Shear-thickening and the glass transition

Mauro Sellitto, Jorge Kurchan

PMMH-ESPCI, Paris
jorge@pmmh.espci.fr
http://www.pmmh.espci.fr/∼jorge

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Viscosity changes induced by stirring

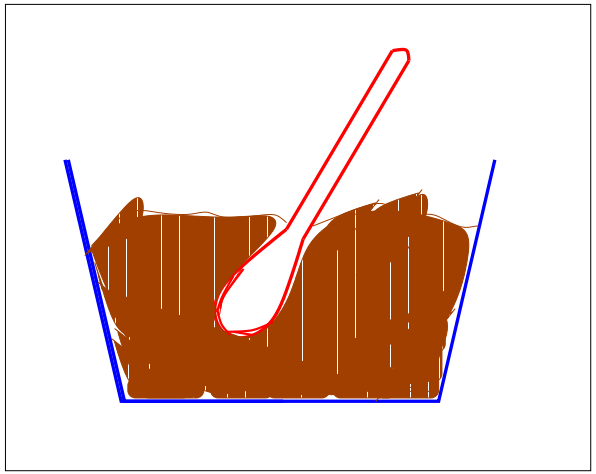
- Shear thinning: blood, paint, ...
- Shear-thickening: corn-starch, talcum mixtures with water.

Structures responsible for viscosities to break upon stirring (i.e. the spatial correlations tend to decrease)

The system tends to move in phase-space, thus becoming more agile

Not surprisingly, shear-thinning is the rule, and shear-thickening the exception

Stirring-induced glass transition Bertrand, Bibette and Schmitt, PRE (2002): BiOCl + poly(sodium acrylate)



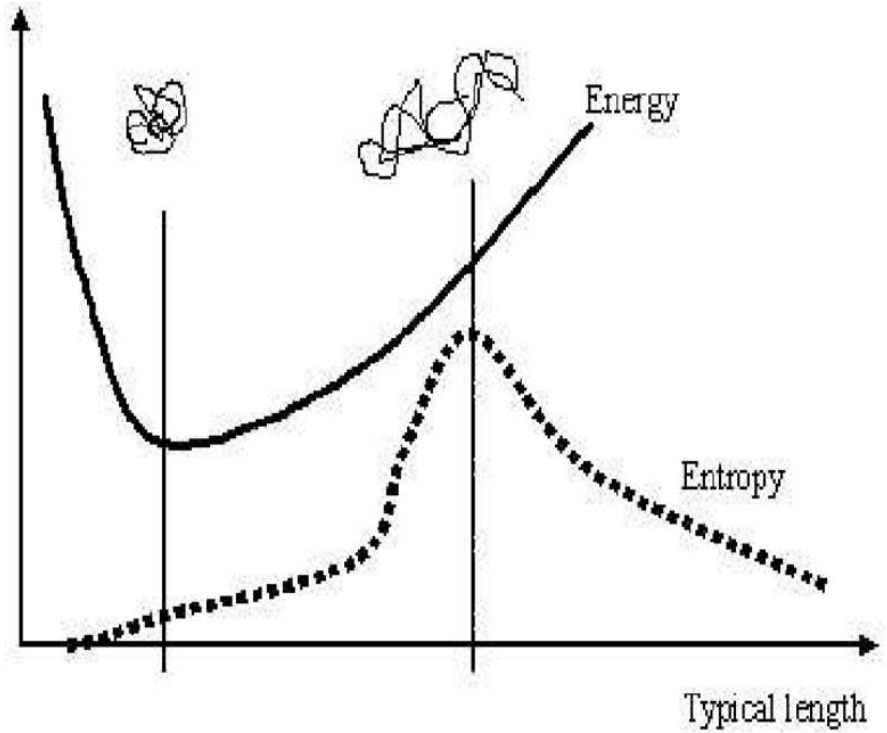
- A theory of (at least this form of) shear-thickening must also be a theory of the glass transition
- To be credible, a theory of the glass transition must naturally incorporate the generic shear-thinning (rejuvenation) phenomena, but also explain when and how shear-thickening happens.

