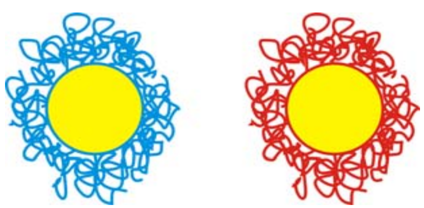
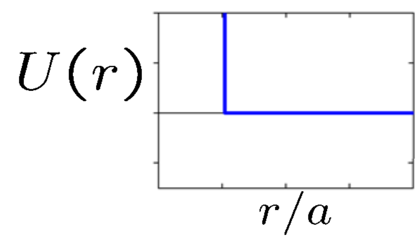
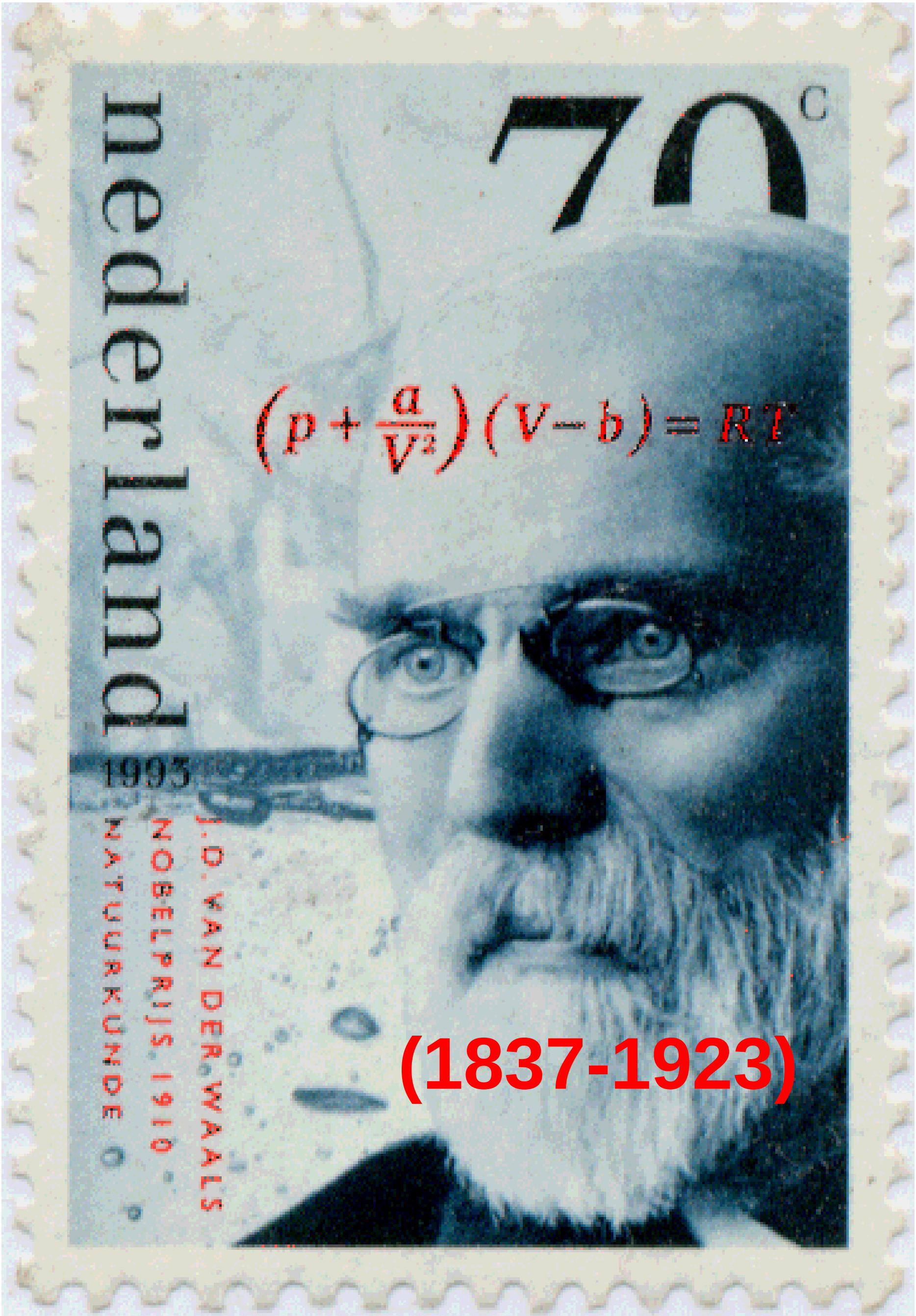
The Program

- Lecture 1: Phase transitions in atomic and molecular systems
- Lecture 2: Colloids as atoms
- Lecture 3: Hard spheres





- Lecture 4: Hard spheres + attraction
- Lecture 5: Rods
- Lecture 6: Platelets



Over
De continuiteit van den gas –
en vloeistoftoestand.

Proefschrift Leiden, 1873.

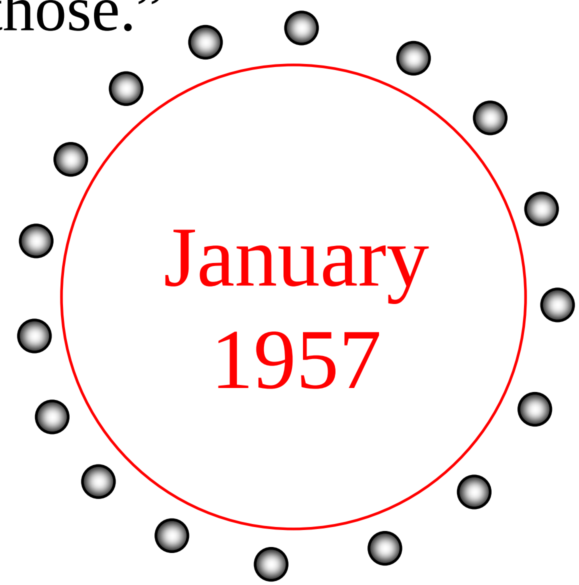
Condensatie vereist
attractie en repulsie

maar kristallisatie…

Geen attractie, toch faseovergang!?

George E. Uhlenbeck
(1900-1988)

"...the transition goes a little bit against intuition; that is why so many people have difficulty with it, and surely, I am one of those."

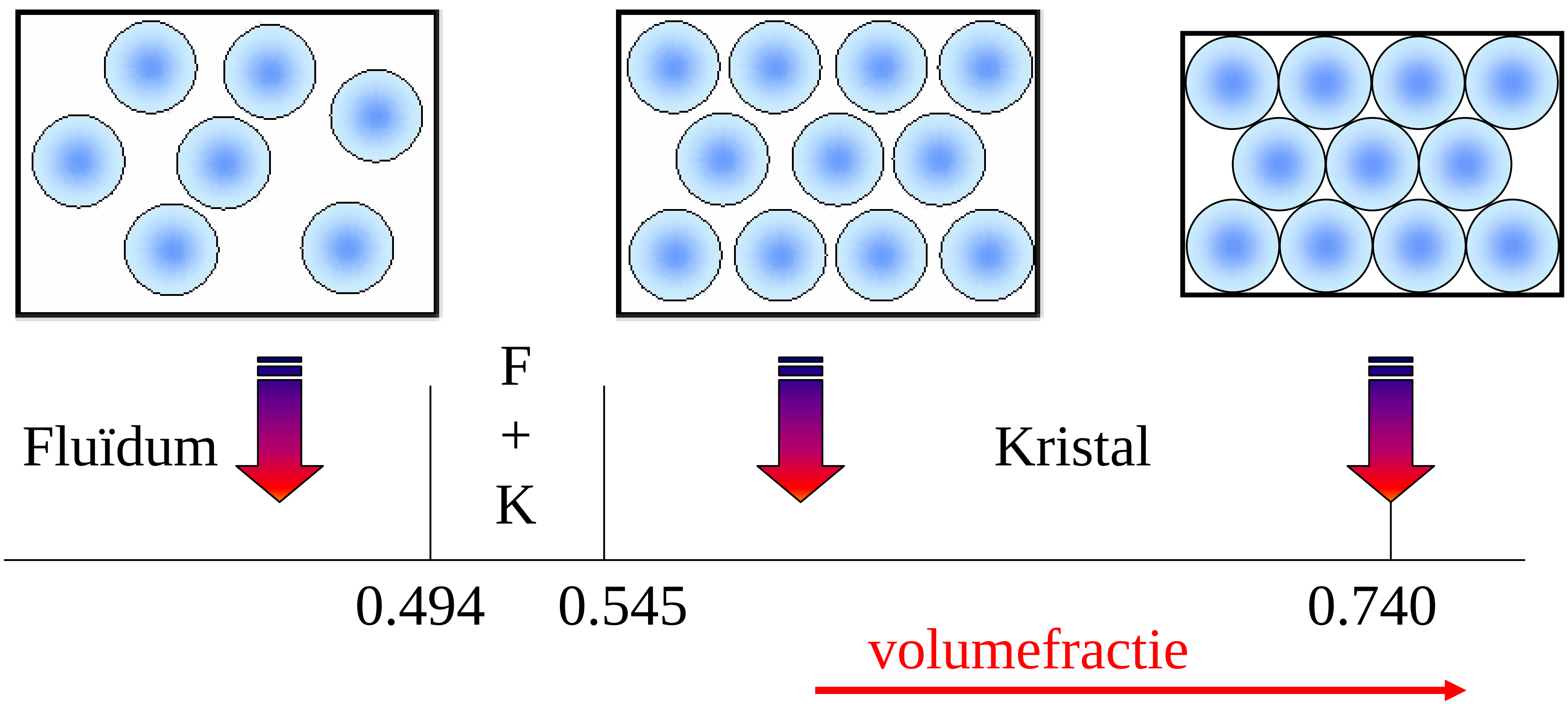


"I think it is quite unnecessary to have an attractive force to achieve a crystalline phase and one can produce simple intuitive arguments for that."

