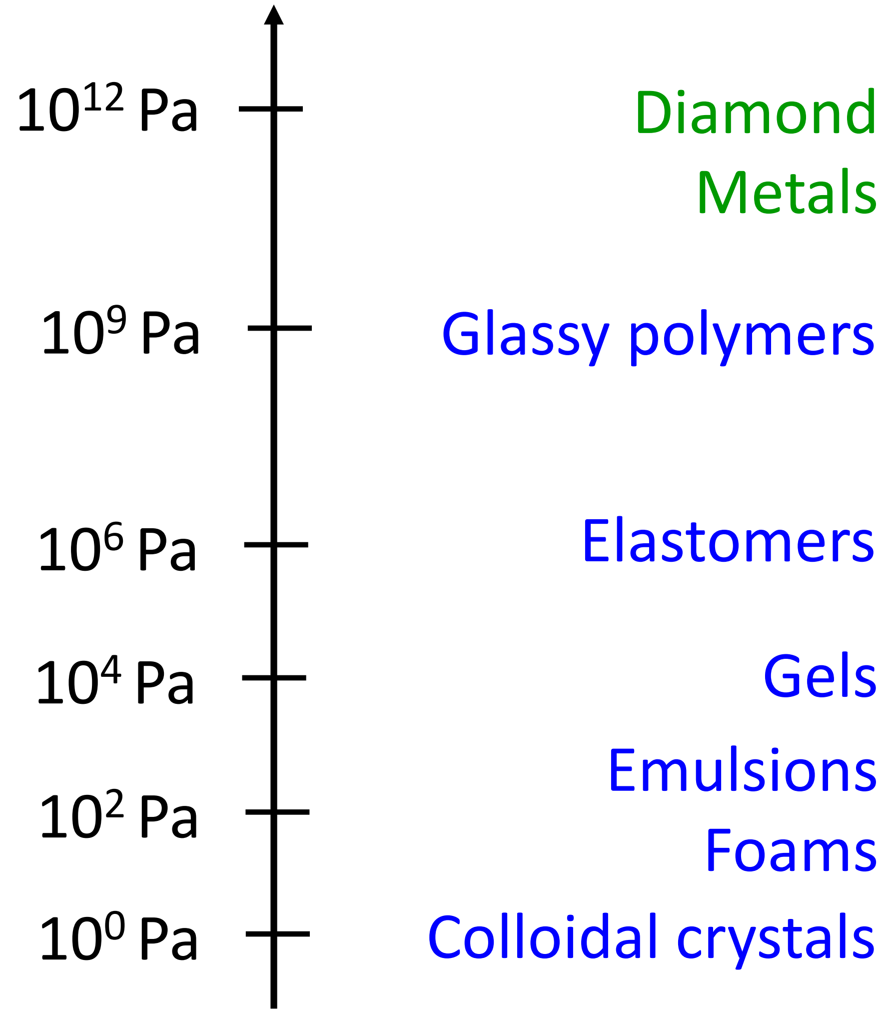
$$\Rightarrow l(t) = l(t_0)\exp\left(\dot{\varepsilon}(\Delta t)\right)$$





Material elastic energy





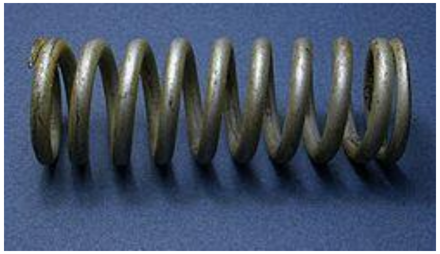
Young modulus: $G = \frac{\sigma}{\gamma} = \frac{\text{stress}}{\text{deformation}}$

$$G \approx \frac{\text{Energy}(kT)}{\text{Volume}}$$

Great sensitivity to external stimuli (mechanical stress)

Soft matter: small stimulus induces large effects (deformation)

