Depolarization of backscattered light

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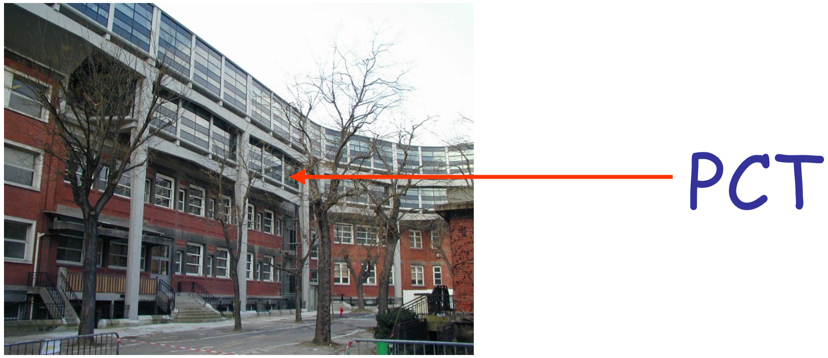
Physico-Chimie Théorique (PCT),
ESPCI, Bat F, 3ème étage



ESPCI

Outline of the talk

- Introduction: polarization in multiple light scattering

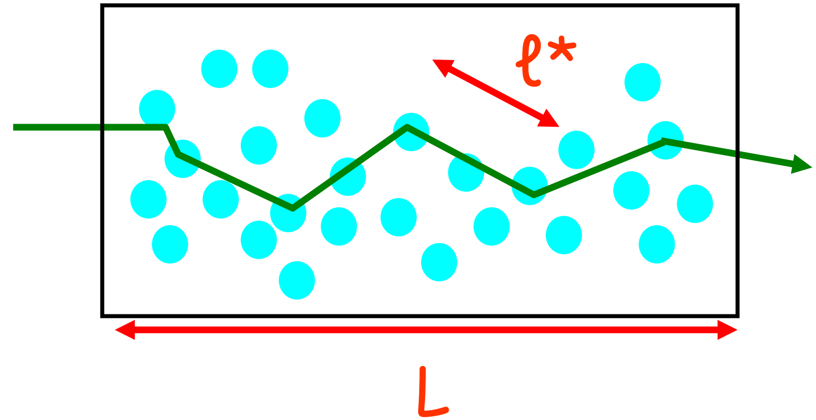
- Patterns formed by linearly polarized backscattered light
  T. Maggs, V. Rossetto (PCT, ESPCI),
  M. Cloître, R. Barkatis (Matière molle et Chimie, ESPCI),
  F. Jaillon, H. Saint-Jalmes
  (Université Claude Bernard, Lyon)
  V. Loriette (Laboratoire d'Optique, ESPCI)

- Measuring light depolarization in backscattering with DWS:
  F. Scheffold, L. Rojas (Université de Friburg).