John G. Kirkwood
(1907-1959)

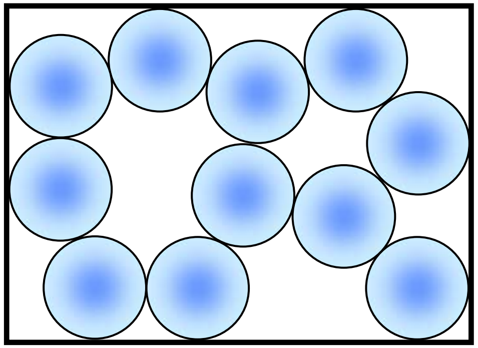
Harde bollen met thermische beweging

Computersimulaties: Alder & Wainwright (1957)
Wood & Jacobson (1957)

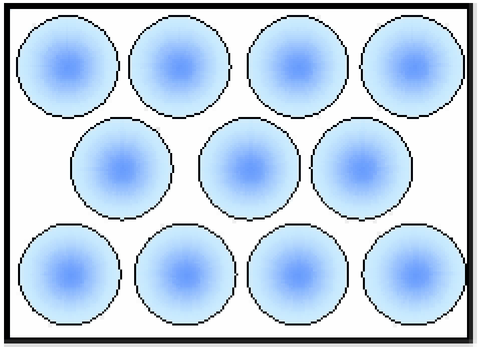


Ordening door entropie

Fluïdum:
wanordelijke stapeling

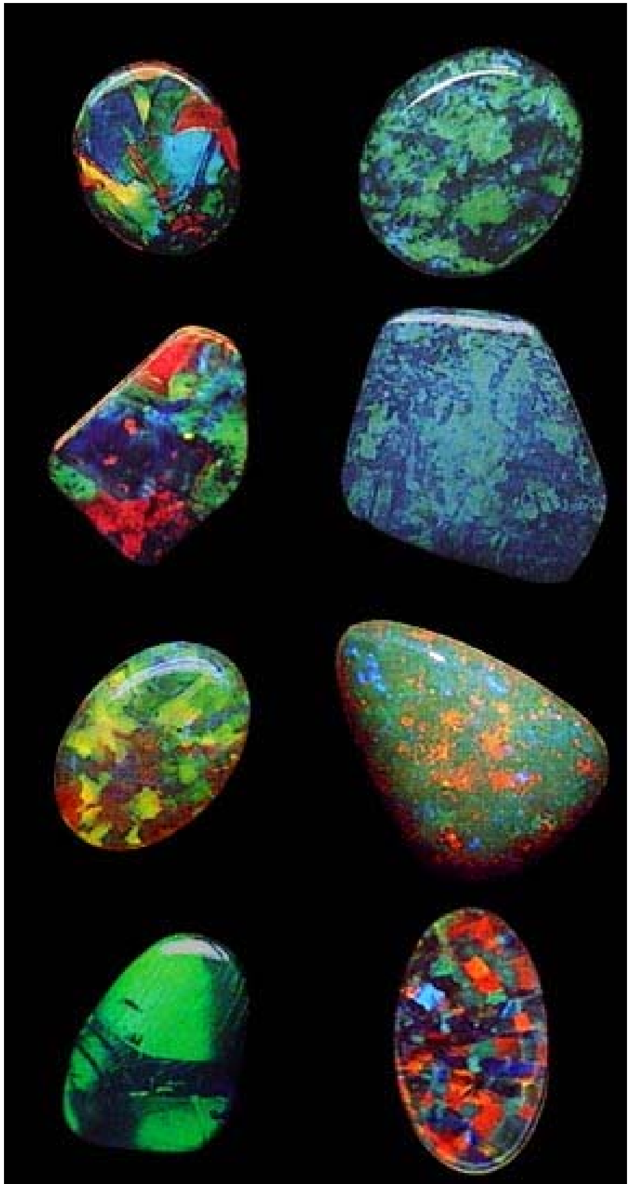


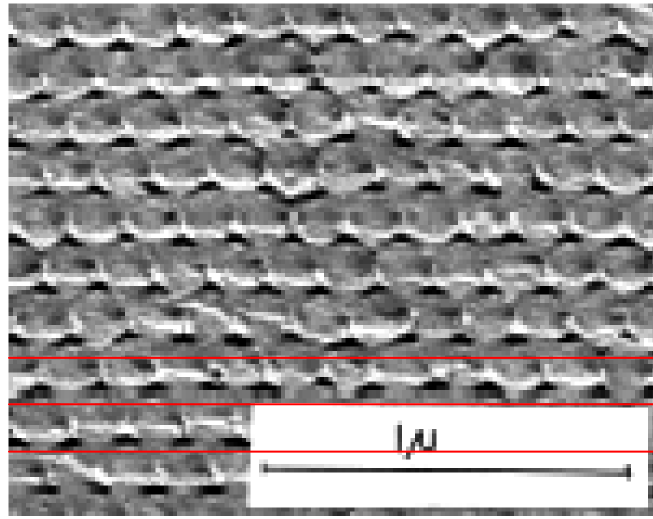
Kristal:
geordende stapeling

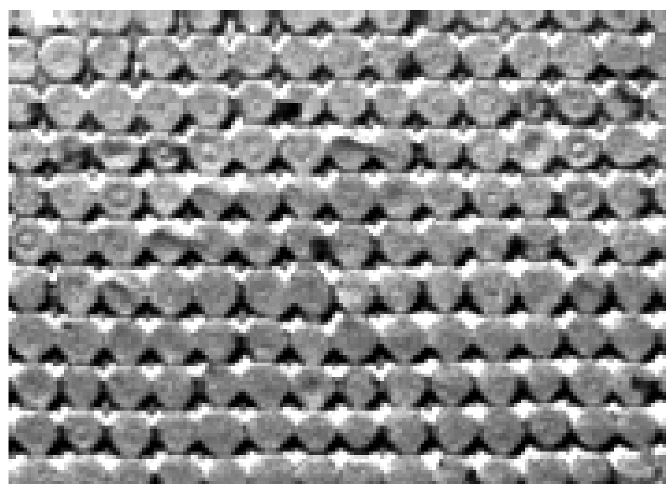


	Fluïdum	**Kristal**
$S_{stapeling}$	hoog	laag
$S_{vrij\ volume}$	laag	hoog

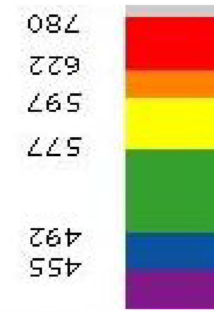
Opaal: geordende silicabollen

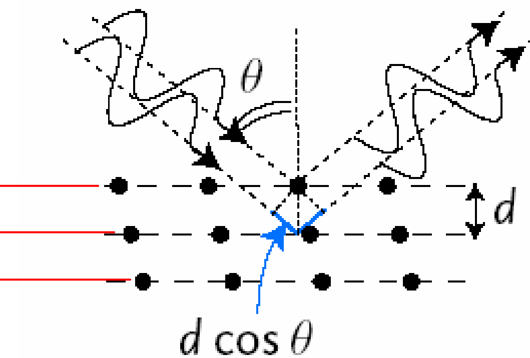






Sanders (1968)



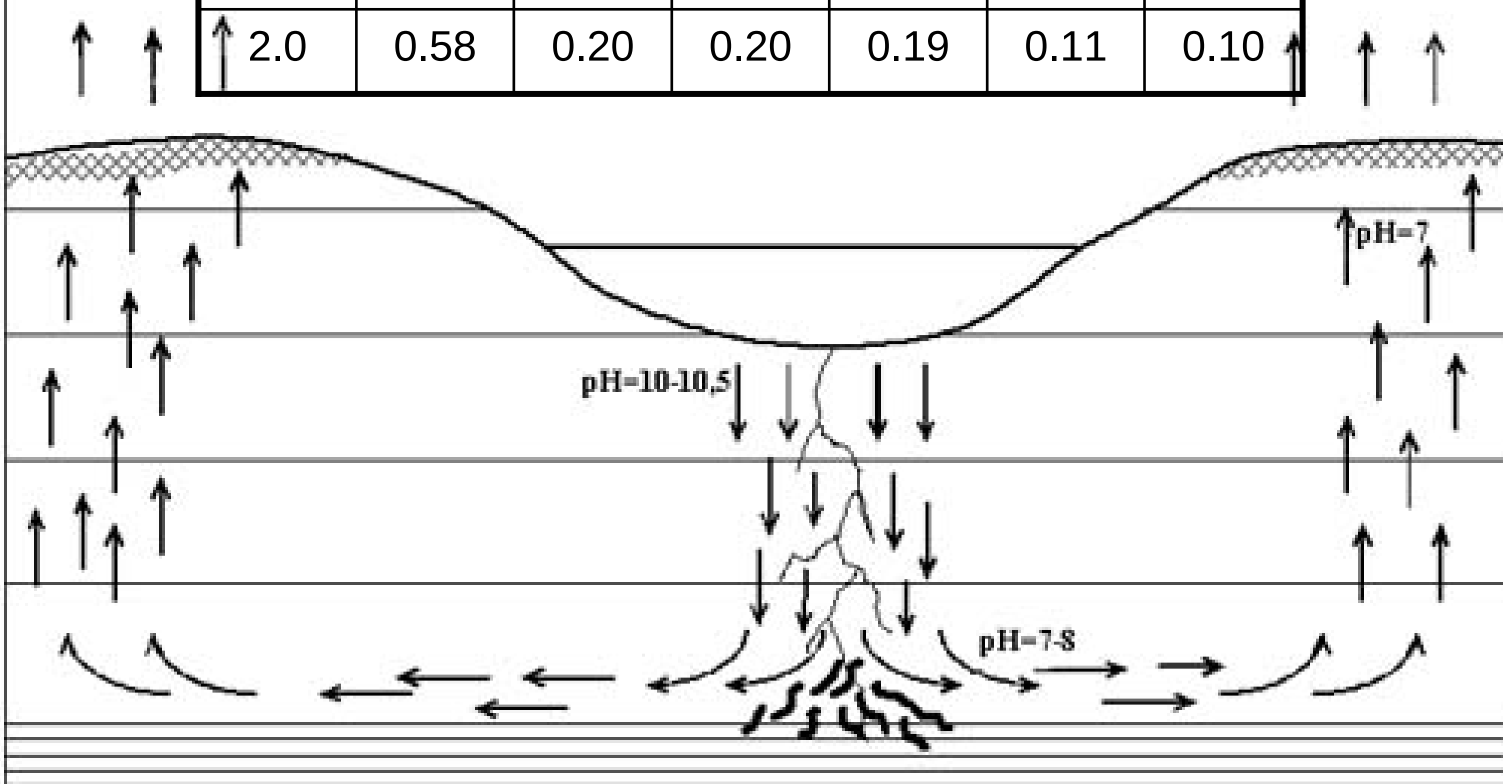


wet van Bragg (1912):

