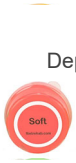
03 Linear Viscoelasticity: Hands-On Data Interpretation



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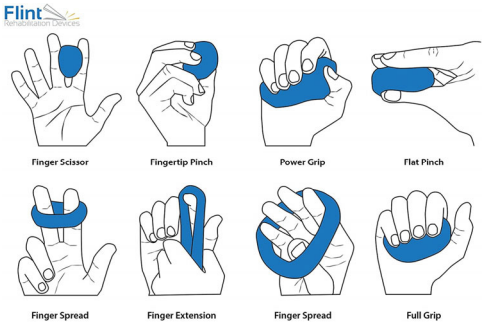
extra-soft soft medium medium-firm firm extra-firm

Reference:

Corman, R. E., and R. H. Ewoldt,
"Mapping linear viscoelasticity for design and tactile intuition,"
Applied Rheology, 29 (1):141–161 (2019).
https://doi.org/10.1515/arh-2019-0013
(Open Access)

Therapy Putty

(compare two putties: “Soft” versus “Firm”)



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What is different (rheologically) between putties?

Push, pull, bounce,…is difference Viscous? Elastic? Relaxation timescale?

Source (images & data):
Thera-Flex therapy putty

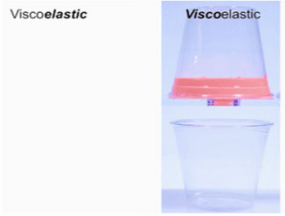
Source (2021 putty samples):
Therapy Putty from Flint Rehabilitation Devices, LLC

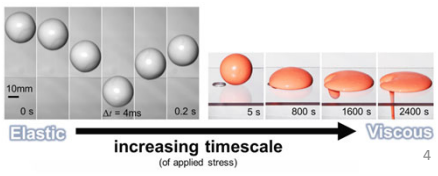
What rheological test would measure this?

What deformation? (shear, extension, …)

What is controlled input? (strain, strain-rate, stress, …)

Scheduling of input (step, oscillation, …)





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Actual material functions

RESULTS

Results to be shown *after* your hands-on 'do it yourself rheometry' session

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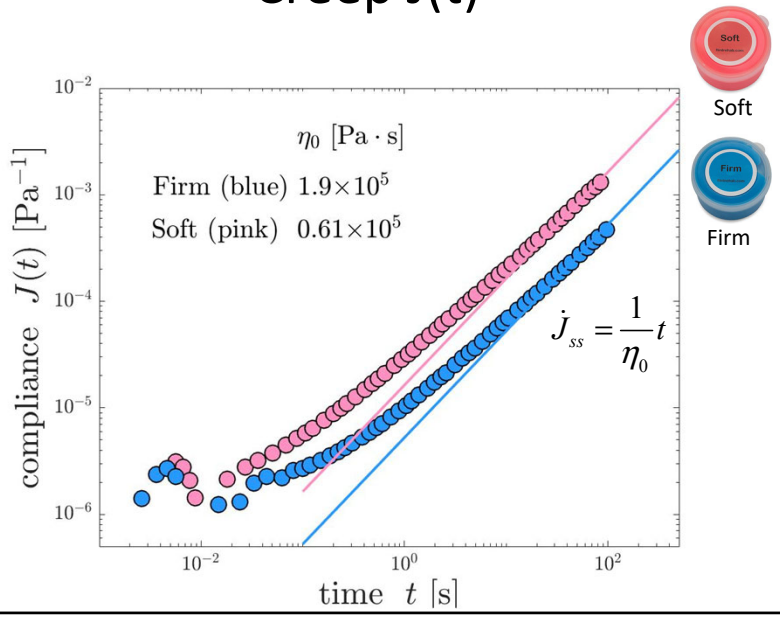
Data from Yilin Wang (Illinois)
August 2020

Creep J(t)



