FRUSTRATED STATES OF MATTER – GLASSES

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FRUSTRATION – What does it mean?

Definition from http://www.merriam-webster.com

FRUSTRATION:

1. the act of **frustrating**
2. **2 a:** the state or an instance of being **frustrated**

    2 b: a deep sense of dissatisfaction arising from unfulfilled needs

3: something that **frustrates**

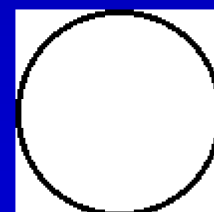
For example:

- I'd like to own a Ferrari but I don't
- I'd like to be able to bat better than Dhoni but I don't
- I'd like world peace, but no one will listen to me
- I'd like it if there were no board exams…
- I'd like to be at equilibrium

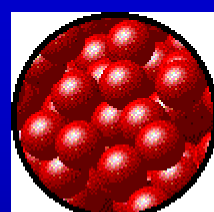
What are STATES OF MATTER?

Increasing temperature
Increasing internal energy

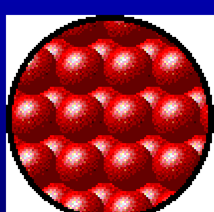
PLASMA



GAS



LIQUID



SOLID

Equilibrium States of Matter

Also, new more exotic states like Bose-Einstein/Fermion condensates

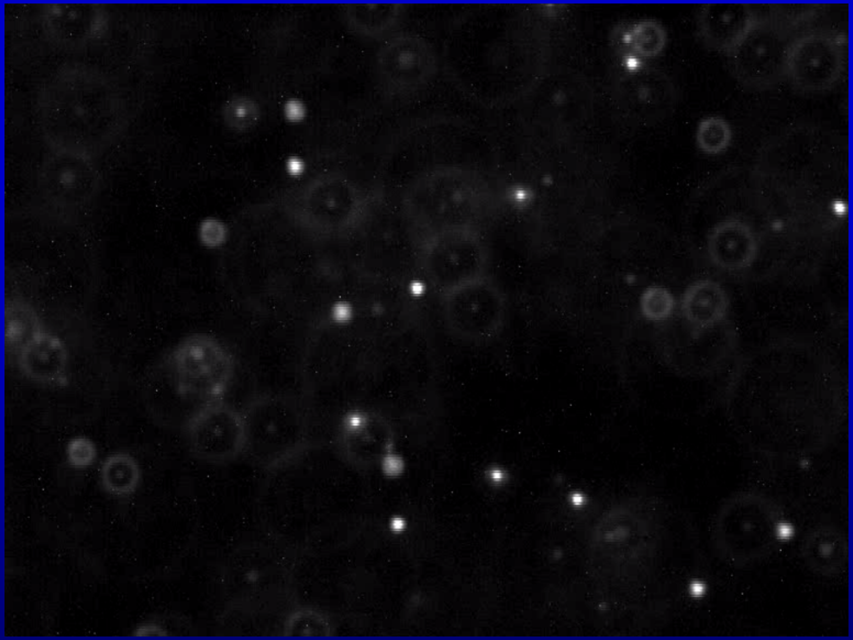
http://www.chem.purdue.edu/gchelp/atoms/states.html

Temperature

Temperature – Amount of motional energy for molecules (per degree of freedom)

– Defines the direction in which heat flows (from hot to cold)

The higher the temperature, molecules jiggle around more



Small particles, each about 1/1000 cm in water at room temperature – observed under a microscope

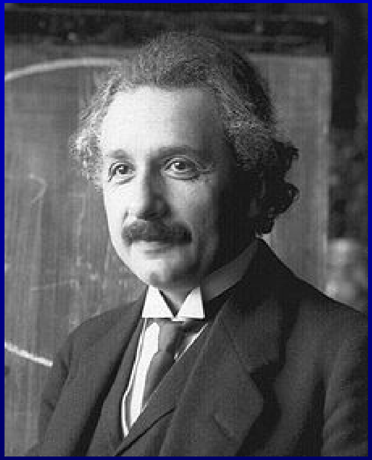
http://cs.princeton.edu/courses/archive/fall05/cos226

Temperature: Brownian motion

BROWNIAN MOTION – due to water molecules jiggling around and pushing the pollen grains (Robert Brown, Scottish botanist, 1827)

Brownian motion simulation

In 1905 (his INCREDIBLE year), Einstein explained Brownian motion – how much the particle moves depends on temperature. At higher temperature, higher diffusion.



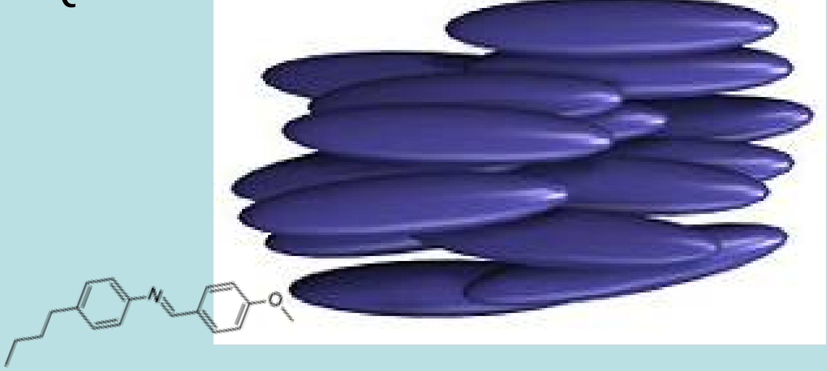
At ABSOLUTE ZERO, all motion ceases: 0 K = -273.15^{o}C

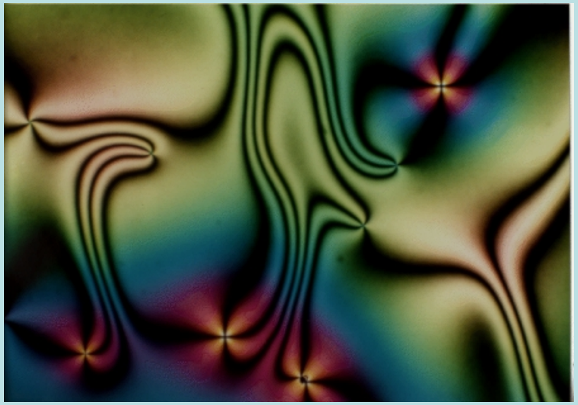
http://galileoandeinstein.physics.virginia.edu; http://www.wikipedia.org