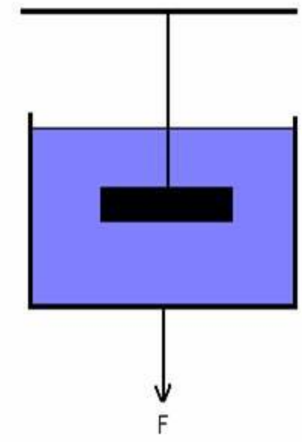
Elastic solids: constant modulus



Hooke

$$\sigma = G\gamma$$

Newtonian fluids: constant viscosity



Newton

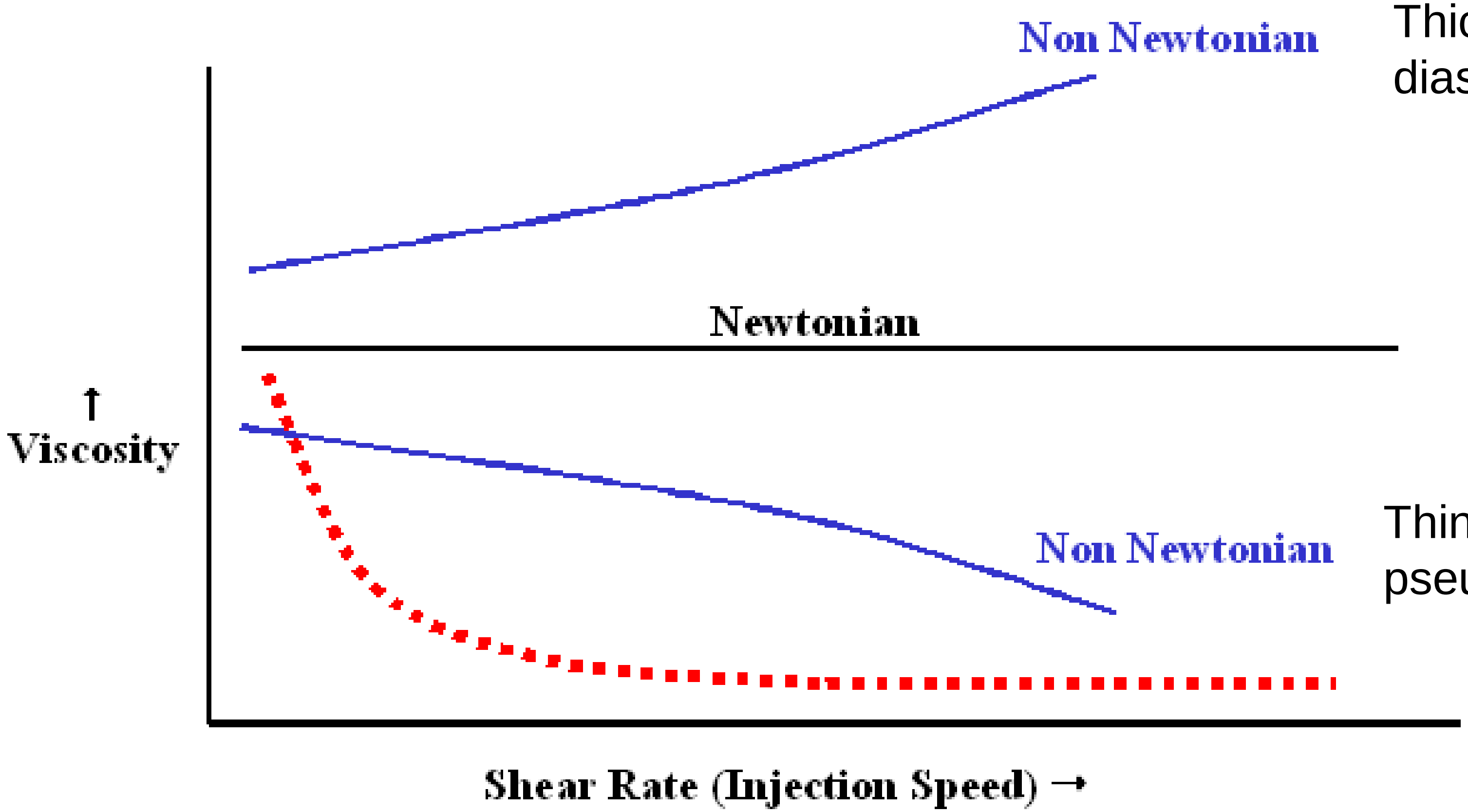
$$\eta \equiv \frac{\sigma}{\dot{\gamma}}$$

$\dot{\gamma}$: deformation rate

Non-Newtonian fluids:

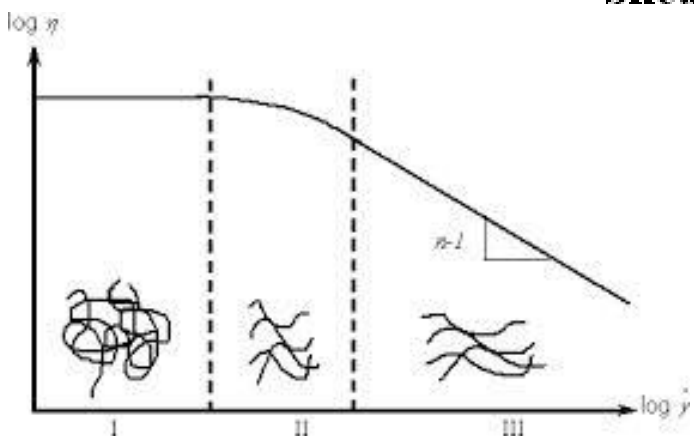
$$\sigma = \eta(t, \dot{\gamma})\dot{\gamma}$$

Classify fluids from viscosity curve



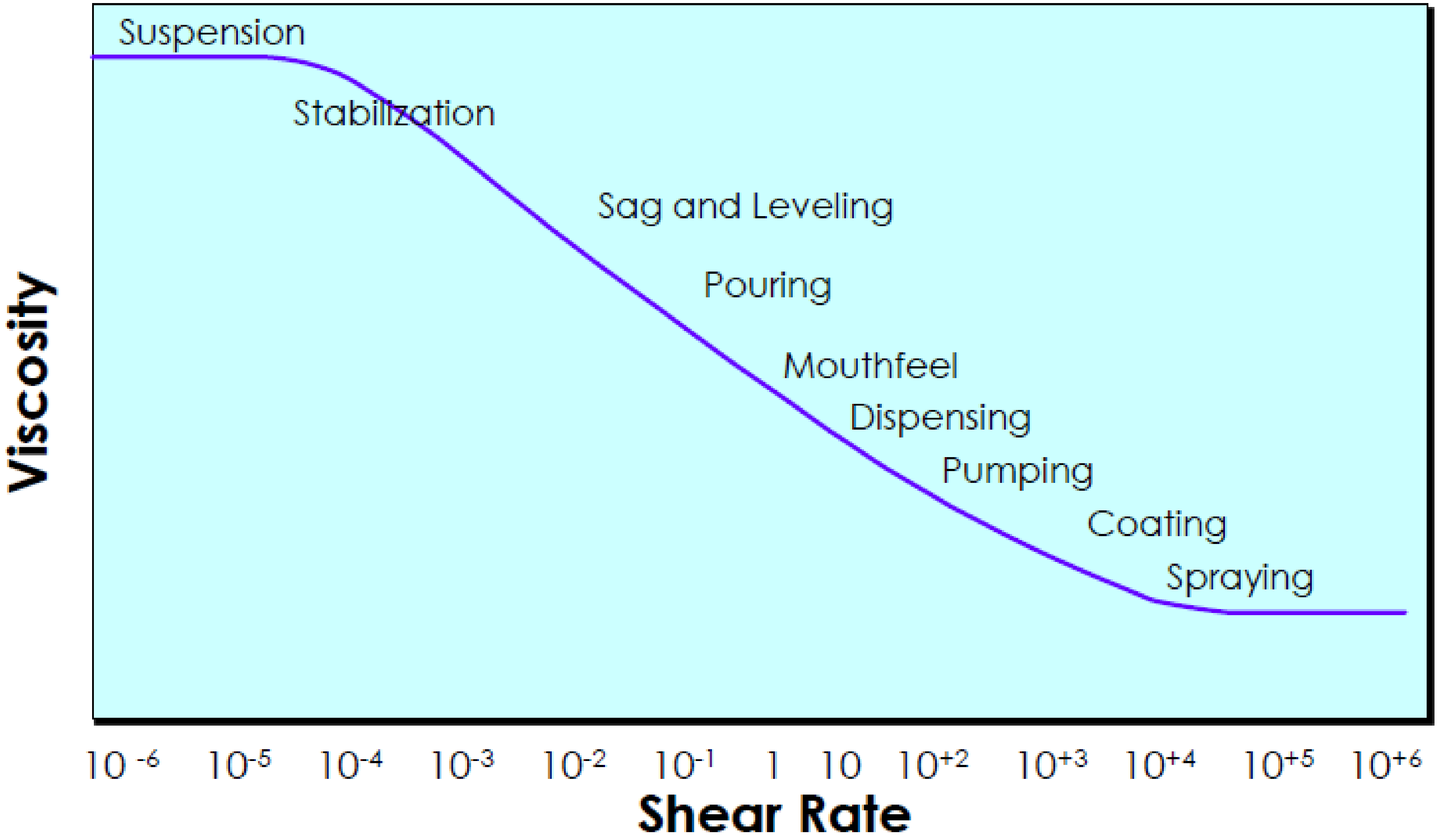
Thickening diastolic

Thinning pseudoplastic



Typical long polymer