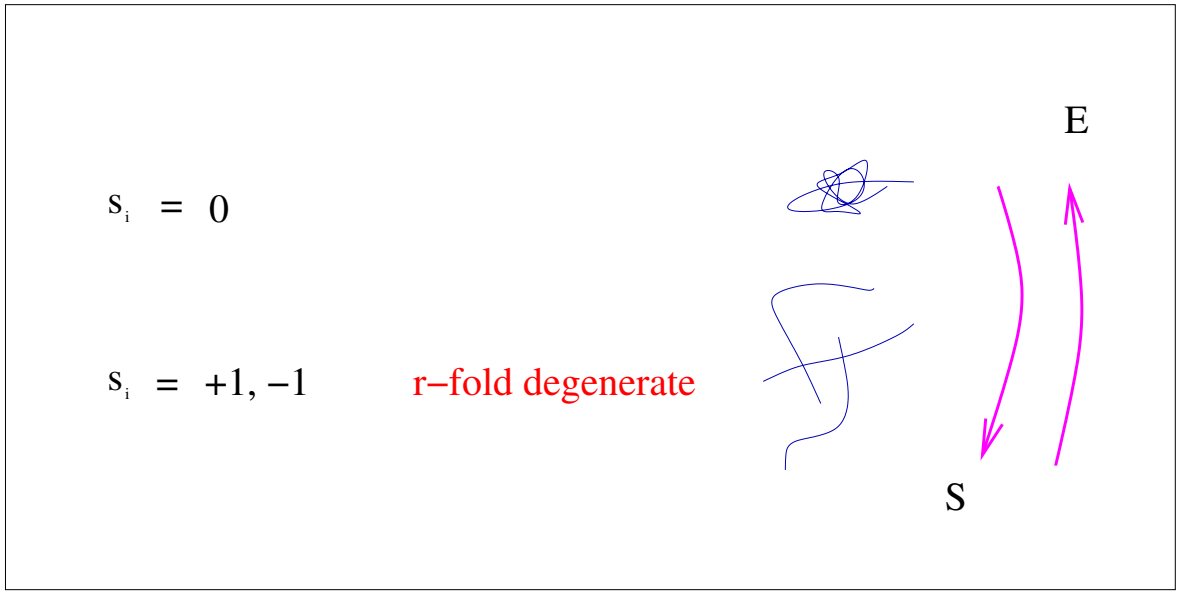
Holmes, Fuchs, Cates, Sollich, Haw: phenomenological theory in the Mode-Coupling format.

Inspiration

A scernario for phase-reentrance: Schupper and Shnerb (2004).

Methyl cellulose in water





$$E = \sum_{ij} J_{ij} s_i s_j + D \sum_i s_i^2$$

disordered interaction + *folding term*

Stirring can play a role similar to entropy

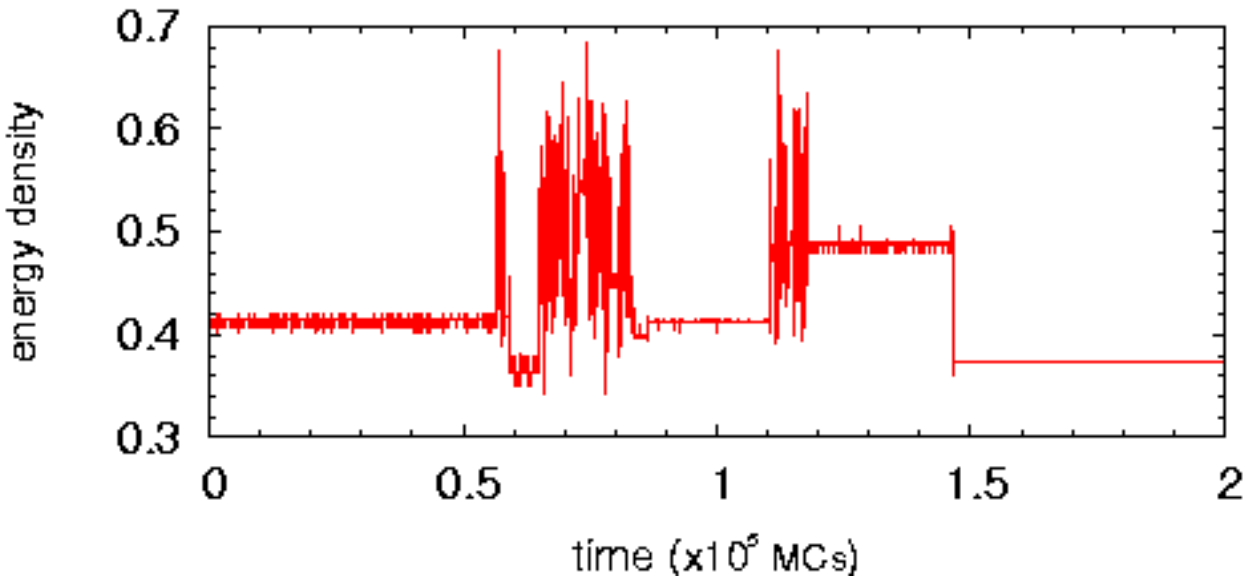
e.g. unfolding polymers (de Gennes (1974))

