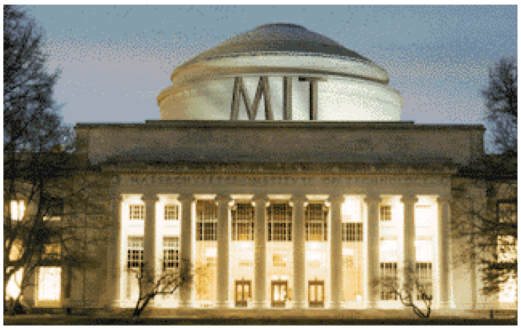
Aging and Shear Rejuvenation

McKinley Group Summer Reading Course
2006

Monday 3rd July

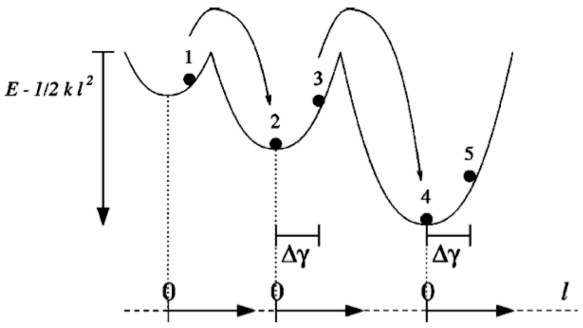


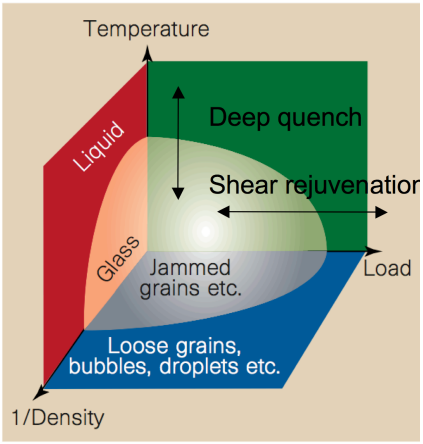
Outline

- Basic Ideas
- Experiments on Microgel Pastes
- Some experiments on dough systems

Shear-3temperature equivalence and SGR model

- Trap jumping
- What are the initial conditions?
- Annealing and deep quench - impractical.
- In practice shear rejuvenation is usually used. Apply a large strain with moderate to high shear rates to “erase” all memory.
- Need to include additional physics to account for shear rejuvenation?
- Specifically, what is this equivalent temperature *x*?

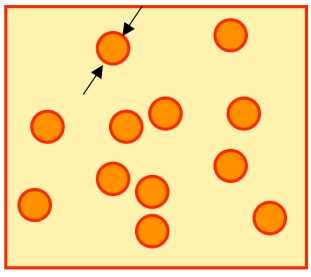




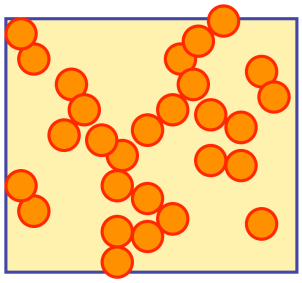
Structure of Microgel Paste

- Cross-linked acrylate chains

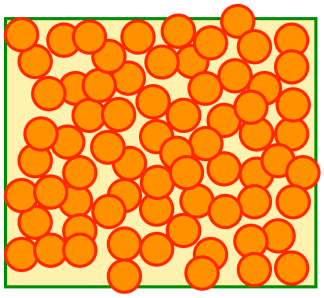
200nm



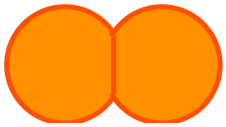
1. Sol state. Low viscosity, fluid behavior.