Commonly encountered shear rates



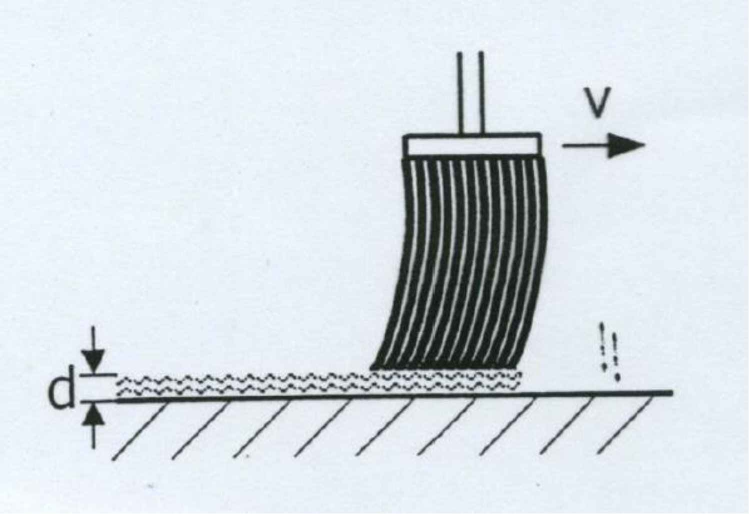
source: CP Kelpo

Question:

How can I rationalize a shear rate of 10^3 s^{-1}?

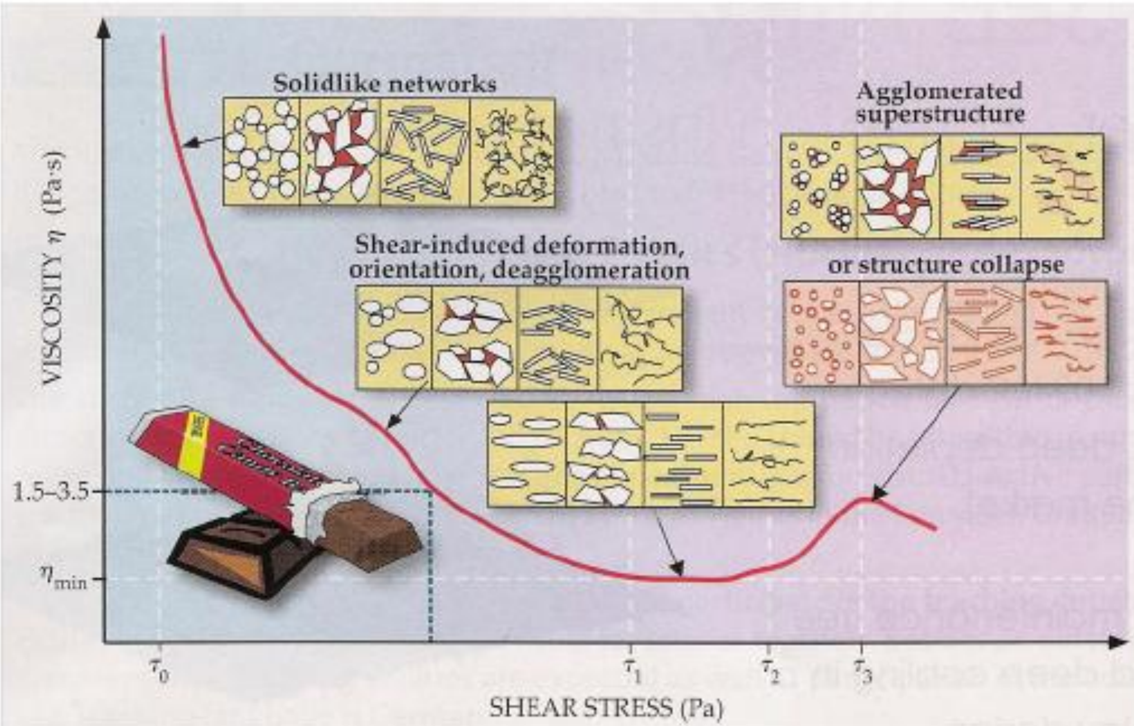
Think of coating:

Speed of rolling/coating?
Thickness of coating film?