for example, in this simple model:

$$f_i = \sum_j J_{ij} s_j + 2D s_i + \sigma f_i^{non-conservative}$$

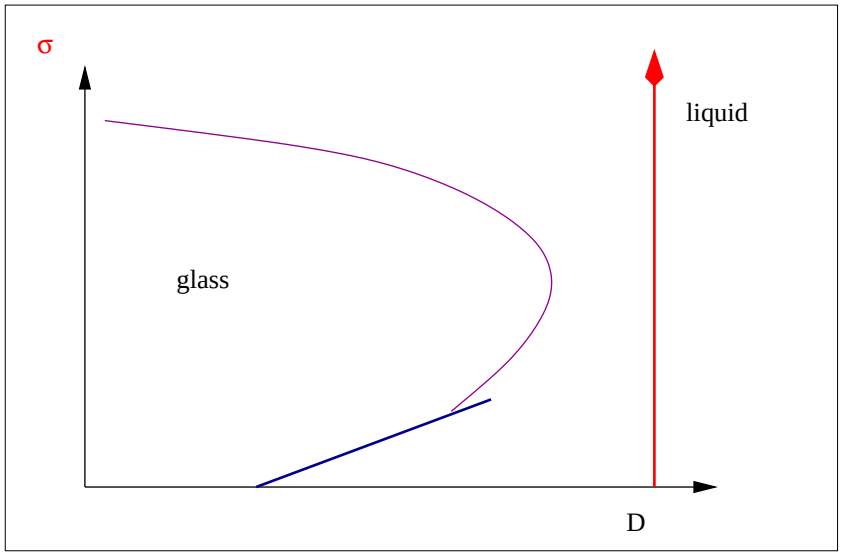
where $f_i^{non-conservative}$ are forces that do not derive from a potential and hence do work.