2. Gel state. Sample spanning structure is formed. Solid like behavior at low strains. (i.e. apparent yield stress)

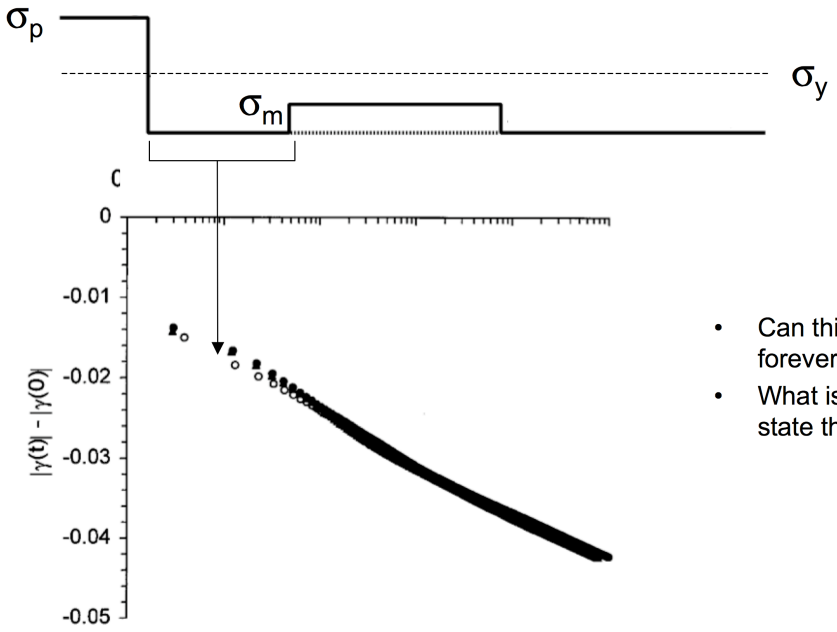


3. Paste state. A concentrated suspension. Particles are able to adapt their volume and shapes to steric constraints.
   - Flat facets can develop at contacts
   - Internal structure of pastes are instrinsically disordered and metastable



Logarithmic Relaxation

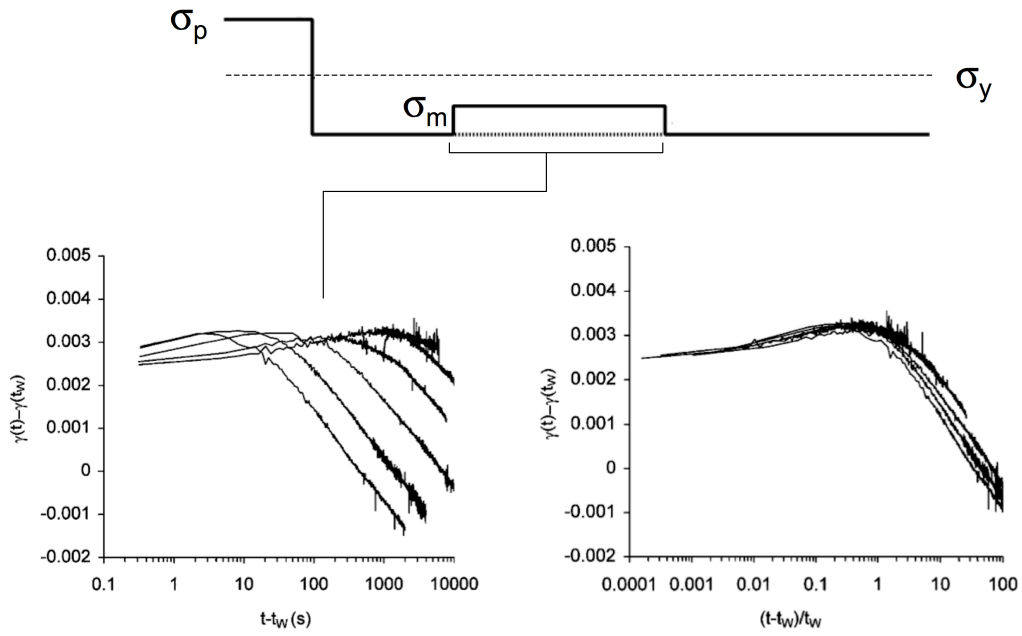
- Relaxation after steady state flow.
- Dubious logarithmic relaxation.