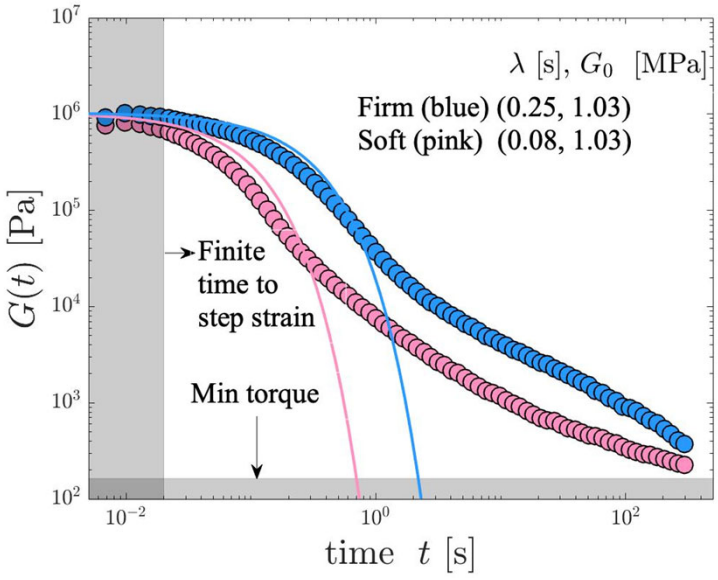
Soft

Firm

Data from Yilin Wang (Illinois)
August 2020

Stress relaxation $G(t)$

(with Maxwell model fit: not perfect!)



Firm

Soft

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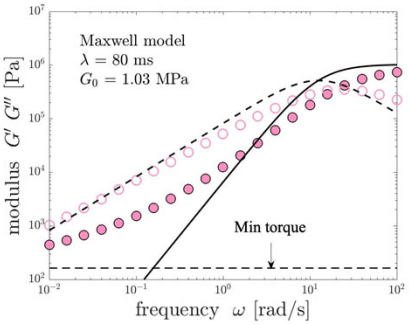
Data from Yilin Wang (Illinois)
August 2020

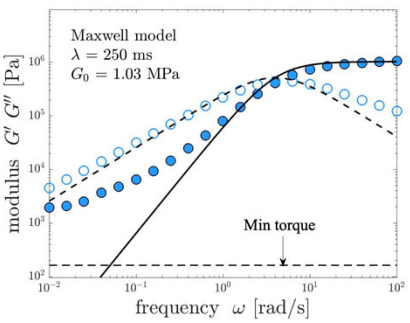
Oscillation: Dynamic Moduli

(with Maxwell model fit: not perfect!)

Soft



Firm



Plateaus from Dynamic Viscosity & Modulus

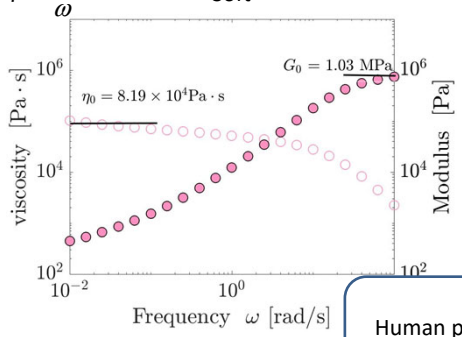
Can be used to evaluate an 'average' timescale from a broad distribution:

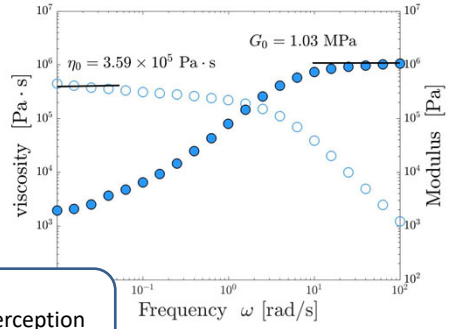
$$\tau_1 = \frac{\eta_0}{G_0}$$

$$\eta' = \frac{G''}{\omega}$$

Soft

Firm





$$\tau_1 = \frac{\eta_0}{G_0} = 0.08 \text{ s}$$

Human perception limits at short times?

$$\tau_1 = \frac{\eta_0}{G_0} = 0.349 \text{ s}$$

Soft

Firm

$\tau_1 = 80$ ms

350 ms

Table 1: Perception limits relevant to human handling of putties and gels. See text for details.