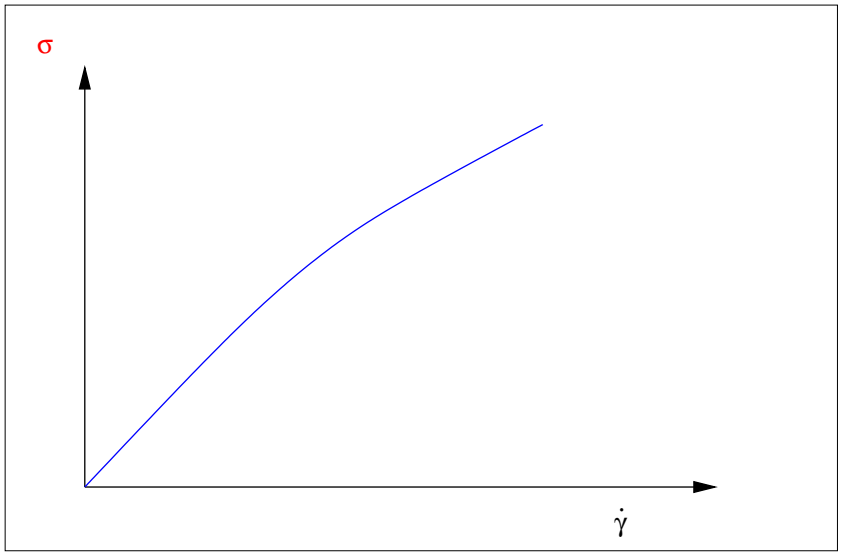
Jamming with aging



PHASE AND FLOW DIAGRAMS

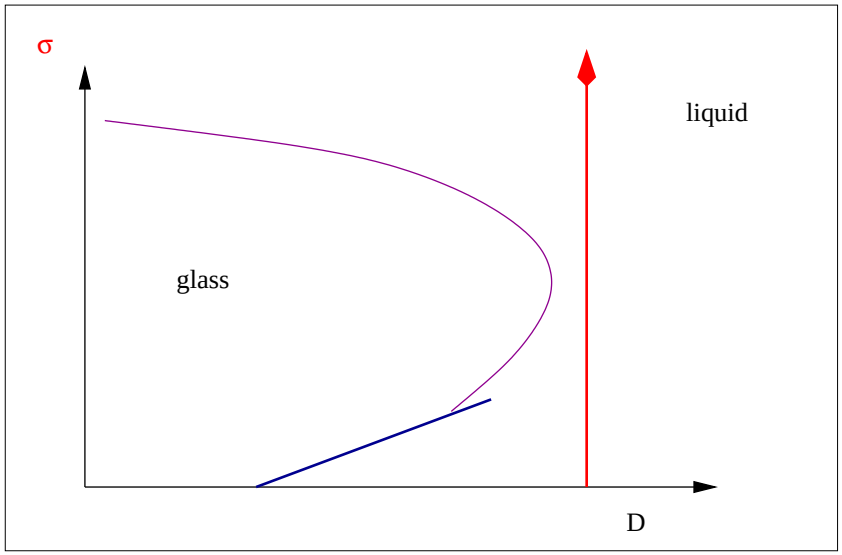
Shear Thinning

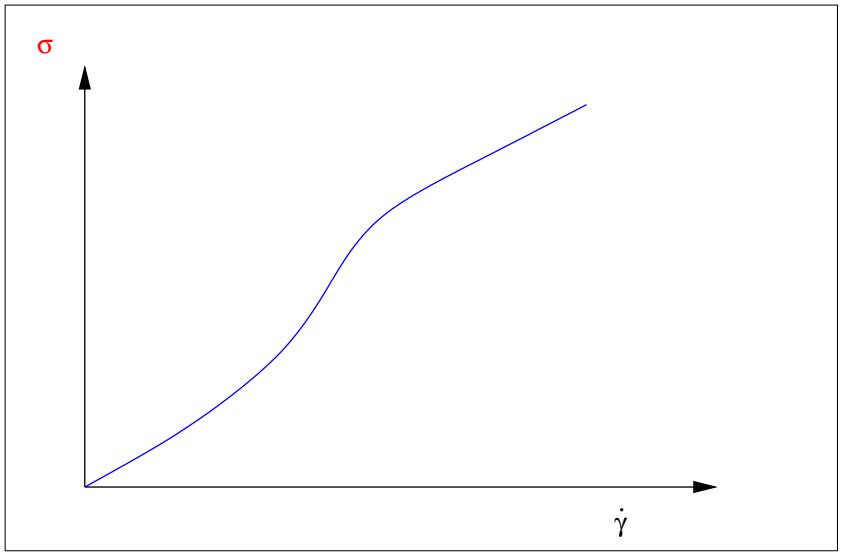




PHASE AND FLOW DIAGRAMS

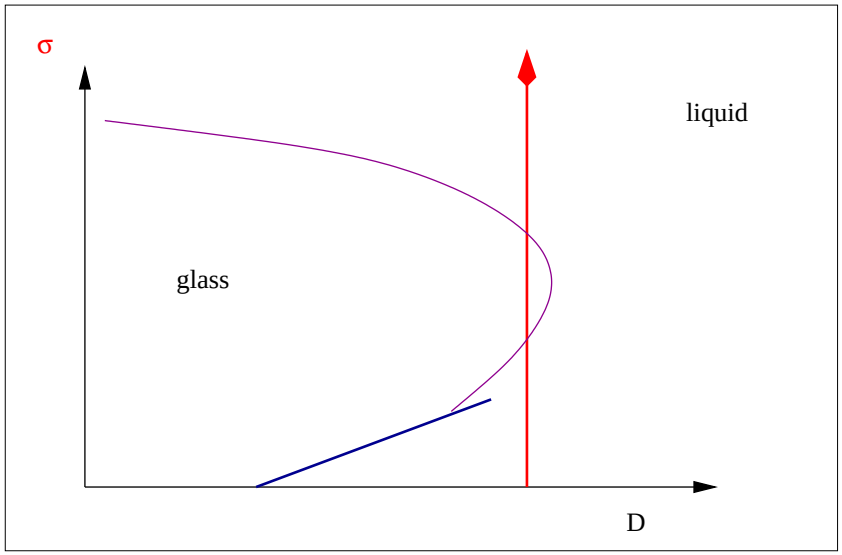
Shear Thickening

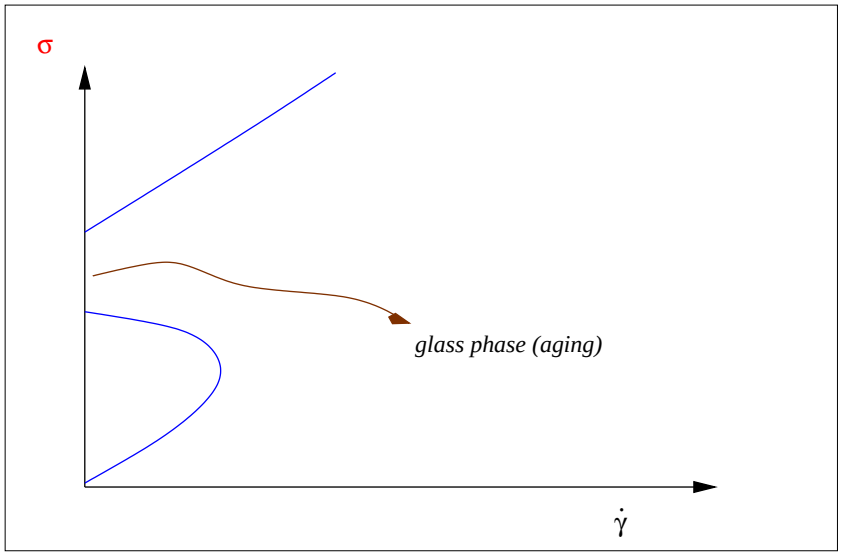




PHASE AND FLOW DIAGRAMS