$$2d\ \cos\theta = \lambda$$

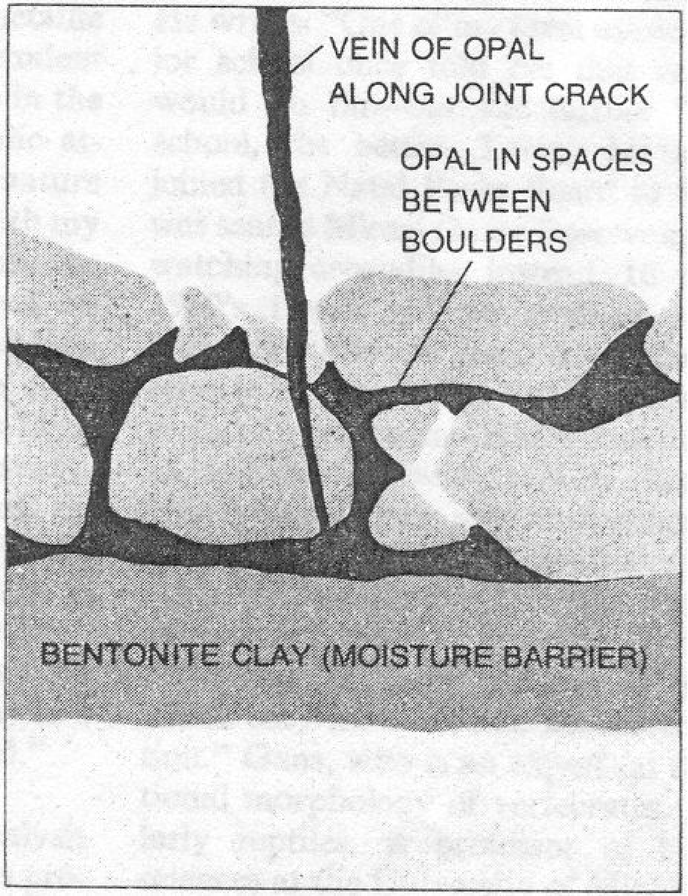
Geochemical formation of opal

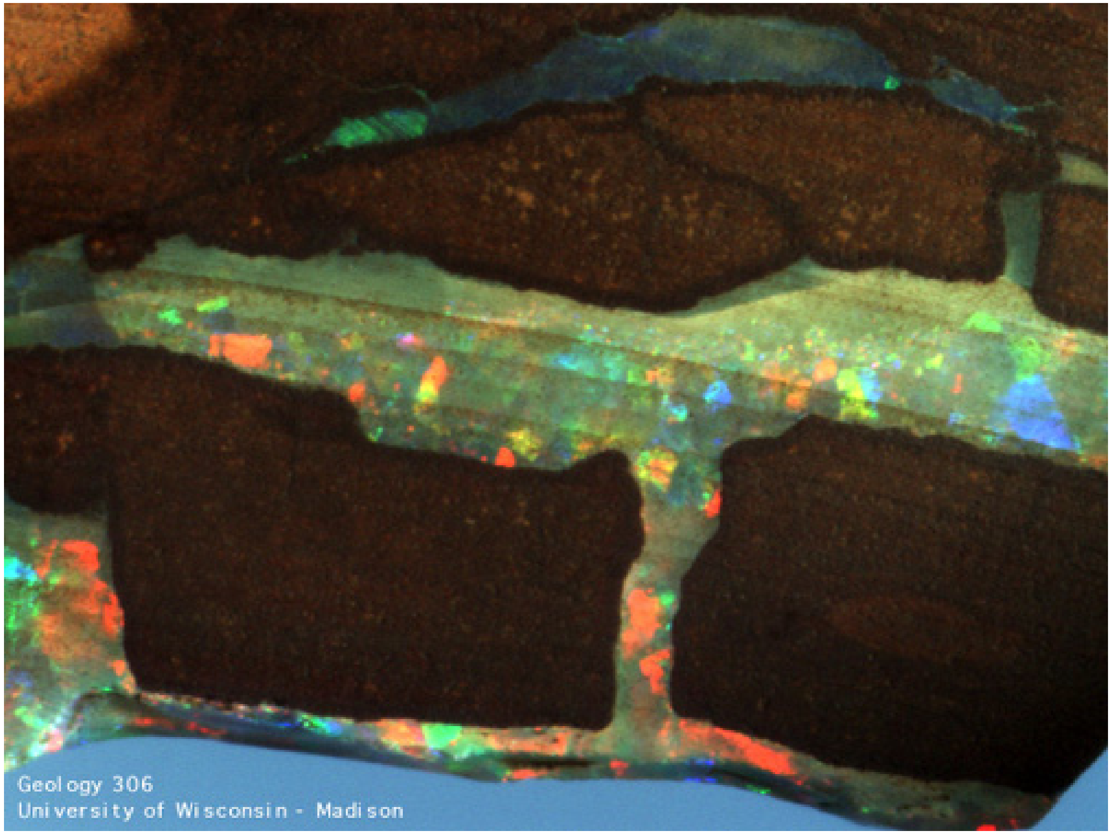
O	**Si**	**Al**	**Fe**	**Ca**	**Na**	**K**
46.5	28.0	8.1	5.1	3.5	2.8	2.5
Mg	**Ti**	**H**	**C**	**Cl**	**P**	**S**
2.0	0.58	0.20	0.20	0.19	0.11	0.10



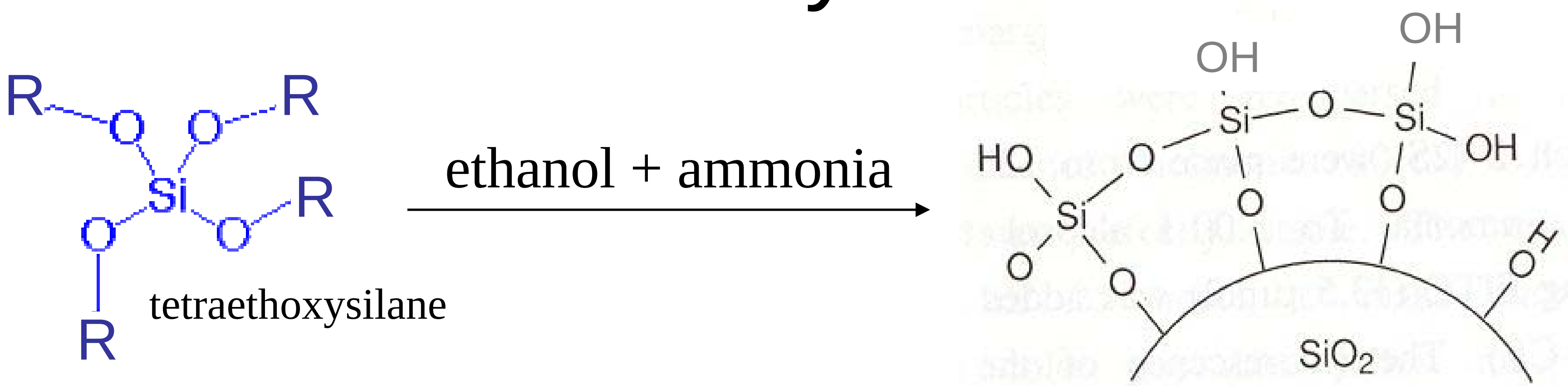
$$n\ \mathrm{Si(OH)_4} \longrightarrow (\mathrm{SiO_2})_n + 2n\ \mathrm{H_2O}$$

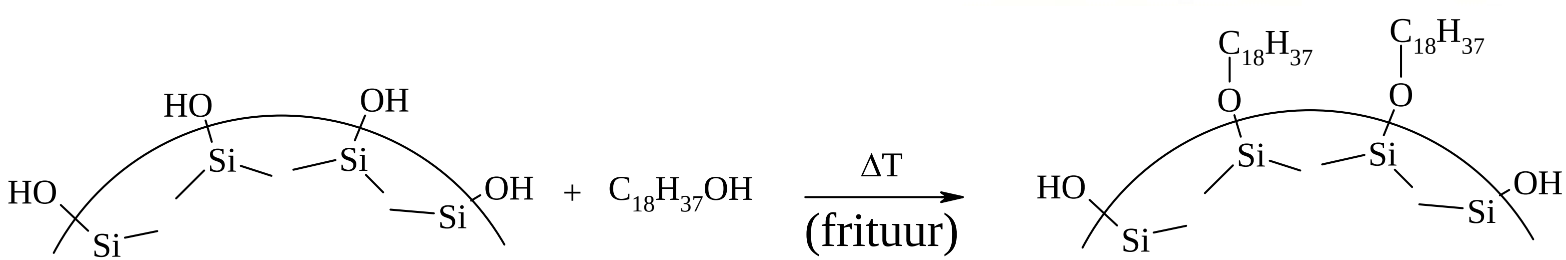
Geochemie


VEIN OF OPAL
ALONG JOINT CRACK
OPAL IN SPACES
BETWEEN
BOULDERS
BENTONITE CLAY (MOISTURE BARRIER)