Other States of Matter: Between Liquids and Solids

LIQUID

LIQUID CRYSTALS





AMORPHOUS SOLIDS – “GLASSES”

FRUSTRATED, OUT-OF-EQUILIBRIUM SYSTEMS

viz. they’re stuck in a disordered state and don’t like it

SOLID

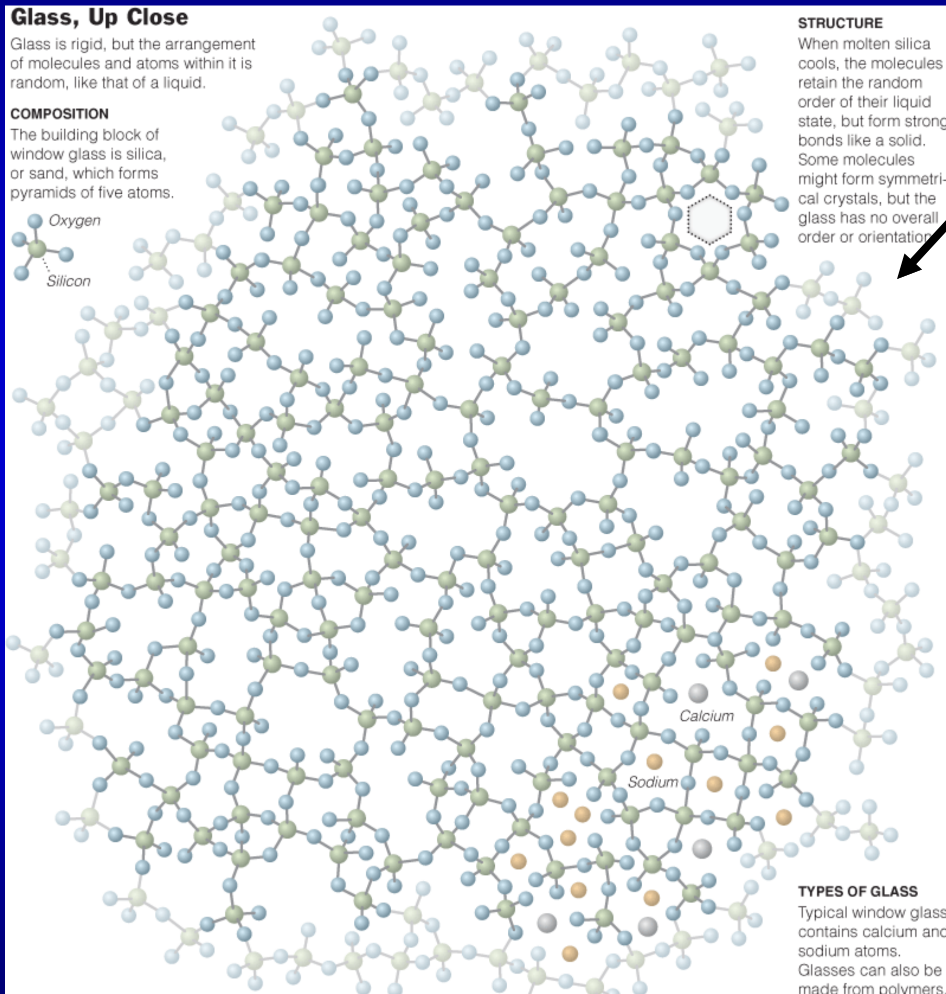
http://www.wikipedia.org/wiki/liquid_crystal