	Min & Max	Comments
Stress (tactile)	200 Pa 50 kPa	Light touch [78, 79] Hand grip strength [80, 81]
Time (tactile)	200 ms 10 min	Neuro-muscular max frequency [82, 83] ← Patience while squeezing
Time (visual)	13 ms -	Visual comprehension [84] Patience while observing

Note: "blink of an eye" is even longer:
572 ± 25 ms (faster closing than opening)
Kwon et al. (2016)
https://dx.doi.org/10.1098%2Frsif.2013.0227

Corman, R. E., and R. H. Ewoldt,
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Given: Two different "putties"
Find: Feel difference, describe in terms of material functions (Elastic? Viscous? Timescale?)
<u>Solution: Viscous resistance (& maybe timescale, but < 0.35s)</u>

Putty	G_0 (Pa)	η_0 (Pa.s)	τ_1(s)
Soft	1.03×10^6	0.82×10^5	0.080
Firm	1.03×10^6	3.59×10^5	0.349

Soft

Firm

Recall:
200 ms is neuro-muscular maximum frequency.

Thus, cannot feel elastic modulus G_0 of soft putty.
But can feel a difference in *viscosity* η_0 at $t > \tau_1$ for each.

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Intuition Unlocked!

Modulus & Viscosity

Soft

Firm

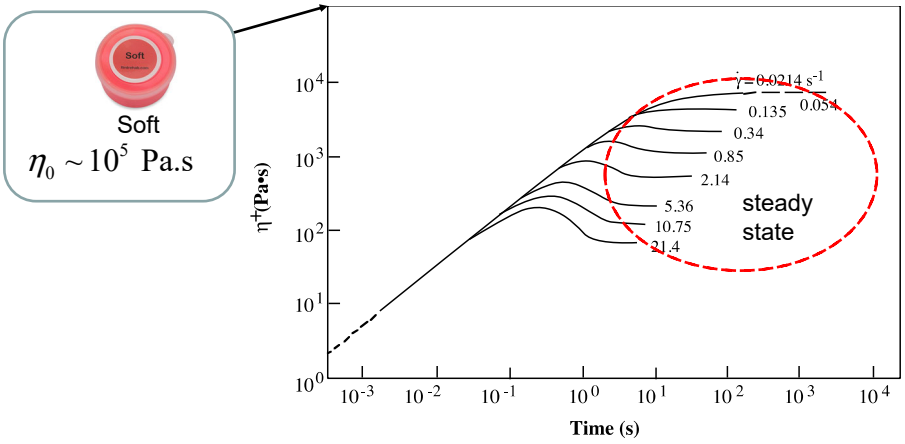
$G_0 \sim 1$ MPa 1 MPa

$\eta_0 \sim 10^5$ Pa.s $(\text{few}) \cdot 10^5$ Pa.s

Examples of how to use this intuition?

From Introduction (viscosity example)

Viscosity also depends on time of shearing (strain)



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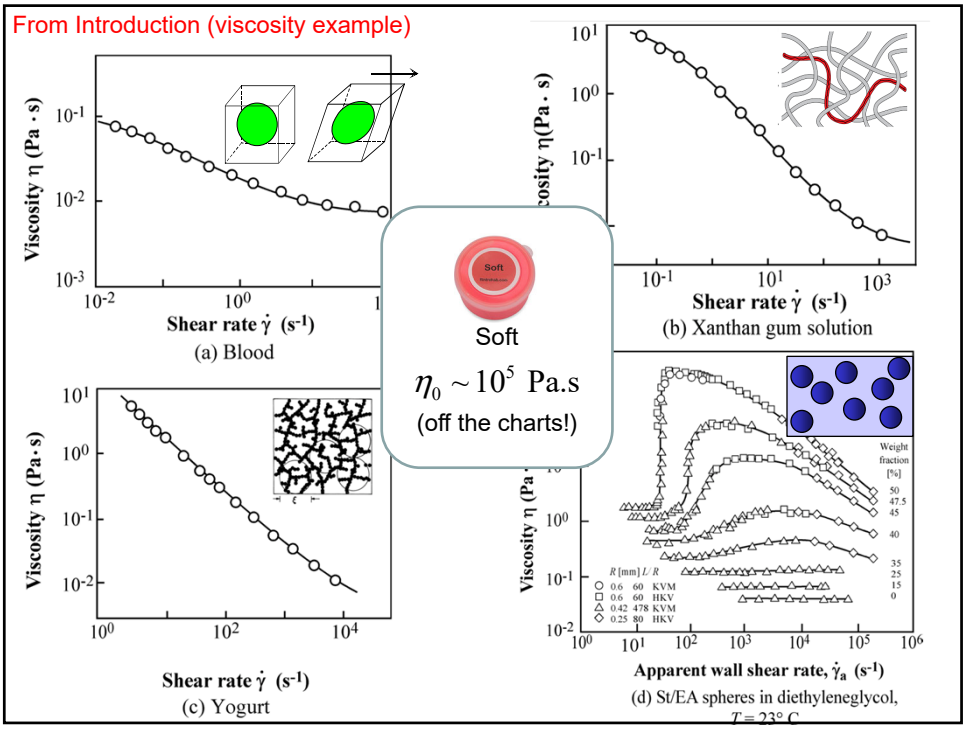
From Introduction (viscosity example)