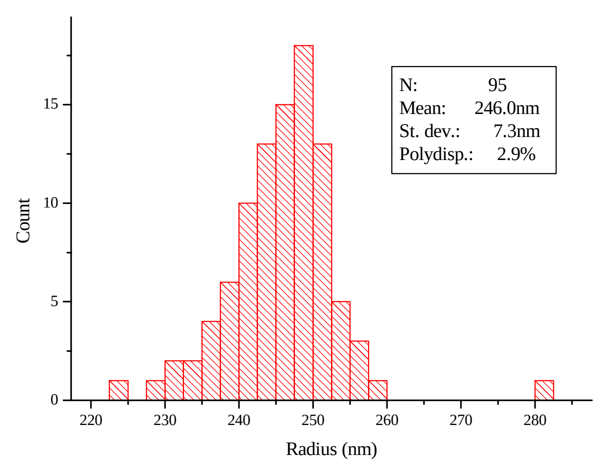

Geology 306
University of Wisconsin - Madison

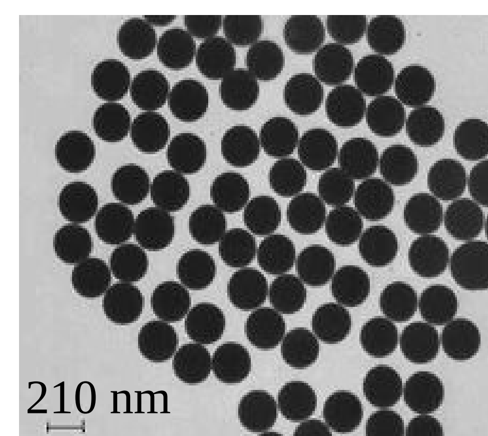
Silica particles in the laboratory: Stöber-synthesis



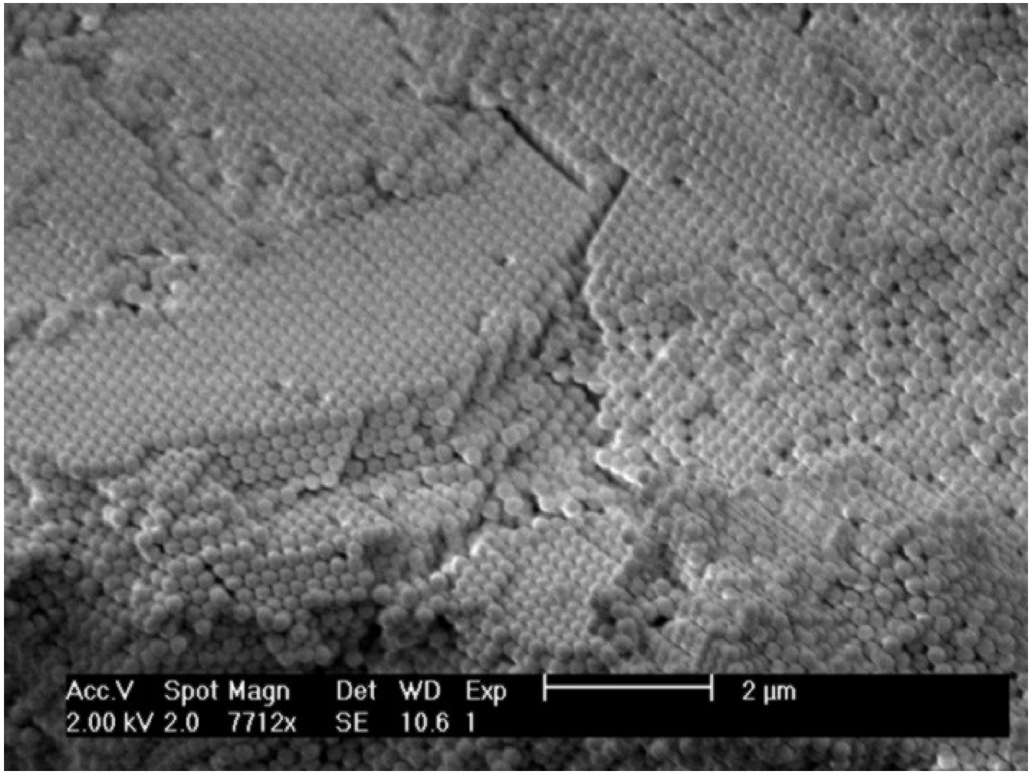


zeer monodispers!



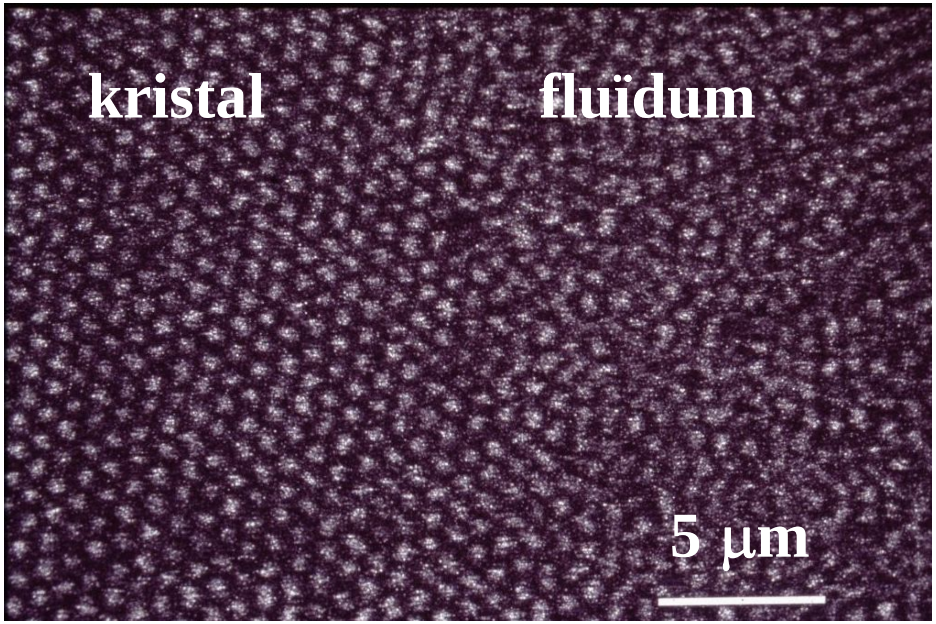


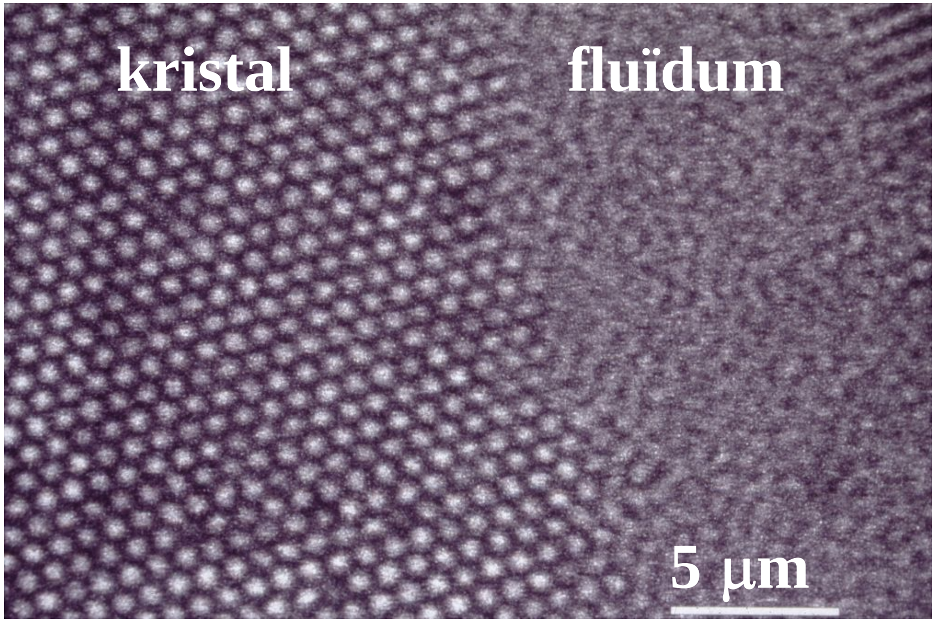
Kristallen van colloïdale bollen

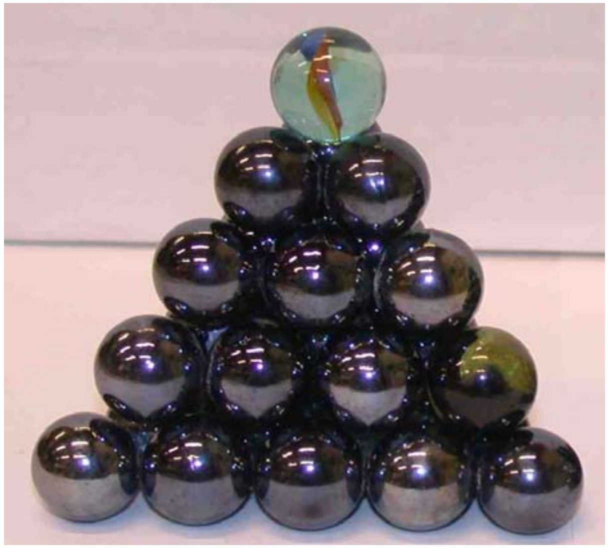


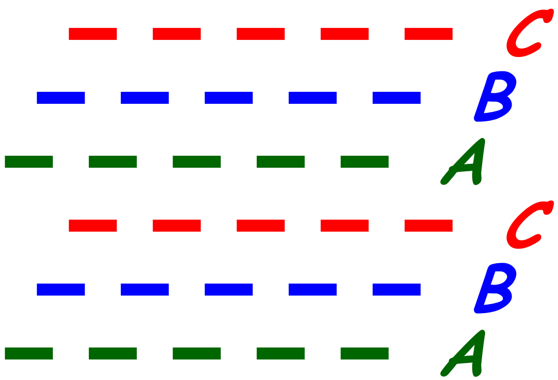
Confocale Fluorescentie -microscopie

Verhaegh en Van Blaaderen (1994).