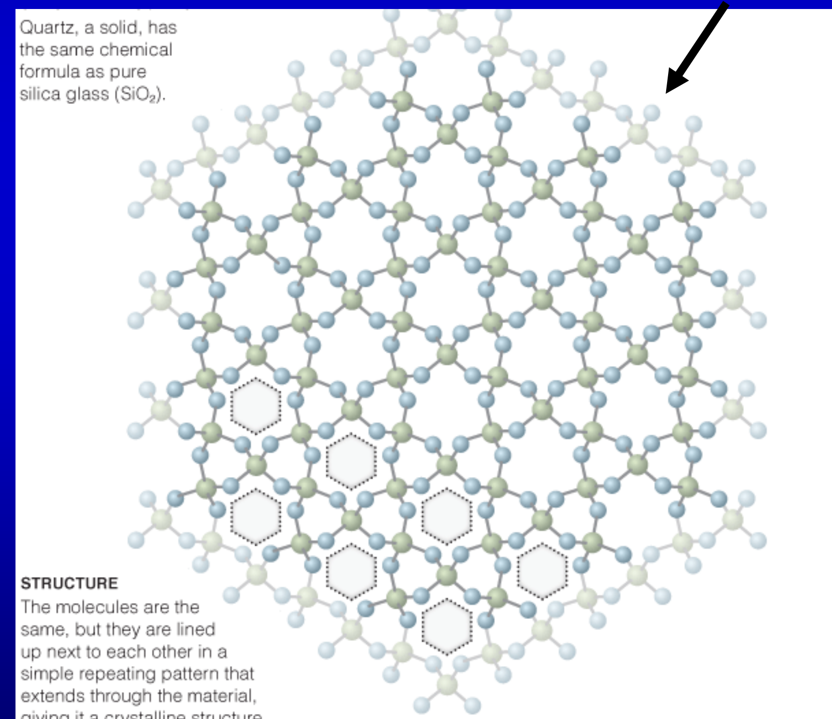
Glass: Window glass – Amorphous silica

Window glass

Spot the difference between these

Quartz





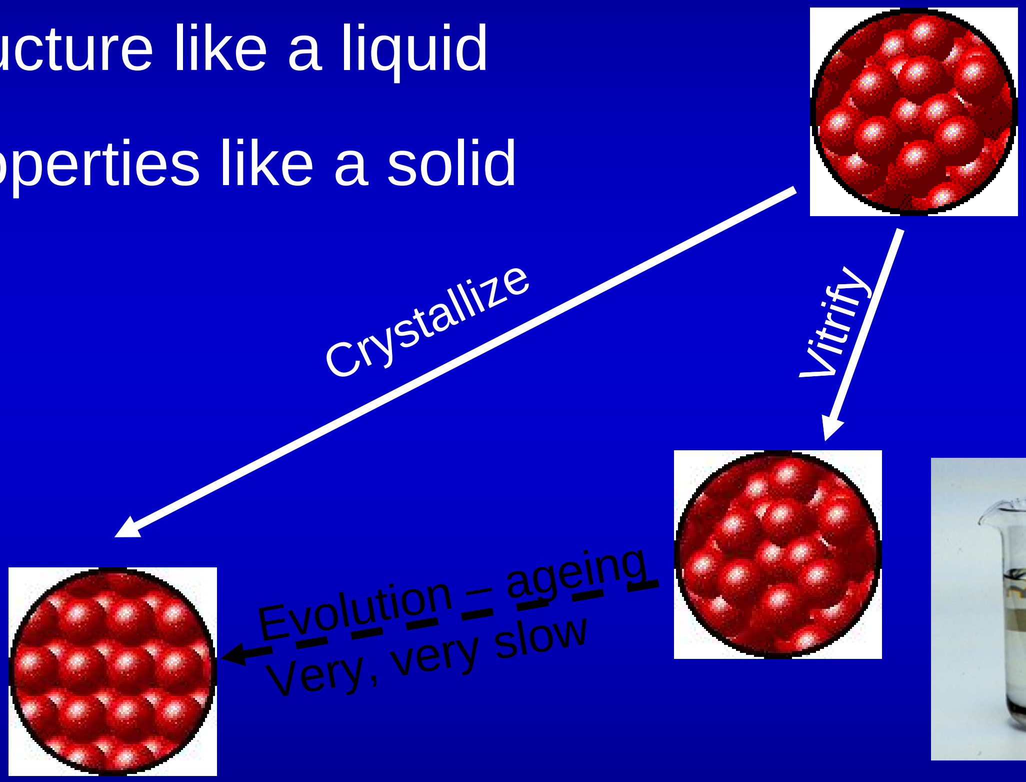
http://www.nytimes.com/imagepages/2008/07/29/science/20080729_GLASS_GRAPHIC.html

Glass – *SUPERCOOLED* liquid – Motions are frozen

GLASS

Disordered structure like a liquid

Mechanical properties like a solid



Beaker of glass (supercooled liquid) containing a “normal” liquid (water)

Glass – *SUPERCOOLED* liquid

As the temperature decreases, the atoms/molecules have lesser energy to move around. If the material is cooled very rapidly (*quench*), it is possible to prevent the formation of an ordered crystalline solid (*vitrification)*

On cooling: molecular volume decreases AND free volume (viz. space to wiggle) decreases

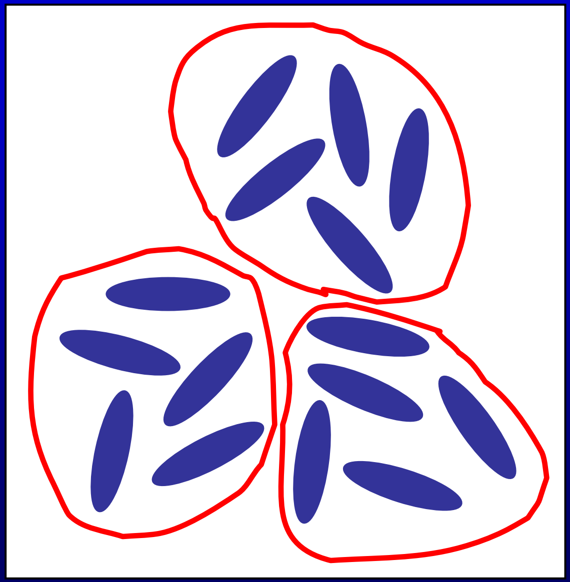
If free volume decreases very suddenly (rapid cooling), then no chance to move into a crystalline arrangement – “frozen” glassy system

In a glass, motions have to be co-operative

viz. you cannot move unless everyone around you cooperates and moves

We all know that cooperation is difficult

Flow becomes very sluggish

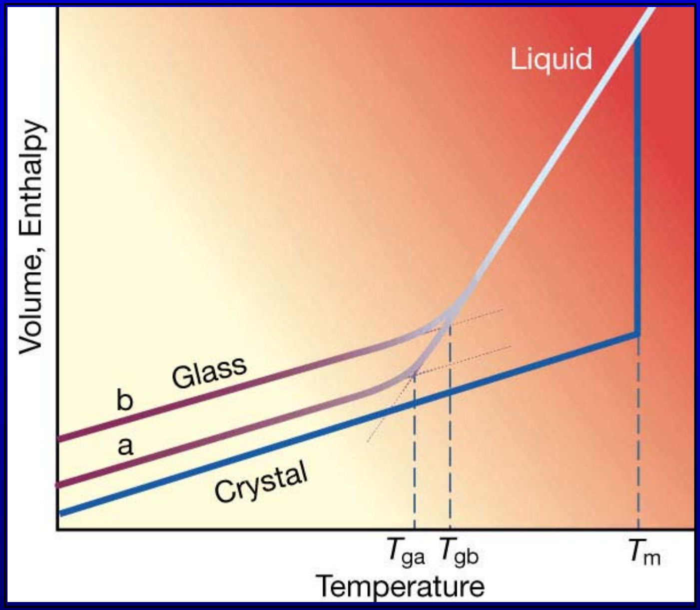


Glass

“Glasses are liquids whose molecules are so tightly packed, and hence are so sluggish, that they cannot relax to equilibrium even over periods of months or years”

Alternate definition of T_g: temperature at which viscosity = 10^{13} Poise

= million billion times viscosity of water



Change of specific volume is NOT discontinuous – NOT a first order PHASE TRANSITION (examples of first order transitions : melting, viz. solid to liquid; boiling, viz. liquid to gas)

Source: Debenedetti (Nature, 2000)

Other “glassy” materials

All polymers:

Polyethylene (plastic bags) – glass transition temperature, Tg < -100^{o}C

Rubber (in tyres, rubber bands) – Tg = -72^{o}C

PET (soft drink/water bottles) – Tg = 70^{o}C

Polycarbonate (20 liter water bottles) – Tg = 145^{o}C

Polystyrene (styrofoam) – Tg = 100^{o}C

Polymethylmethacrylate (Plexiglass) – Tg = 105^{o}C

Form glasses on cooling relatively slowly

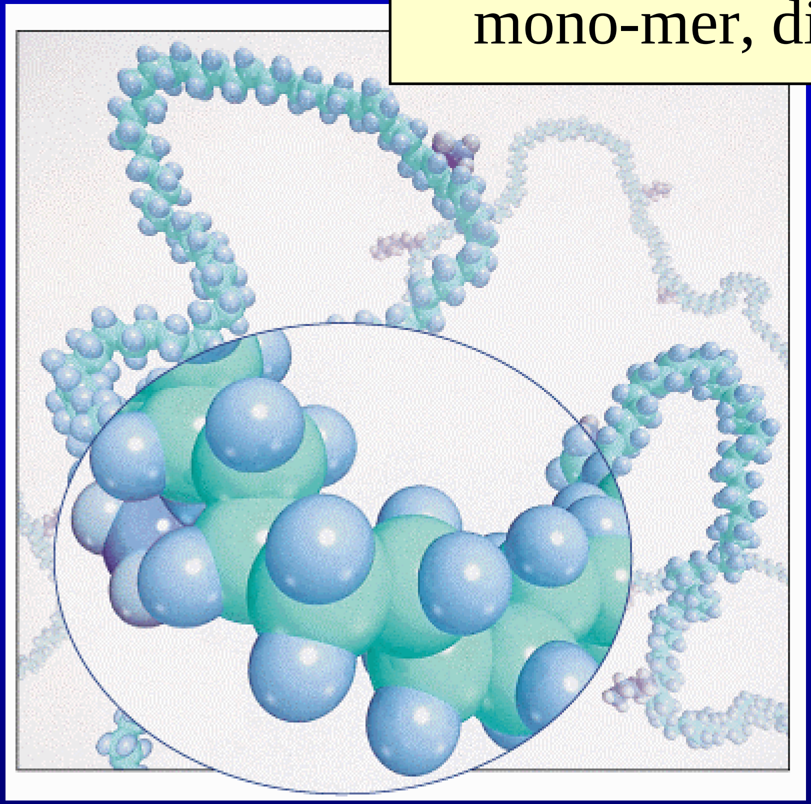
Silica (soda-lime glass) – Tg = 520 to 600^{o}C

Even water and metals can be vitrified – “splat” cooling at million ^{o}C/min

What is a polymer?

Long molecules made up of repeating units

mono-mer, di-mer, tri-mer ….. poly-mer



Staudinger

1953 Nobel Prize to Staudinger for *macro*molecular hypothesis

http://www.wikipedia.org

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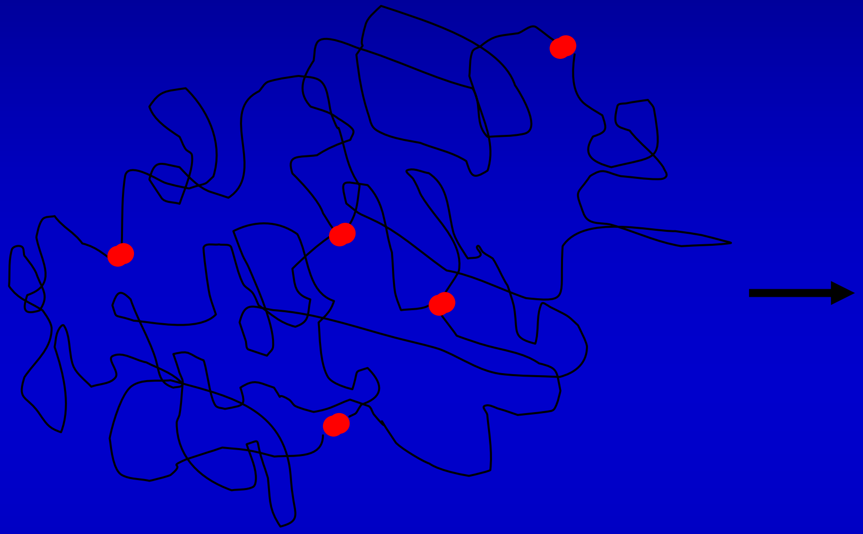
Change in properties at the glass transition

Rubber bands: polyisoprene (natural rubber)



Red balls (chemical crosslinks) connected by “springs” when the molecules are able to wiggle

Stretchy, elastic material

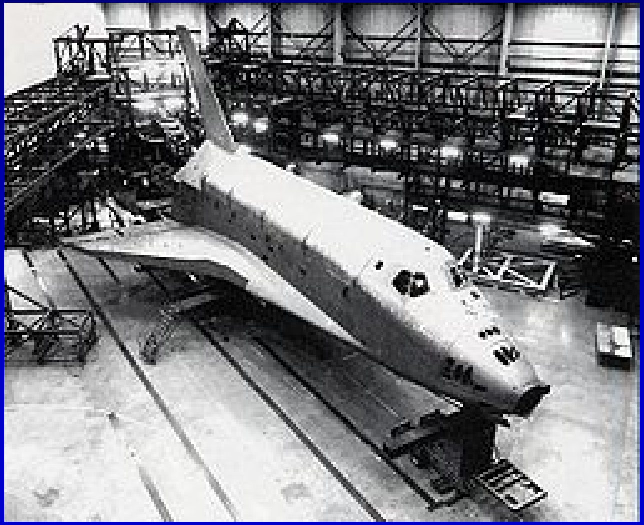
Tg = -72 to -75^{o}C

LET US DO AN EXPERIMENT

What happens to the properties of a rubber-band when we cool it to really, really cold temperatures (liquid nitrogen, -196^{o}C)?