Things can become much more complicated:

Complexity – chocolate as an example



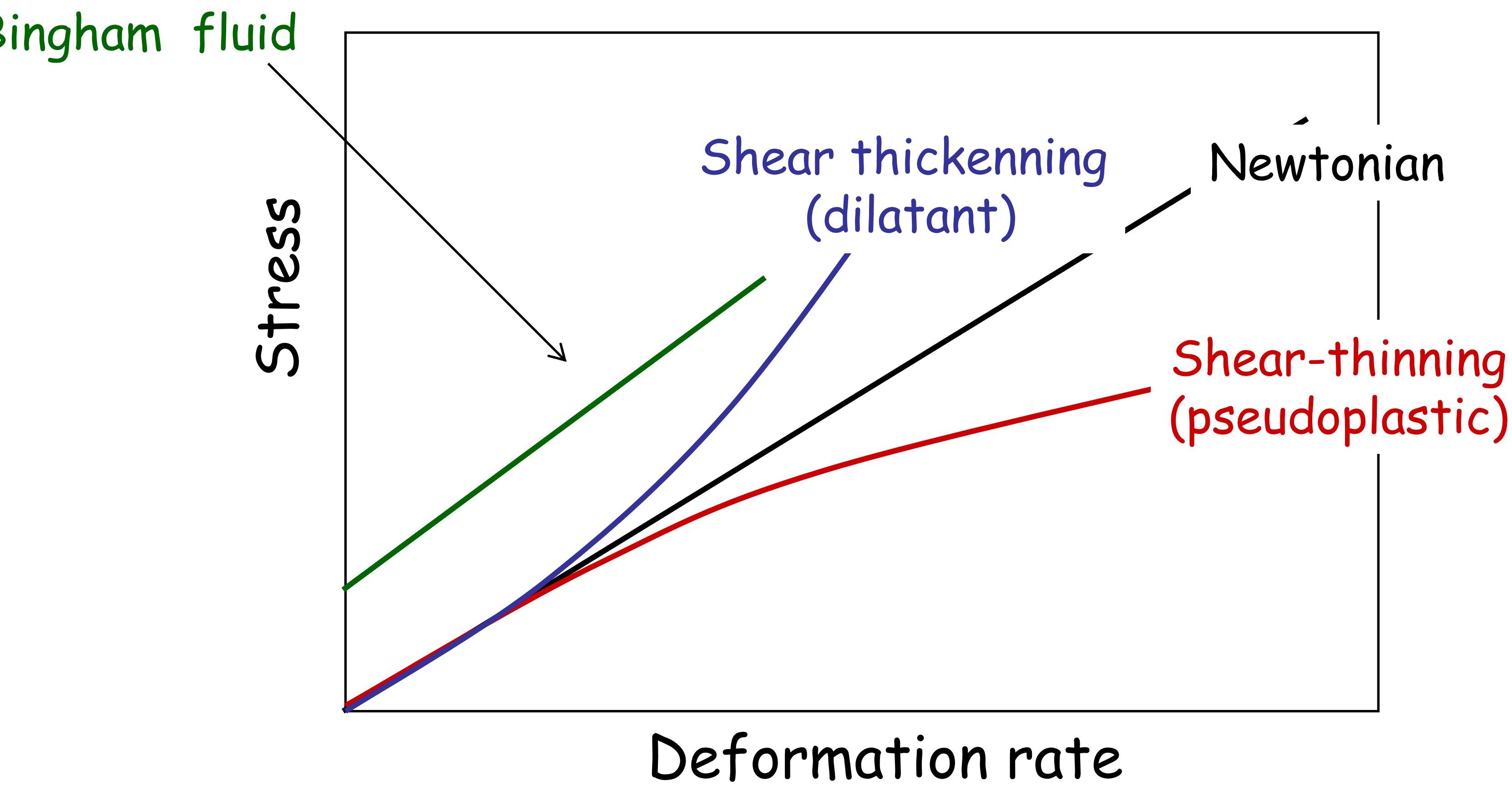
Even such simple and every-day substance as chocolate has a quite complex structure and mechanical properties

A delicious piece of chocolate – solid at room temperature, liquid-like in your mouth