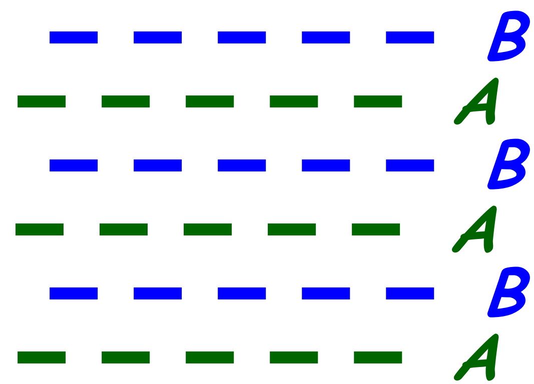






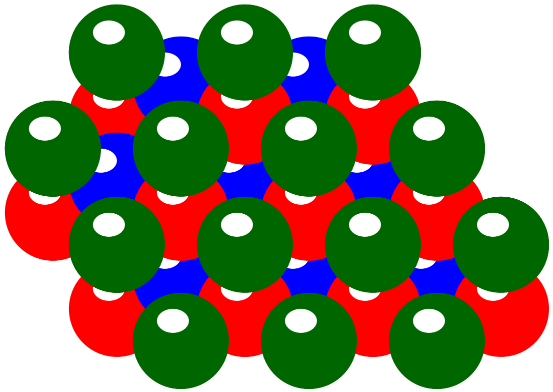


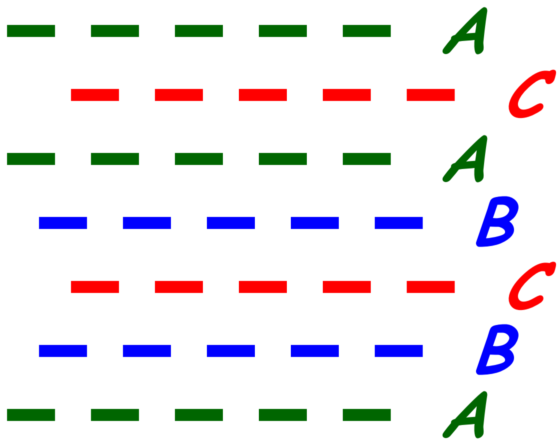
Face-centred cubic (fcc)



Hexagonal close packed (hcp)

FCC or HCP ?

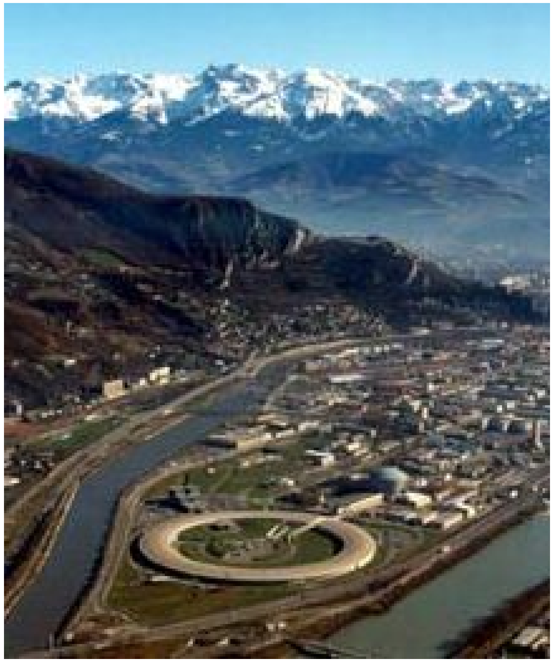


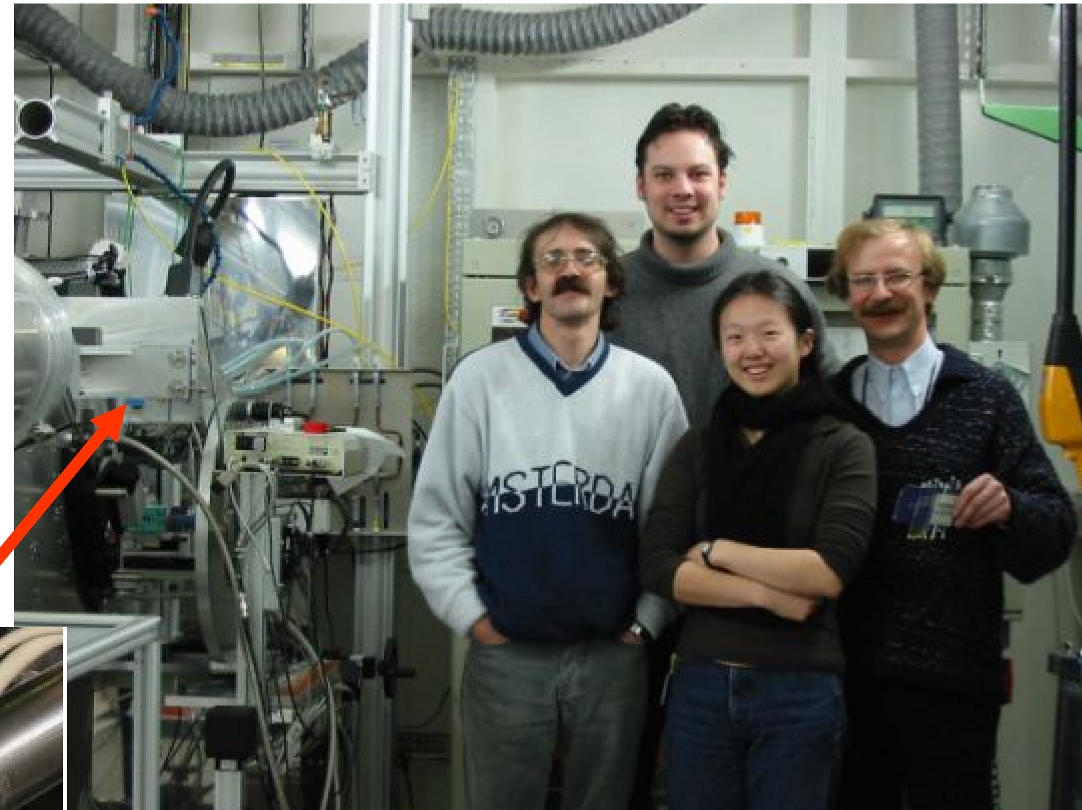


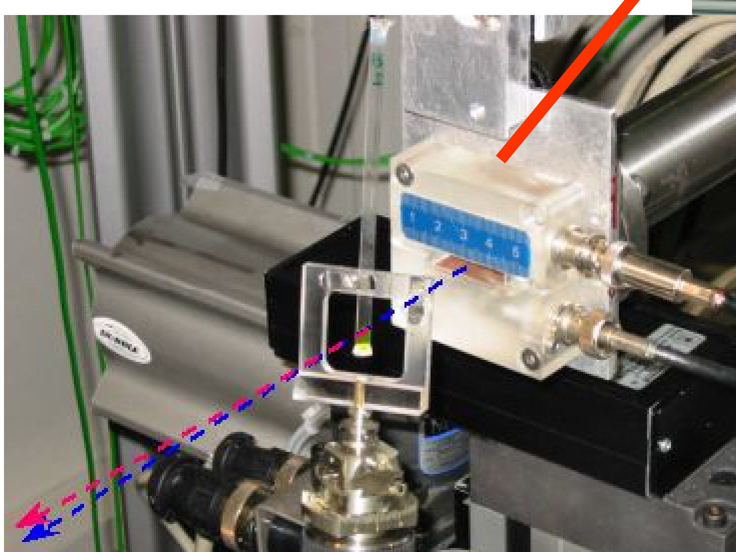
Random hexagonal close packed (rhcp)