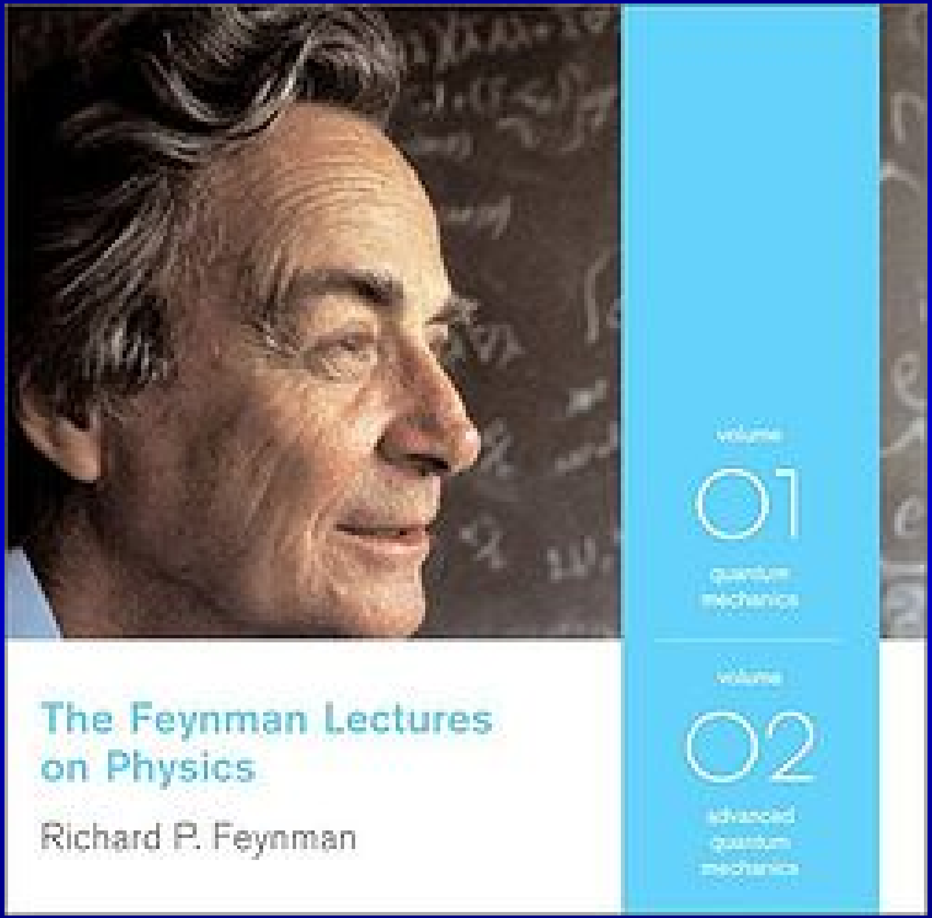
OK, that was interesting, but why should anyone care?

The Challenger Space Shuttle mission (1986)



http://www.wikipedia.org

Feynman's explanation for the Challenger disaster



Richard Feynman

Professor at Caltech

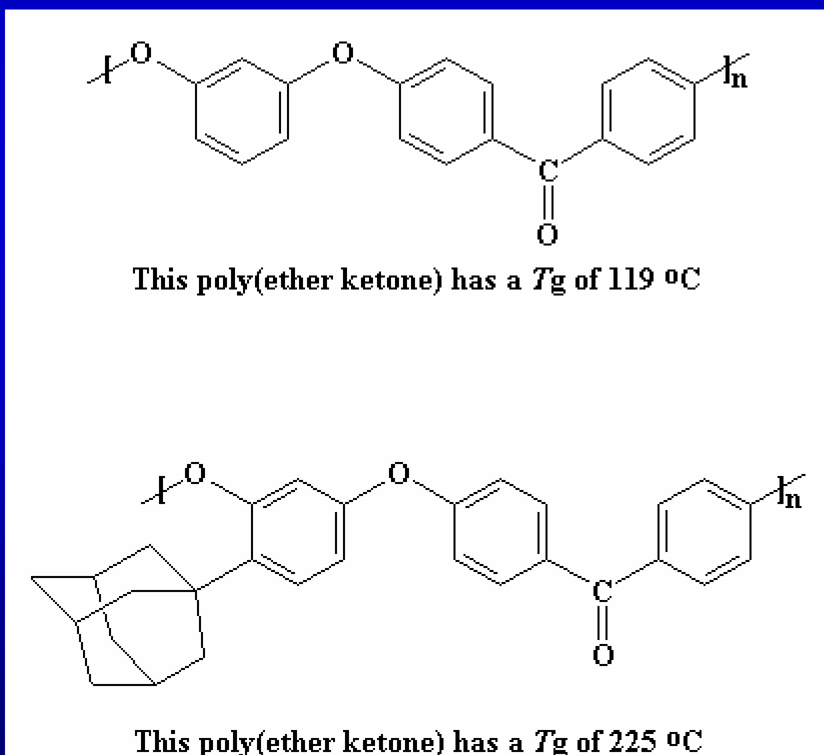
Nobel Prize (Physics, 1965)
for quantum electrodynamics

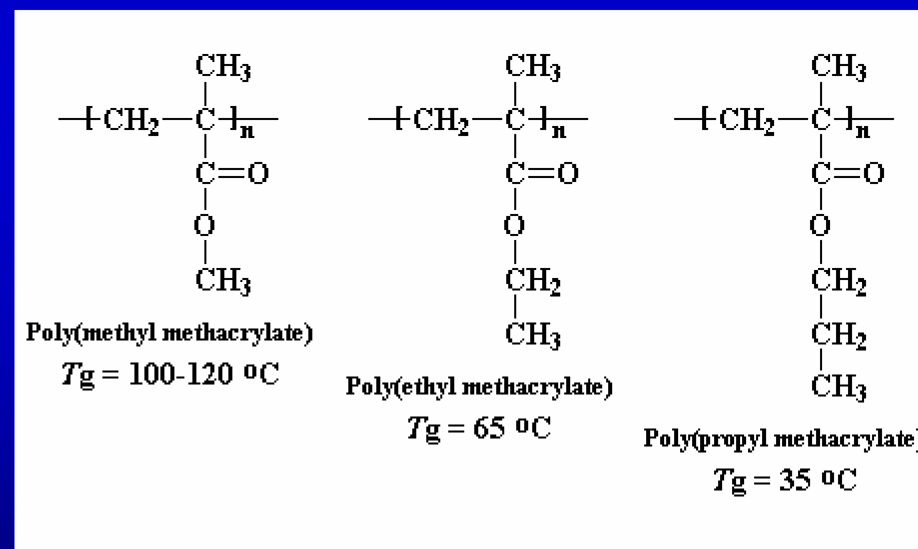
http://www.wikipedia.org

Polymers: Manipulating the glass transition

If we change polymer structure – can change the molecular bulkiness (and therefore, the mobility). Thus can get the properties that we need. That is always useful!