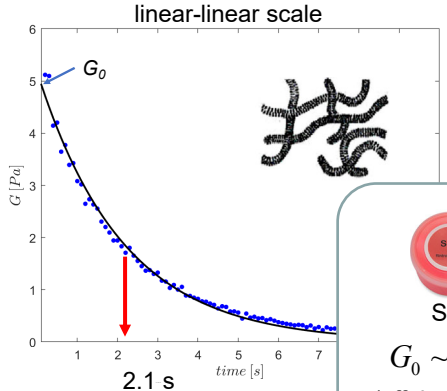


From Introduction (modulus example)

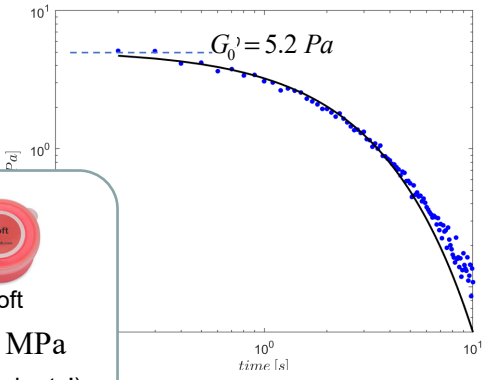
$$G(t) = G_0 e^{-t/\tau}$$

fits relaxation of surfactant with worm-like micelles

linear-linear scale



log-log scale



Soft

$G_0 \sim$ MPa

(off the charts!)

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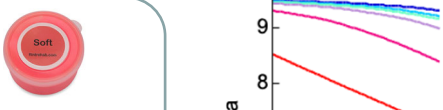
From Introduction (modulus example)

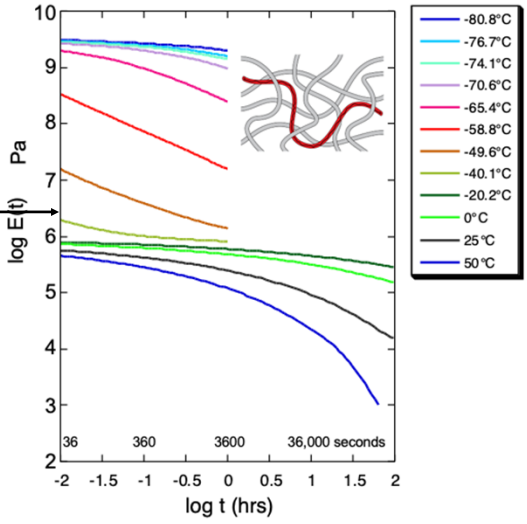
Stress relaxation modulus for PIB (polyisobutylene)



Soft

$G_0 \sim$ MPa

$E_0 \sim$ (few) MPa



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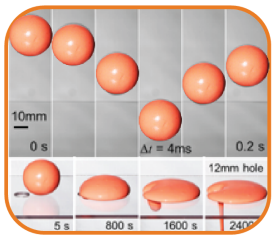
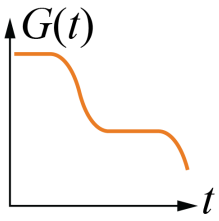
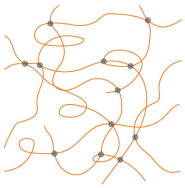
Ferry *Viscoelastic Properties of Polymers* 1980

Summary

Typical workflow of a rheologist:
observe evidence, choose rheometric test(s), think about it

evidence	material function	microstructure
		
visco-elasticity	stress relaxation modulus	transient polymer network

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