All three (fcc, hcp & rhcp) have the same packing ratio…

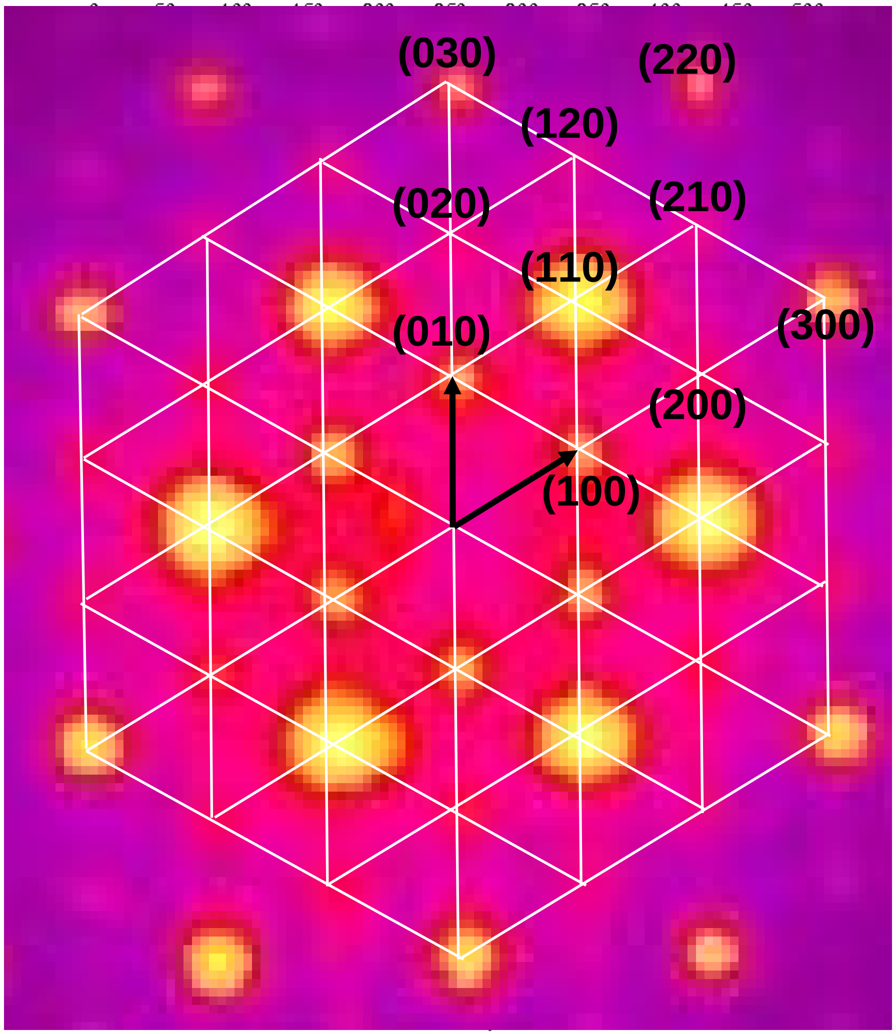
Synchrotron Röntgenverstrooiing

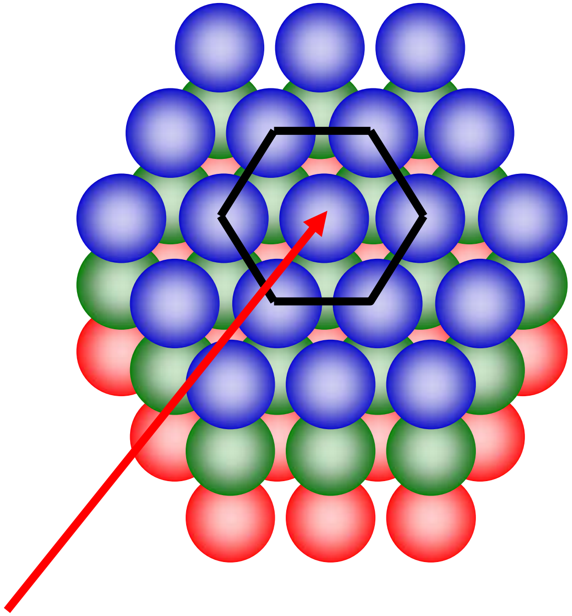






European Synchrotron
Radiation Facility, Grenoble





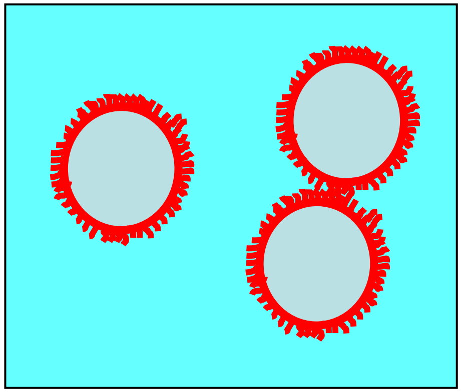
Close-packed crystals:		$h-k=3n$	$h-k\neq 3n$
FCC:	…ABCABC…	1	0
HCP:	…ABABAB…	1	0.25
RHCP:	…ABACBC…	1	0…0.25

- *Petukhov, Aarts, Dolbnya, de Hoog, Kasapidou, Vroege, Bras, HNWL*, **Phys.Rev.Let., 88, 208301 (2002);**
- *Petukhov, Dolbnya, Aarts, Vroege, HNWL*, **Phys.Rev.Let., 90, 028304 (2003).**

Samples

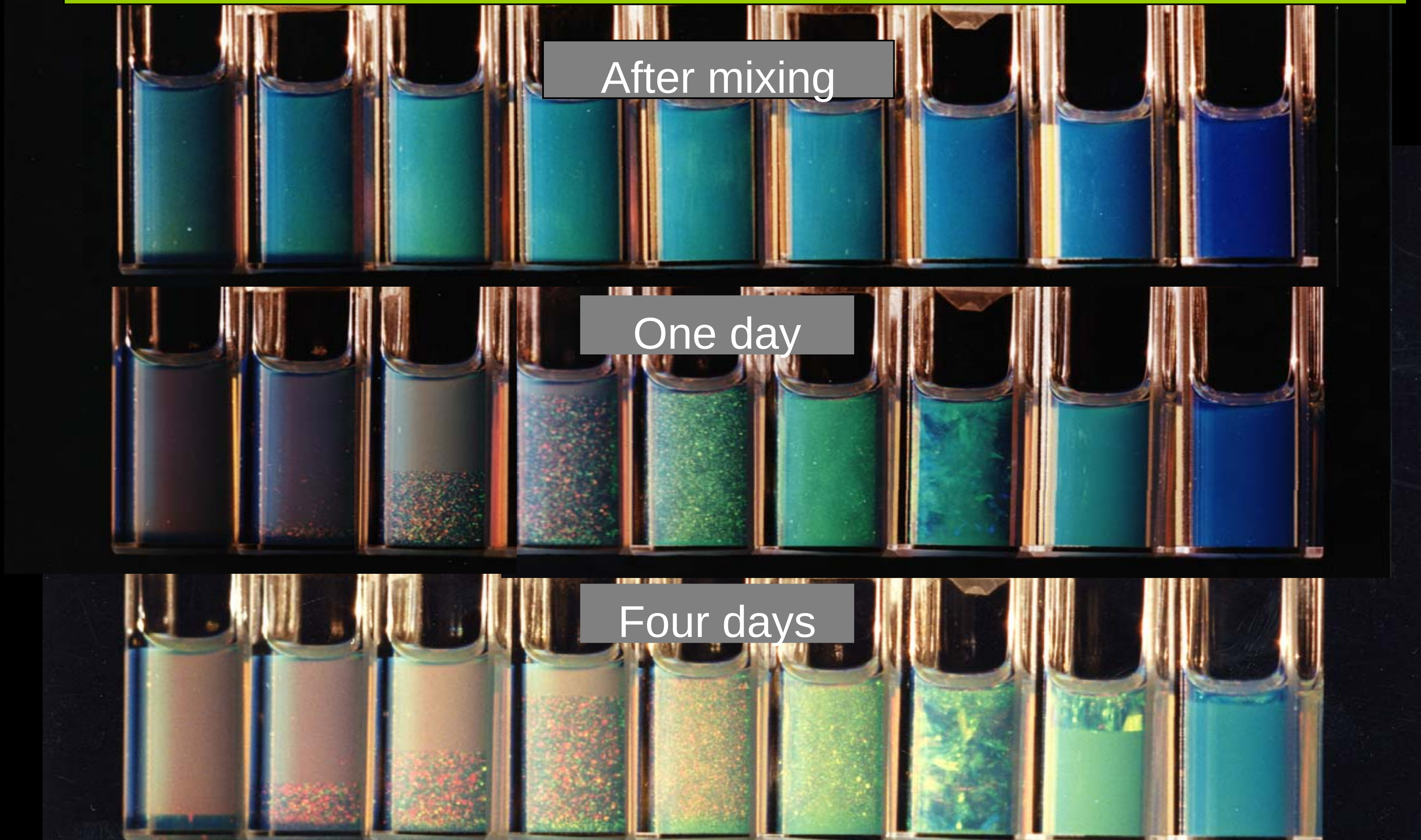
Hard-sphere colloids:

Sterically-stabilised poly-methylmethacrylate (PMMA) colloidal “hard spheres”



- Suspend in mixtures of organic liquids –
  match refractive index and/or density
- No attraction, nearly hard-sphere repulsion (but ? charge ?)
- Radius $R \approx 0.2\ to\ 1\ \mu m$
- Polydispersity ~ 0.05