- Can this go on forever?
- What is the steady state then?

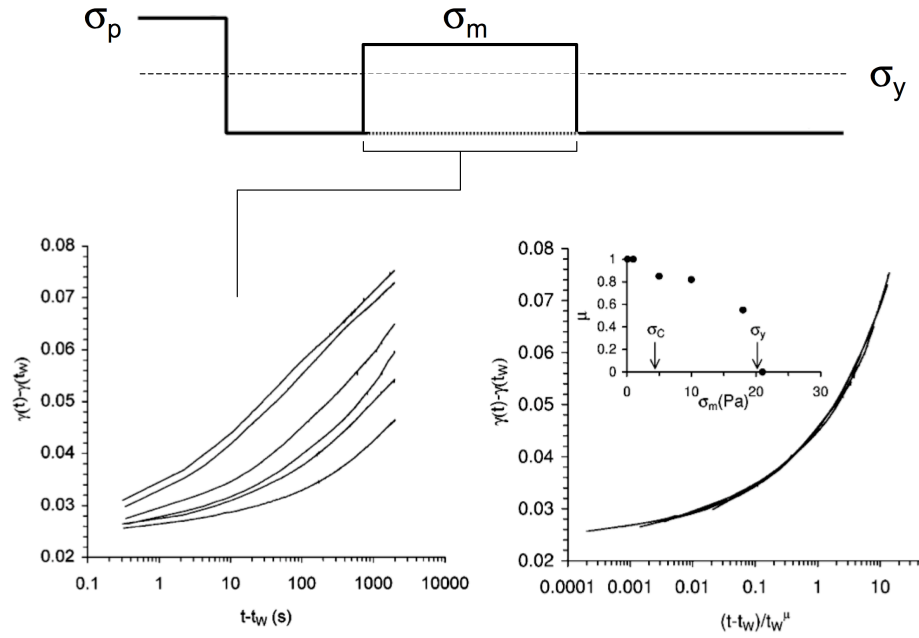
Creep test - linear regime

- Creep test in the linear regime shows typical full aging type of scaling.



Creep test - Non-linear regime

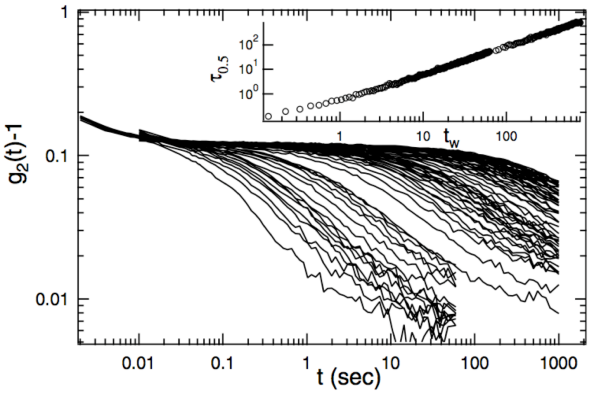
- Apply shear stress greater than the yield stress, so that sample flows.



Rejuvenation through oscillatory shear

- Viasnoff et al 2002.
- Multispeckle Diffusing Wave Spectroscopy (MSDWS)
- $g_2(t_w+t,t_w)$ is a decreasing function of the number of rearrangements occurred between t_w and t_w+t.