Need a good polymer chemist to make these molecular changes…





http://pslc.ws/macrog/index.htm

Polymers: “Softening” using additives

PVC = polyvinylchloride

The same polymer is used for hard pipes…

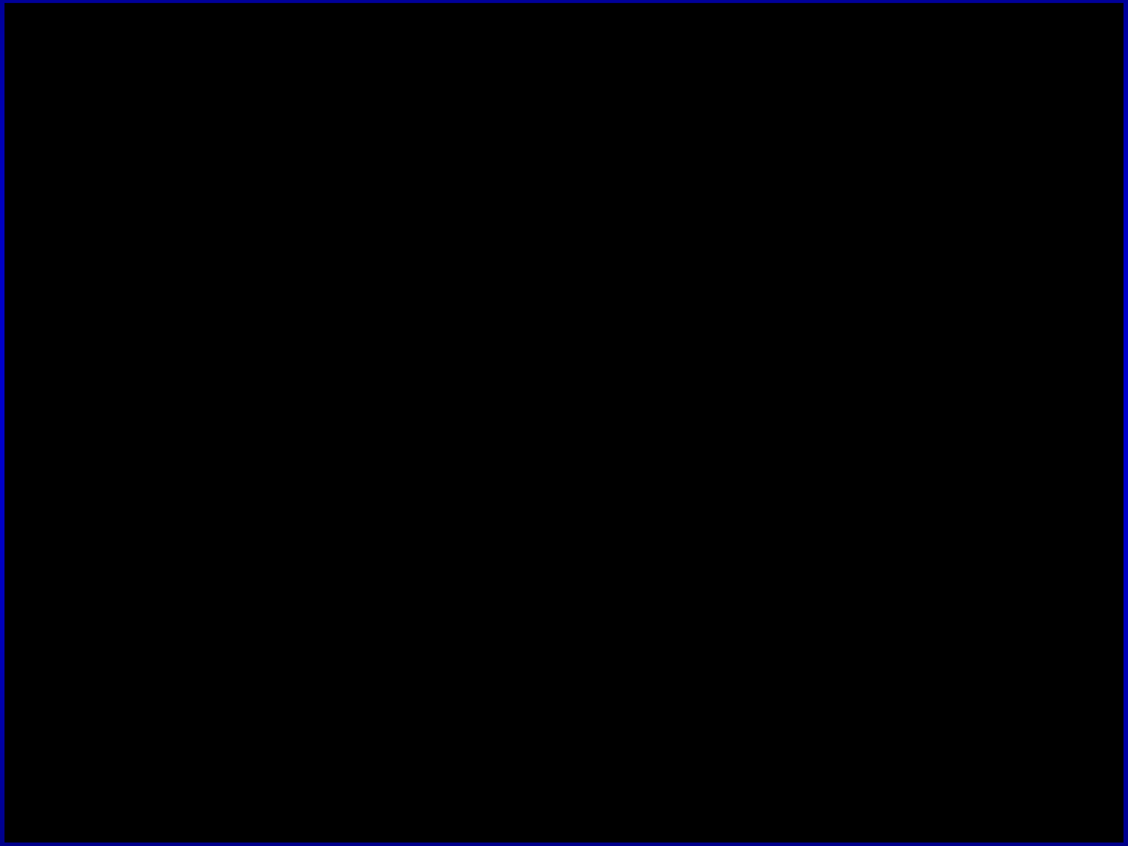
…and for the soft skin on dolls

Changing the glass transition changes the flexibility and softness

Done here using small additive molecules that “lubricate” flow by creating free volume

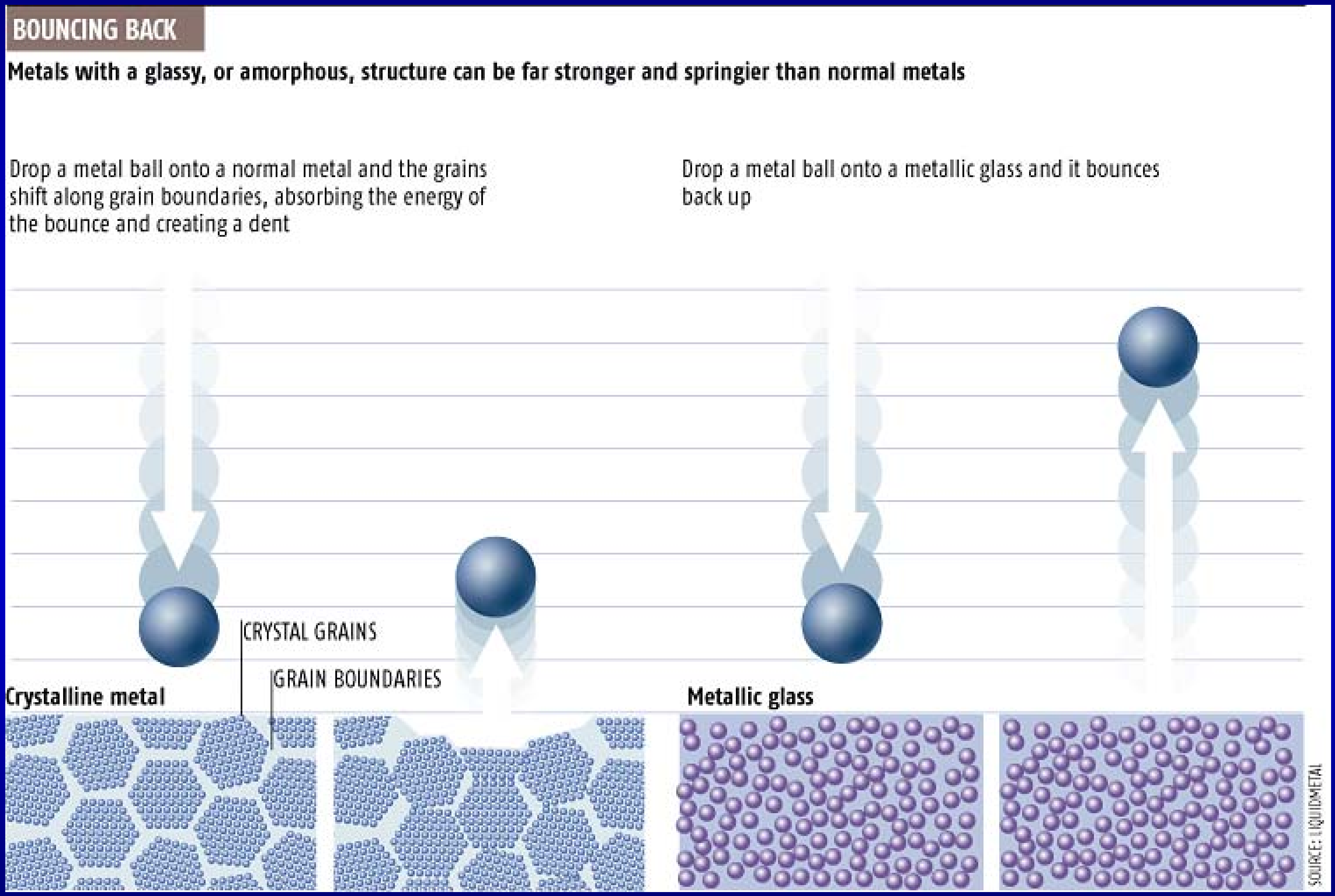
Plasticizers: Also responsible for “new car” smell