Hard-sphere colloidal crystals and glasses

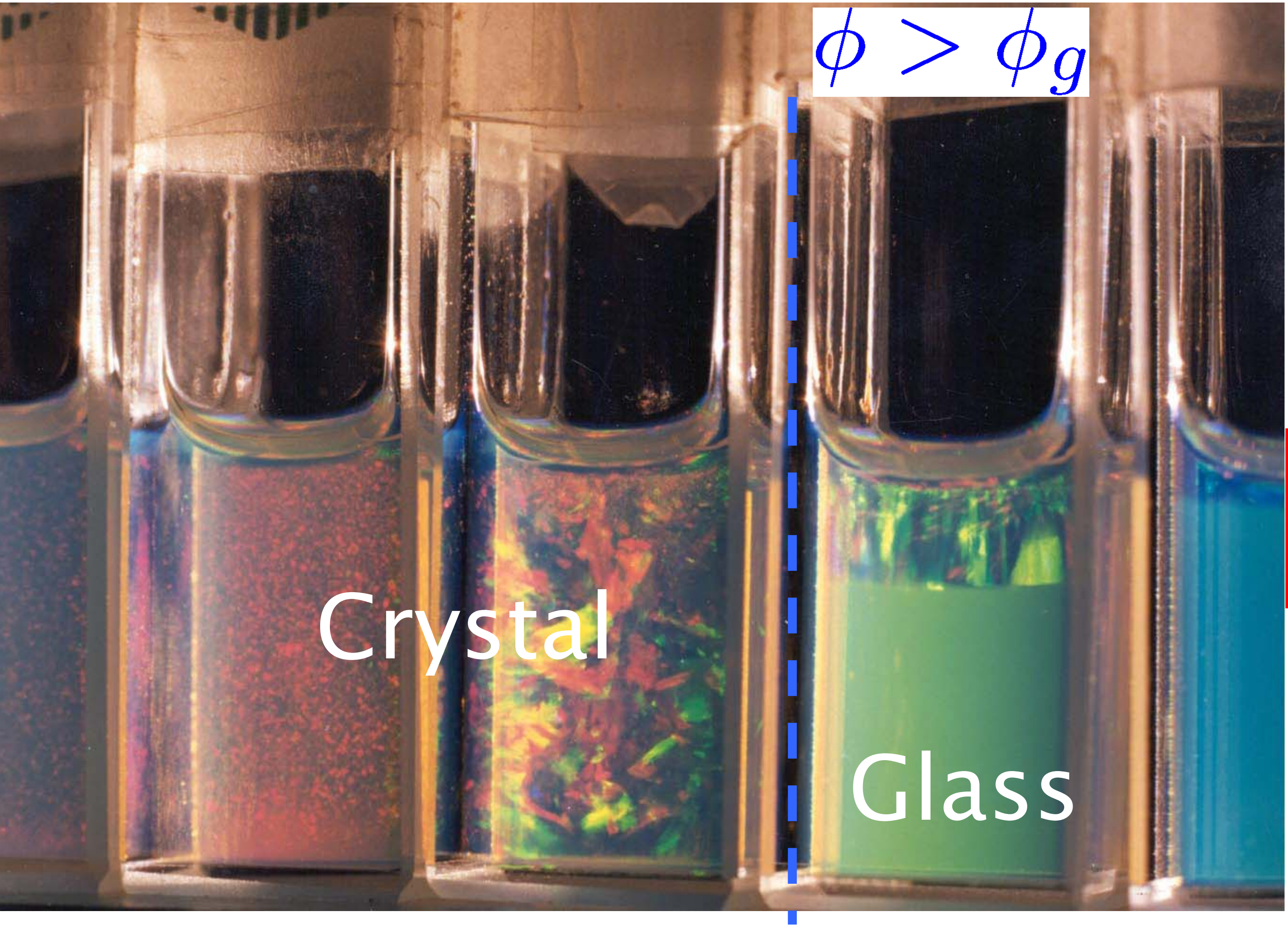


Fluid	Fluid + Crystal	Crystal	Glass
$\phi < 0.494$		$\phi > 0.545$	$\phi > 0.58$

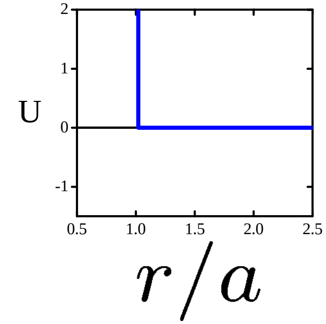
Pusey & van Megen, Nature **320**, 340 (1986)

Repulsive glass

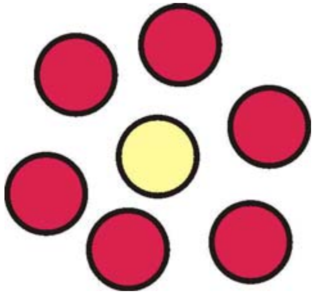
High-density kinetically-arrested disordered solid