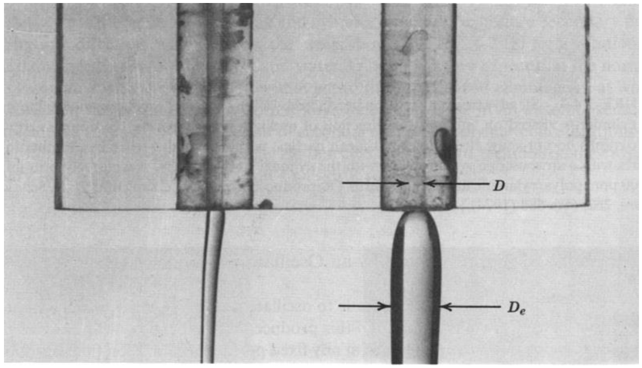
Classify fluids from stress curve

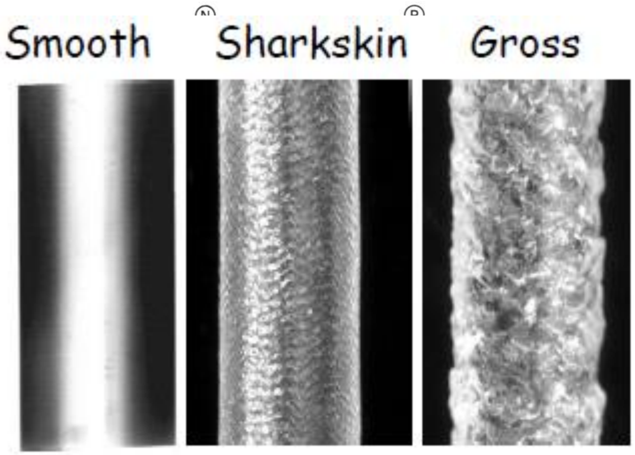
$$\sigma = \eta\dot{\gamma} + \sigma_y$$