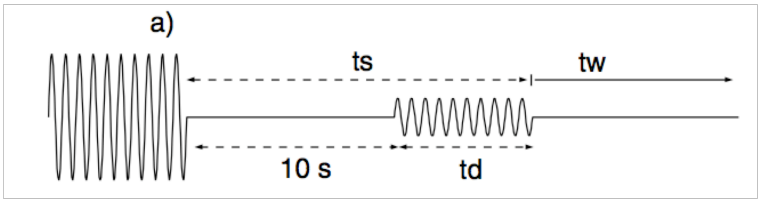
- Short time scale rearrangement
- Corresponding to restricted thermal fluctuations of the particles.
- β modes are independent of t_w



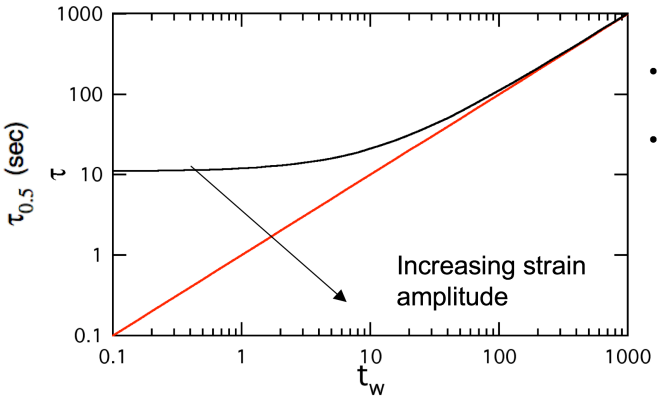
- Long time scale rearrangement.
- Structural rearrangements
- α modes.
- Time scale of th order of waiting time. (inset)

Partial Rejuvenation

- A minimum shear amplitude is required for complete rejuvenation of the sample.
- Below the critical amplitude, only partial rejuvenation is achieved.



- Two limiting case
- $\gamma = 0$. No rejuvenation. Curves are simply shifted by t_s.
- $\gamma > 0.2$. Complete rejuvenation.



- Partial rejuvenation.
- All curves converge because of log scale.

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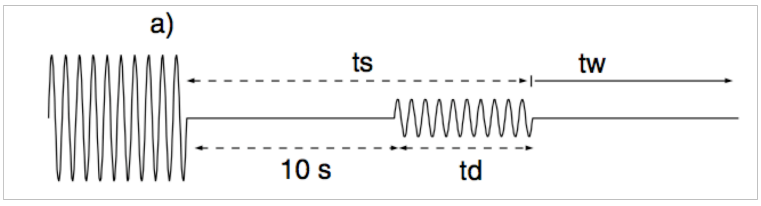

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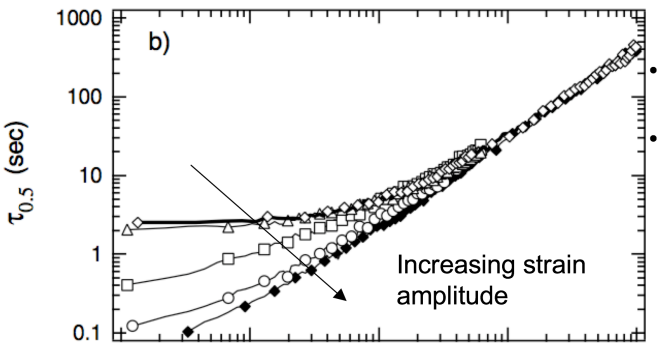

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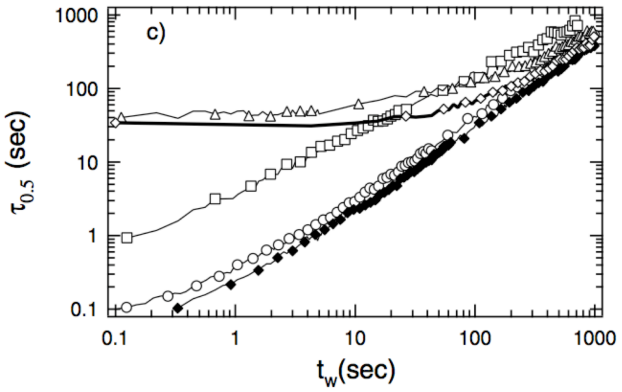
- All curves converge because of log scale.