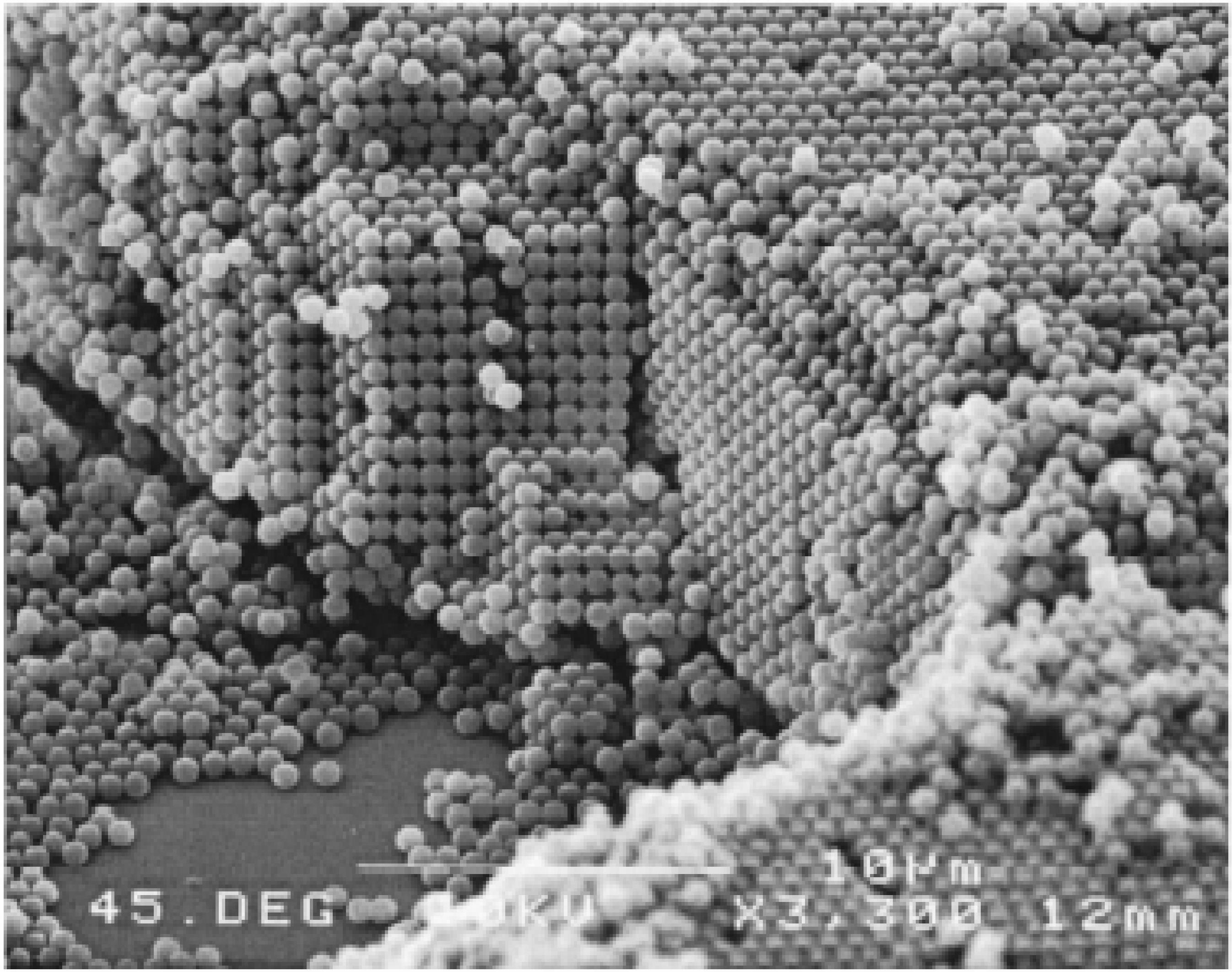


Hard sphere

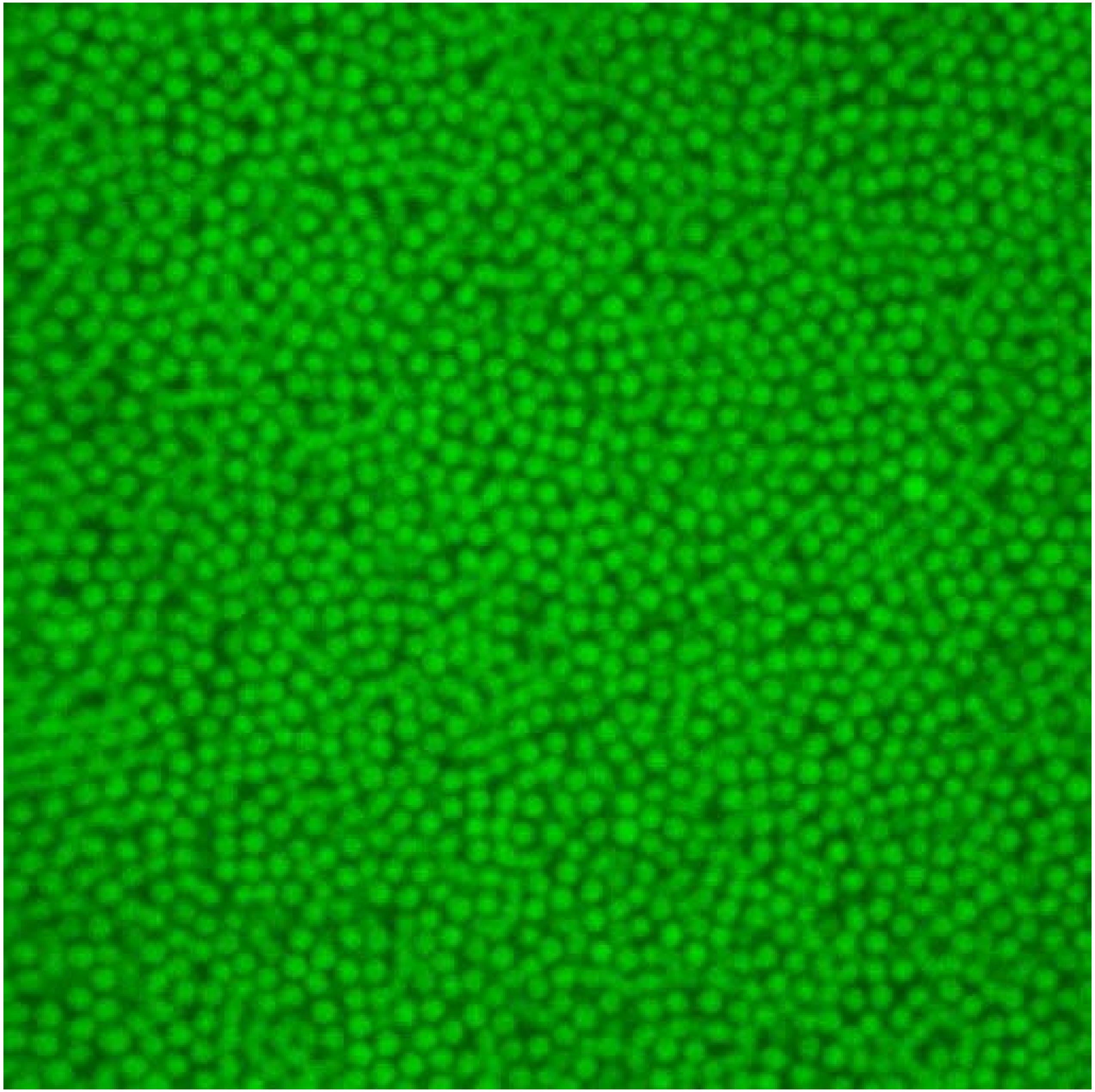


Repulsions dominant



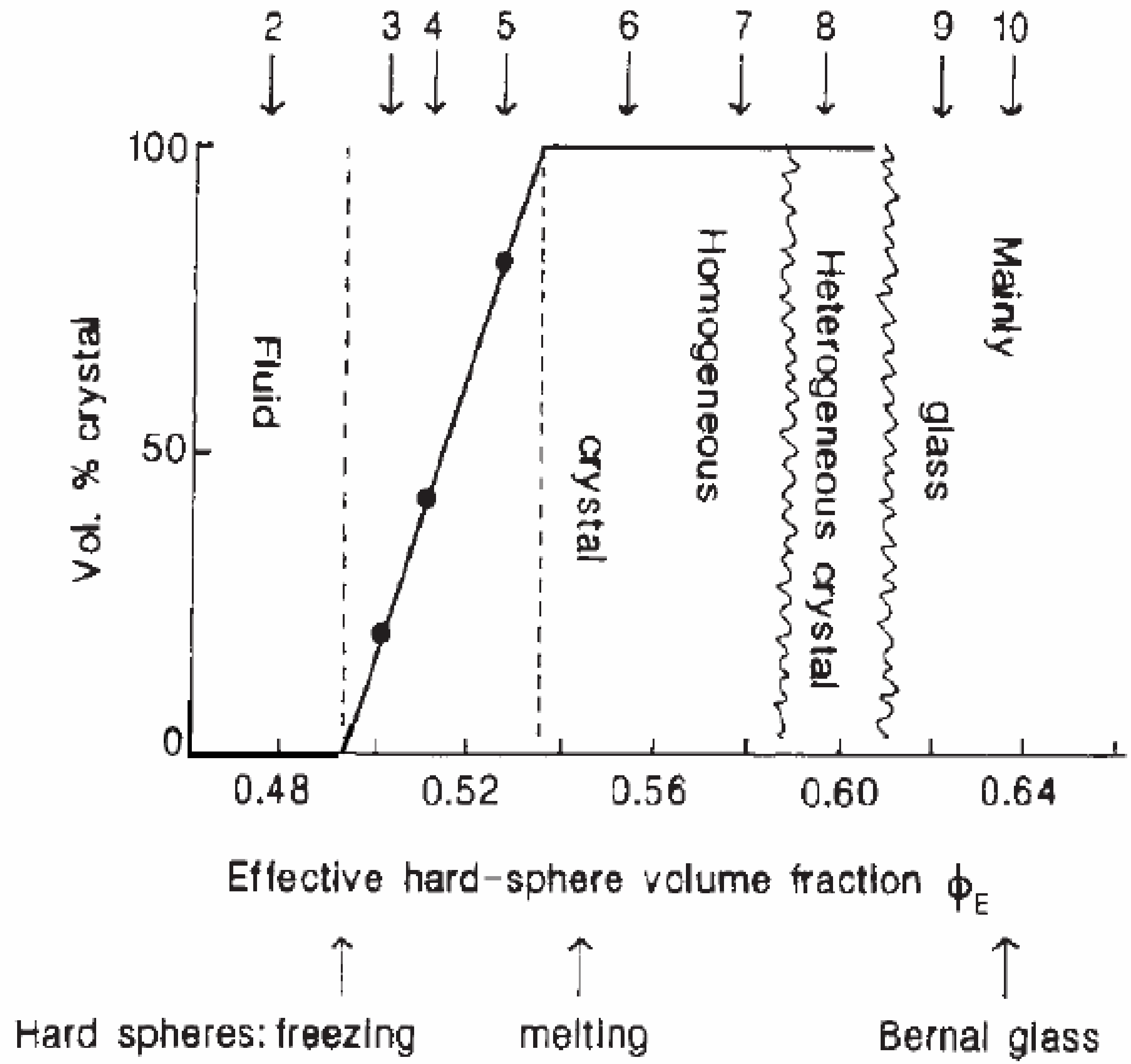


(b) R.M. Amos et al., PRE **61**, 2929 (2000)



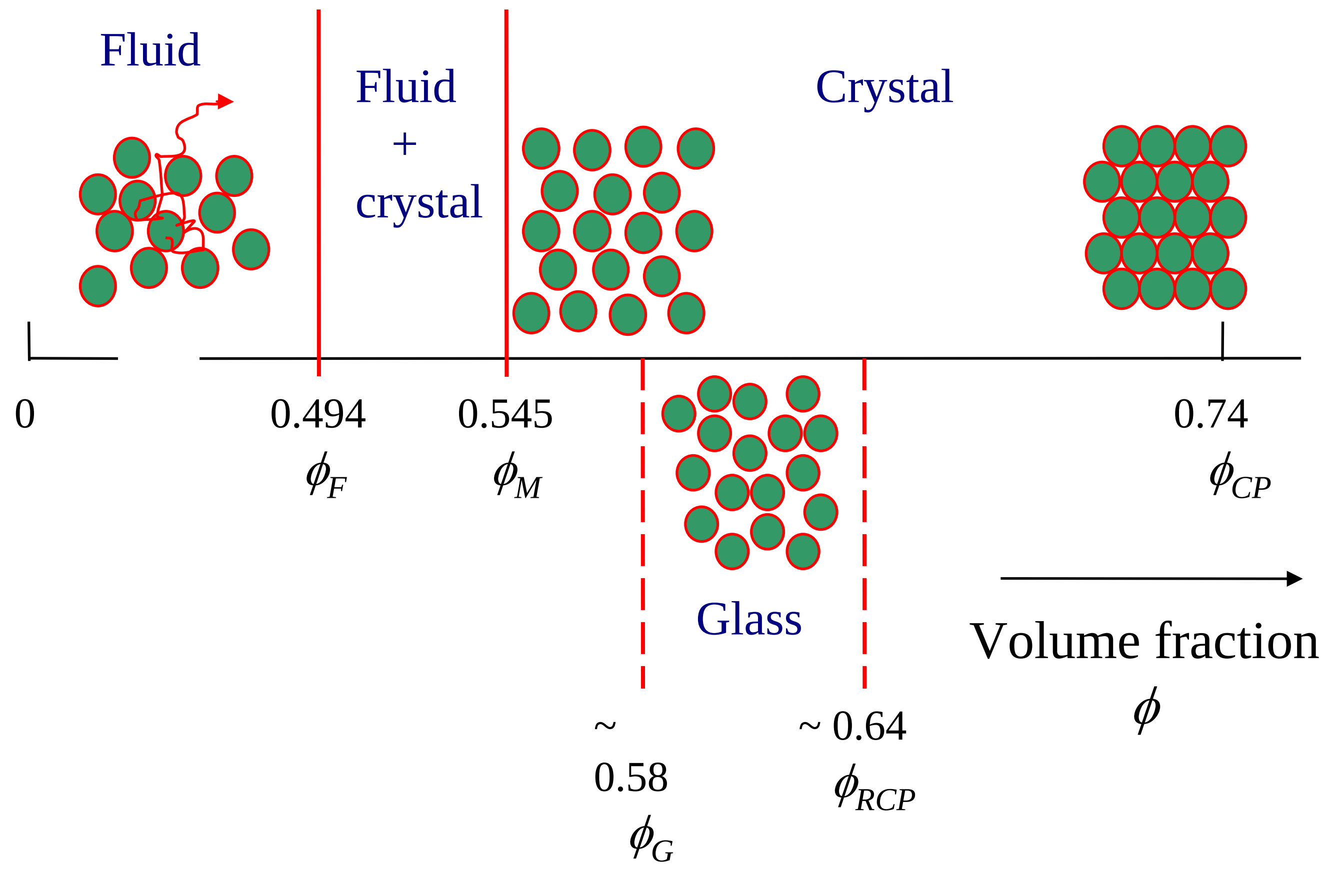
Fluorescent PMMA, Volkert de Villeneuve

Observed phase behaviour



Phase behaviour of hard spheres

Only one variable: volume fraction $\phi = \frac{N}{V} \frac{4}{3} \pi R^3$



The end of lecture 3