Yield stress

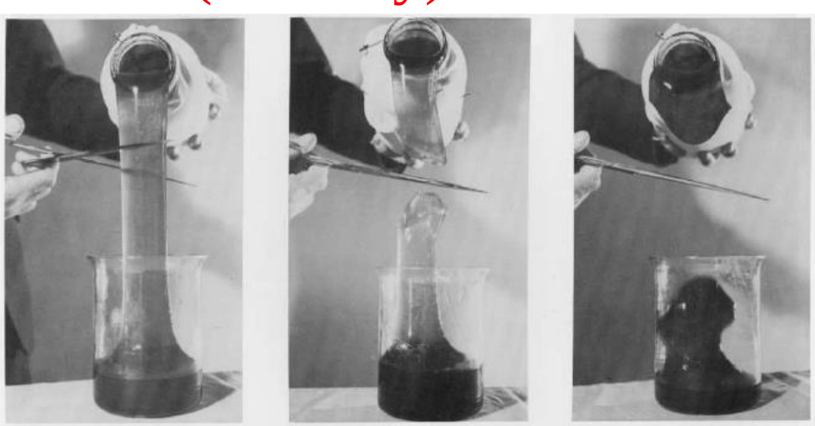


Extrudate swell & wall slip

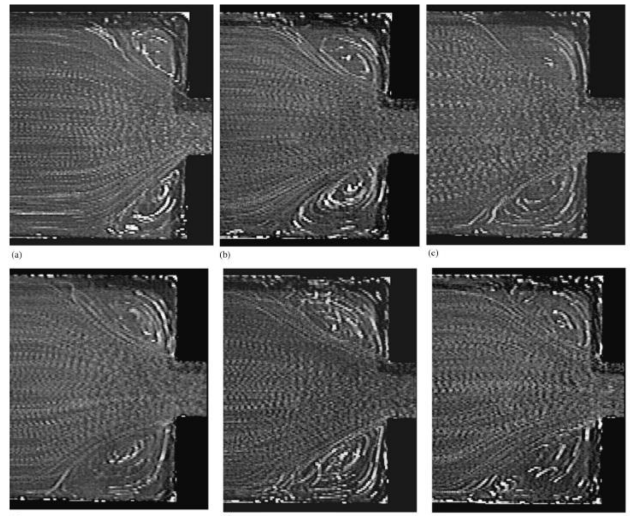




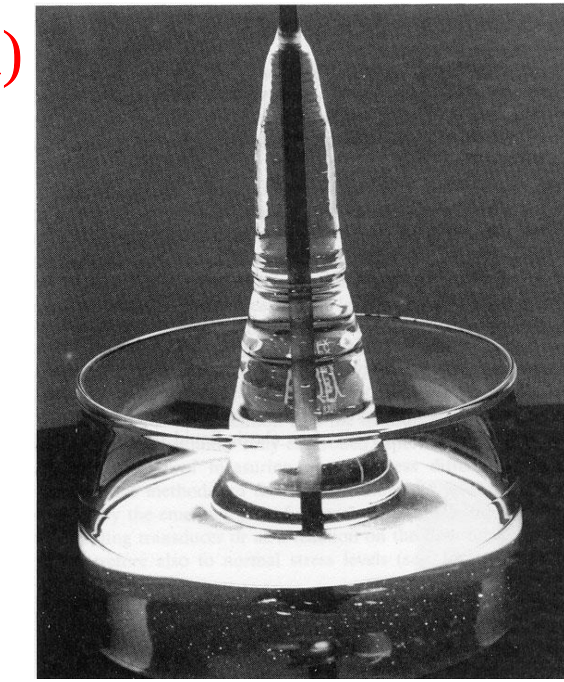
Recoil (memory)



Secondary flows (vortex)



Rod climbing (Weissenberg)



Drag Reduction

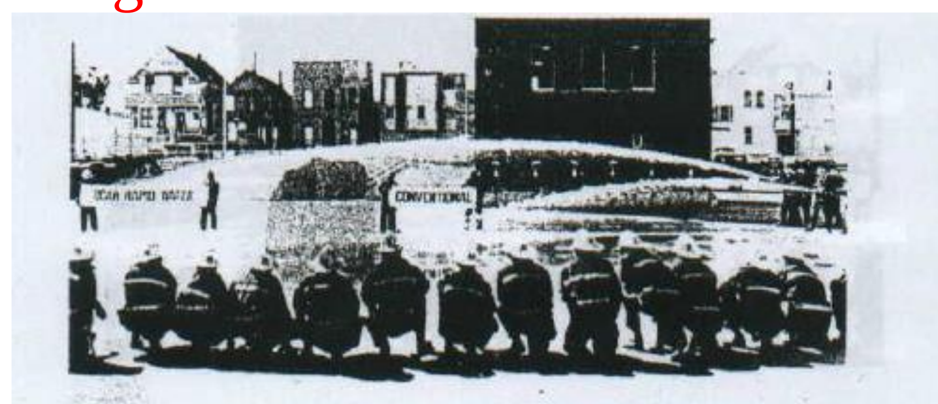
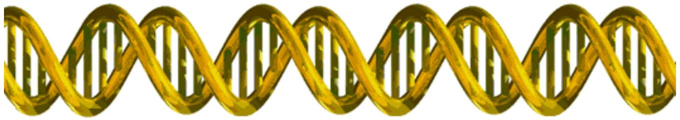


Fig. 1.3. Enhancement of fire-hose range by addition of small amounts of polyethylene oxide to water. (Photograph, courtesy of Union Carbide Corporation.)

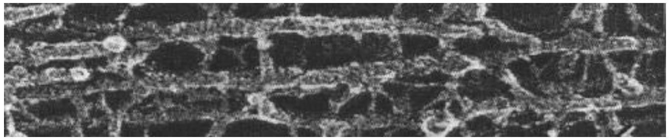
Semi-flexible biopolymers

DNA



16 micron length
2 nm in diameter
40 nm persistence length

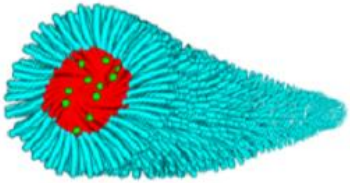
Neurofilament



5 - 20 micron length
12 nm in diameter
~ 220 nm persistence length

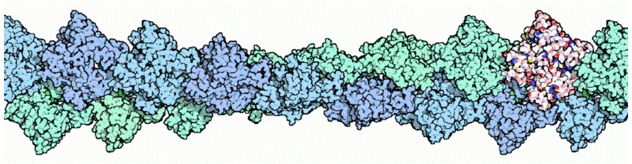
Wormlike Micelle

(polybutadiene-polyethyleneoxide)



10 – 50 micron length
~ 15 nm in diameter
~ 500 nm persistence length

Actin



2 – 30 micron length
7-8 nm in diameter
~ 16 micron persistence length

Architecture (molecular structure)