“Glassy” versions of materials other than polymers



http://www.newscientist.com/article/mg18624931.000; http://www..liquidmetal.com

Glassy Liquid Metal™ - Complex alloys of Zr, Ti, Ni, Cu, Be

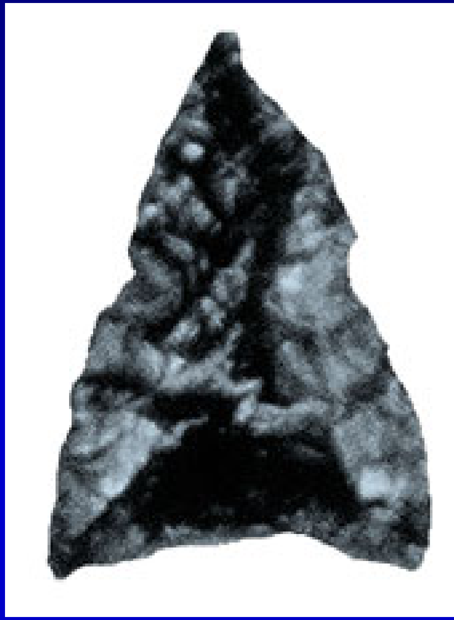


http://www.newscientist.com/article/mg18624931.000; http://www..liquidmetal.com

Liquid Metal™ - Applications

http://www..liquidmetal.com

Glassy materials used by Stone Age "Engineers"



Obsidian – glassy materials from cooled volcanic lava

Glassy, no crystals > Can be sharpened to a very fine edge

Used in the Stone Age to make arrowheads

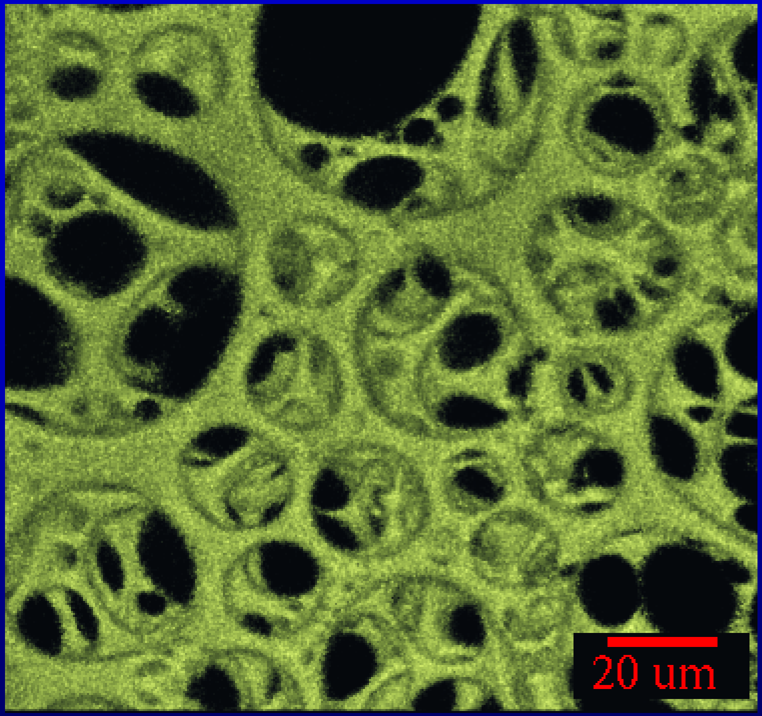
Obsidian is used to make some surgical scalpels today

http://www.wikipedia.org

Glasses in foods too! (not just metals and plastics)

The taste/texture of many foods depends on the structure

Foods are often in the glassy state – for example, curd, mayonnaise, and tasty foams such as ice cream



Confocal microscopy image of mayonnaise – a glassy colloidal emulsion

http://physics.emory.edu/~weeks

How does the transition from liquid to glass happen?

Wikipedia's list of major unresolved problems in physics includes:

Amorphous solids

What is the nature of the phase transition between a fluid or regular solid and a glassy phase? What are the physical processes giving rise to the general properties of glasses?

Philip W Anderson (1975 Nobel prize winner in Physics, from Princeton University) said in 1995 that: "The deepest and most interesting unsolved problem in solid state theory is probably the theory of the nature of glass and the glass transition. This could be the next breakthrough in the coming decade."