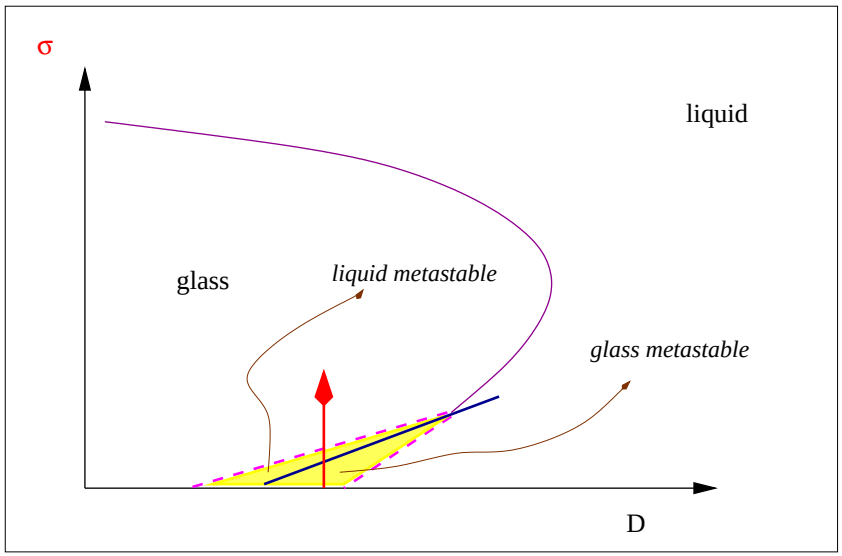
Second order jamming





PHASE AND FLOW DIAGRAMS

First-order jamming

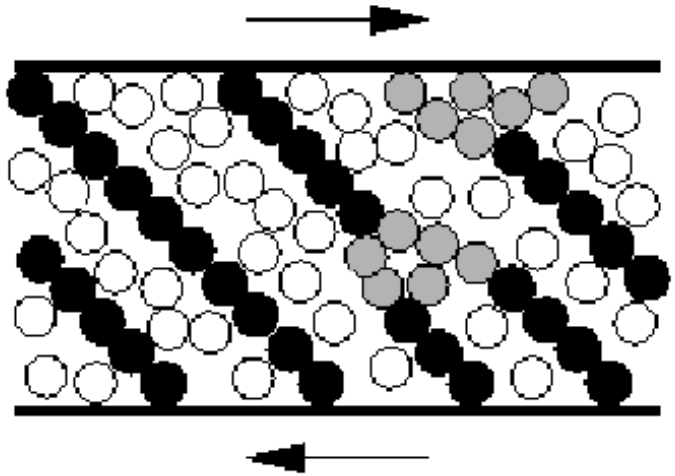


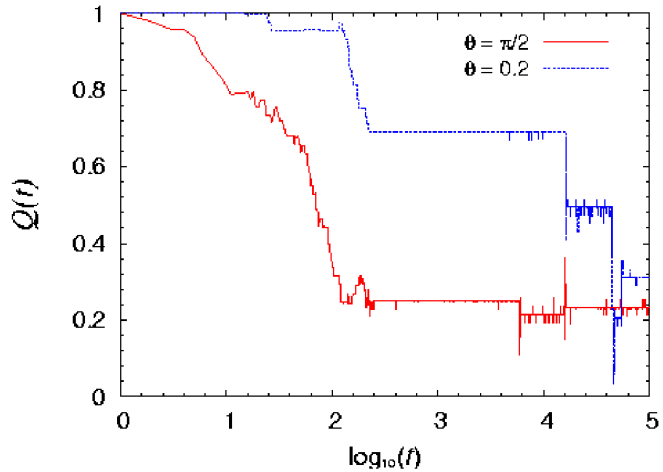
hysteresis

metastable liquid and metastable glass

first order ... see Bertrand et al.

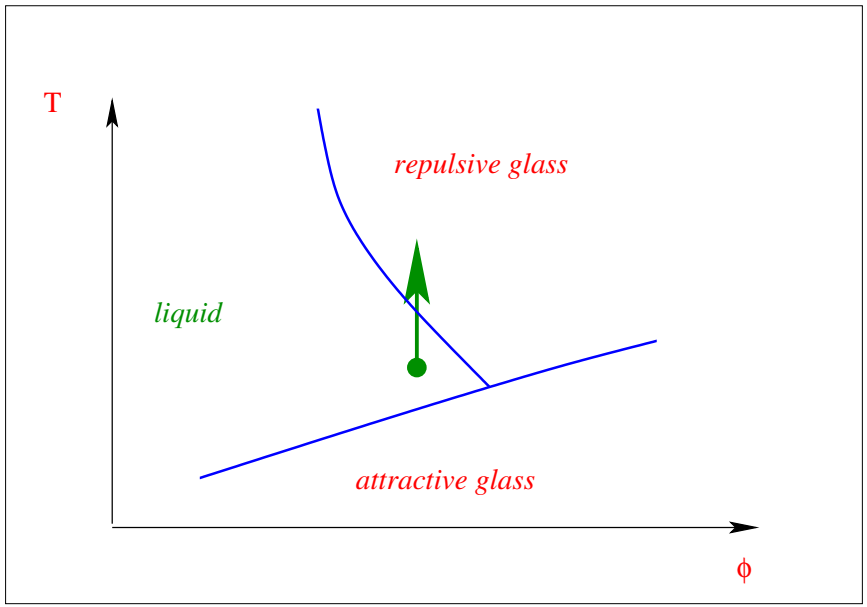
Force-chain rearrangements [Cates et al. PRL (1998)]: stirring force changes bring about force-chain rearrangements. very small changes still induce rearrangements, but these happen slowly.





Some predictions

- Metastability and hysteresis
- Force-chain rearrangements
- Intermittent behaviour [W.J. Frith et al., J. Rheol. (1996)]
- attractive colloids:



Reichman et al.