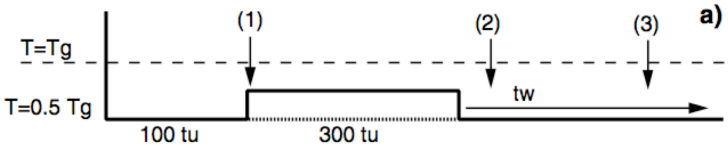
Property of MIT/Kraft

Overaging

- If the duration of shear td is prolonged, for intermediate shear amplitude shows an increase in α mode relaxation.
- This is referred to as overaging.
- A clear illustration of two system with the same relaxation time but different strain history can age in different manners.

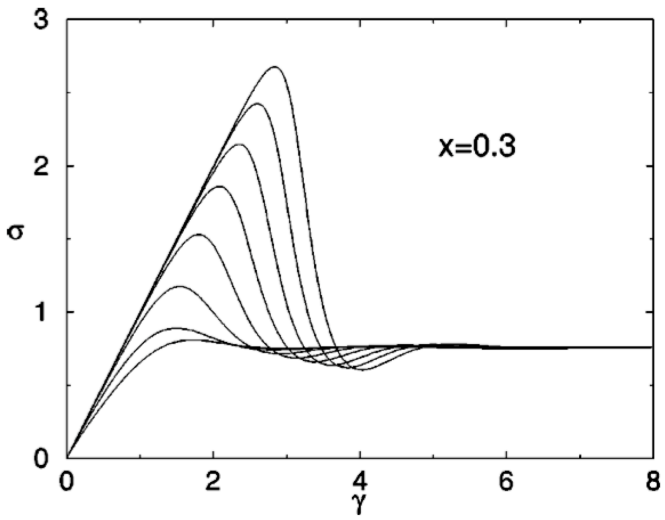


- Increase in relaxation time (Overaging)
- C.f. a purely thermal system.
- Shear can increase activity slightly and speed up the aging process.



Is complete rejuvenation necessary?

- From an experimental point of view, complete rejuvenation might not be necessary.
- Sample can be simply returned to some reproducible initial conditions.

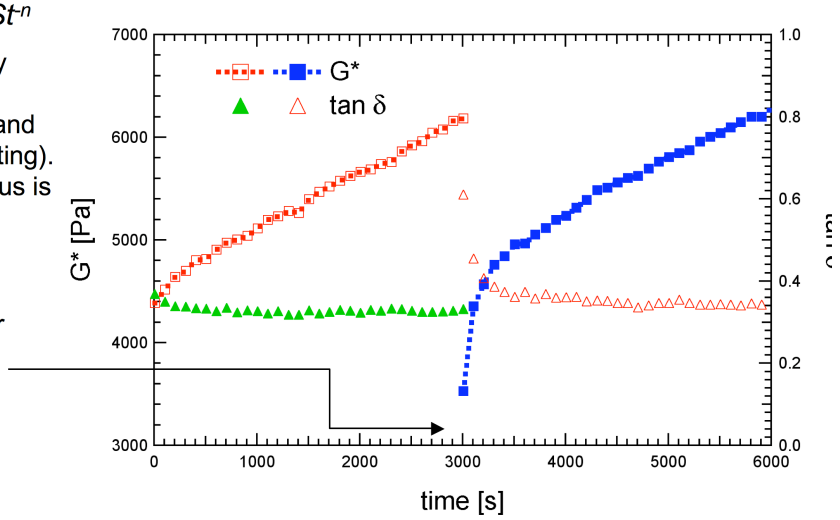


- Steady state is achieved
- Will rheological behavior be reproducible if sample is deformed for a significant period of time under steady state?