In 2008, there is still no consensus on the route to the glass transition.

http://www.wikipedia.org; http://www.nobel.se

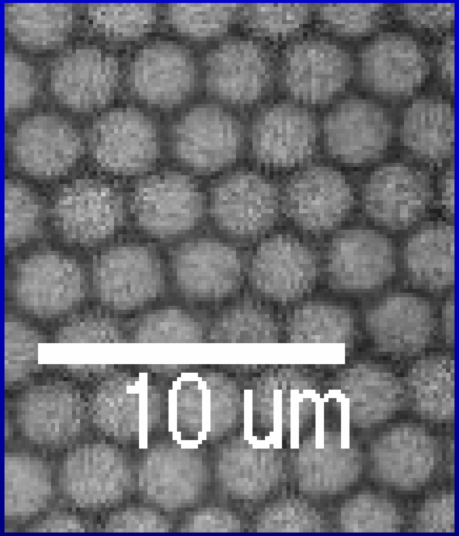
Colloidal glasses – the JAMMED state

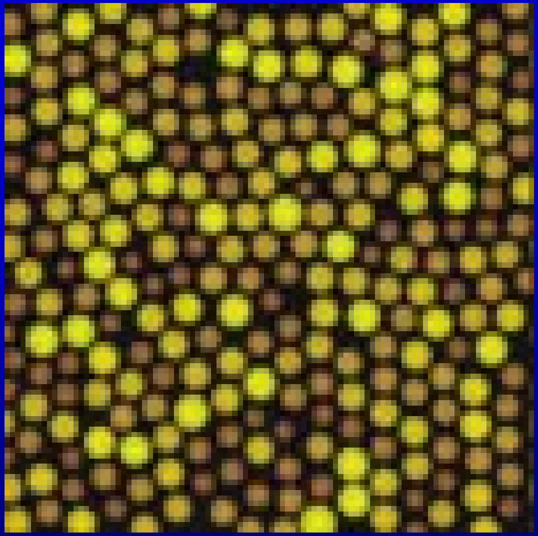
One of the problems with molecular glasses is the difficulty in seeing the details of what the molecules are doing

Model systems: Colloidal glasses

Jamming – can't organize into crystals if there are too many particles

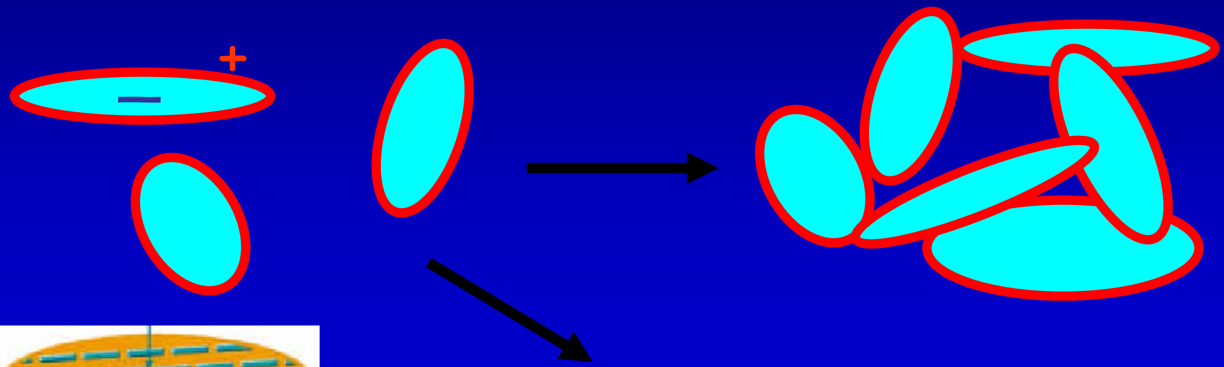
Also, colloidal gels important in their own right, in foods, for example



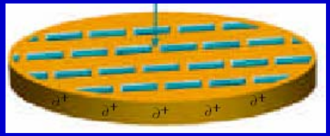


http://physics.emory.edu/~weeks; http://seas.harvard.edu/projects/weitzlab; Tanaka group web page

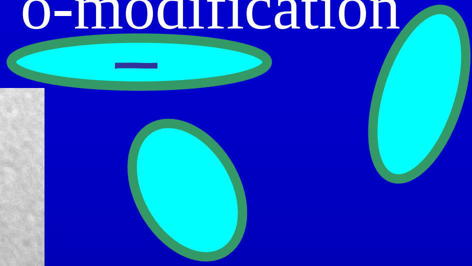
Work in my laboratory: Colloidal nano-plates



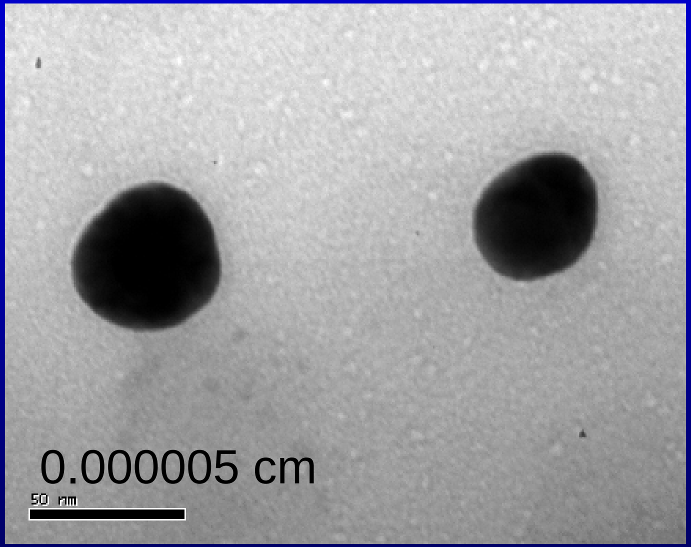
Gelation: driven by edge-face attraction to form house-of-cards



o-modification



Edge-edge attraction and edge-face repulsion



Can we prevent these plates from getting stuck to each other and frustrated?

Can we get a liquid crystal phase with the plates all pointing in the same direction on average?

SUMMARY

There is still a lot of work that needs to be done, both in molecular glasses and colloidal glasses

Glassy states found almost everywhere

Very important to understand this state of matter – we’re not there yet…

THANK YOU FOR YOUR ATTENTION