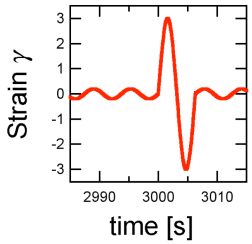
Rheological Ageing

- The stiffness of dough changes even under rest conditions.
- This increase of stiffness can be reversed by applying a large deformation ("reset the internal clock").
- Recall $G(t)=St^{-n}$

¬ dough left in geometry overnight,
¬ edges remained soft and moist (silicone oil coating).
¬ the increase of modulus is **not** a result of drying.



A large oscillatory shear $\gamma = 3$ was applied at $t = 3000$s



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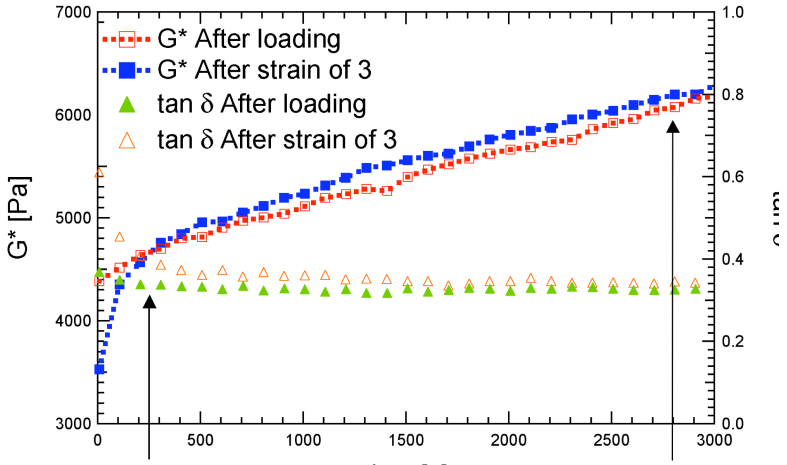

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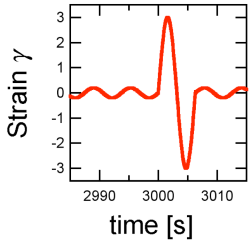
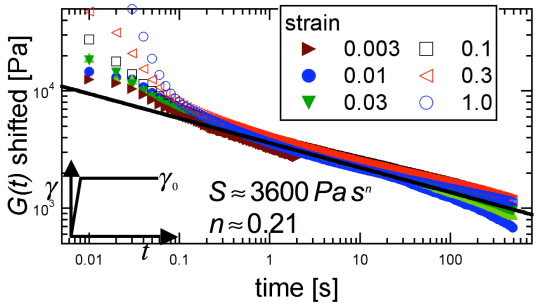


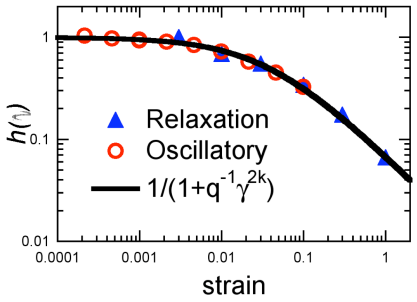
The moduli recover on time scale of ~ 10^2 s. Difficult to probe - require deformation without disturbing the stiffening process.

Moduli of dough increase at ≈ 0.4 Pa/s, while the phase angle remains constant.

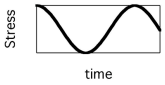
Aging in dough

- Dough exhibits a power-law like relaxation over significant time span ($0.1 \le t \le 200$s).
  - This is similar to the **critical gel** equation suggested by *Winter and Chambon*.
    - See also Gabriele et al., *Rheol. Acta* **40** 2001.
- At moderate strains $\gamma \sim 0.05$, non-linear strain-softening behavior occurs.





$$G(\gamma_0,t) = \frac{\tau_{xy}(t)}{\gamma_0} = St^{-n}h(\gamma_0)$$



We can transform between step stress relaxation and *small* amplitude oscillatory shear:

$$G'(\omega) = \frac{G''(\omega)}{\tan(n\pi/2)} = \Gamma(1-n)\cos\left(\frac{n\pi}{2}\right)S\omega^n$$