Simple facts about multiple light scattering

Mesoscopic regime

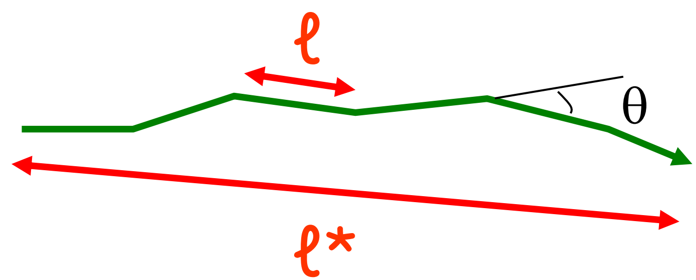
$\lambda \ll \ell^* \ll L \ll L_{abs}$



Anisotropy in scattering

$$g = \langle \cos\theta \rangle$$

in most cases $g>0$



Length scales for memory of polarization

linear polarization: $\ell_p \approx \ell^*$

circular polarization: $\ell_c \approx \ell^*$

Images of 9 laser diodes through a diffuse medium of ℓ^*=1.27μm, L=1cm

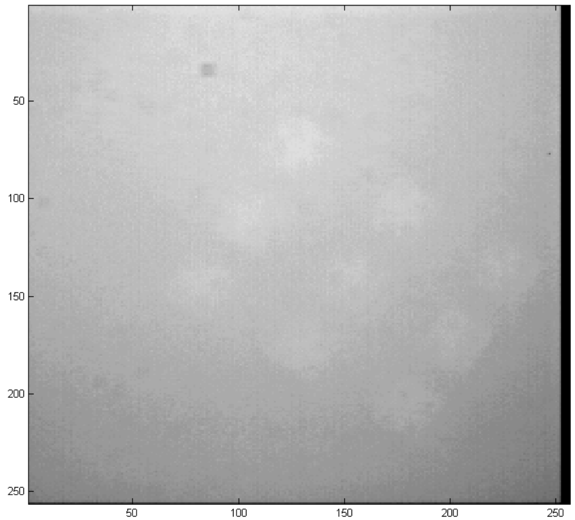


Image with non-polarized light

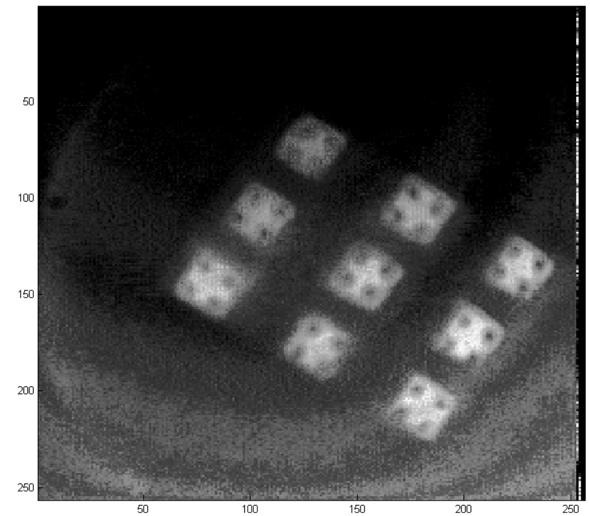
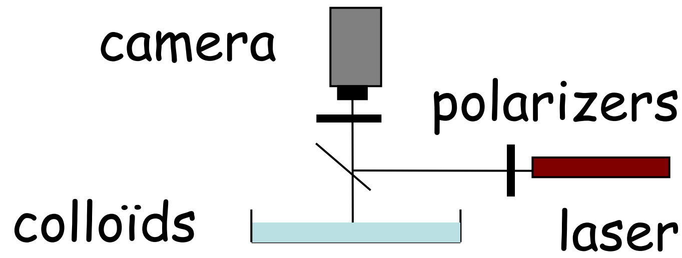
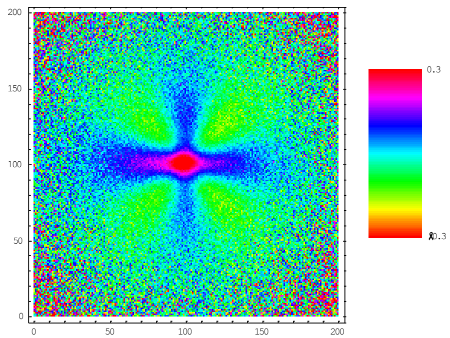


Image with polarized light

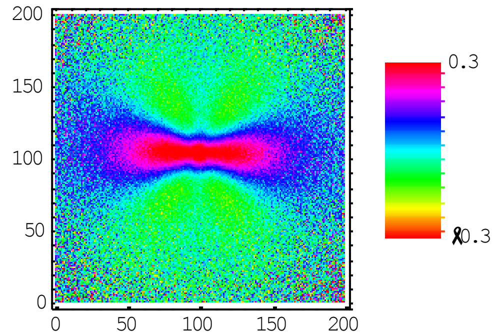
(pictures taken by Vincent Loriette, Laboratoire d'Optique ESPCI)

Experimental set-up :
a local analysis of the medium

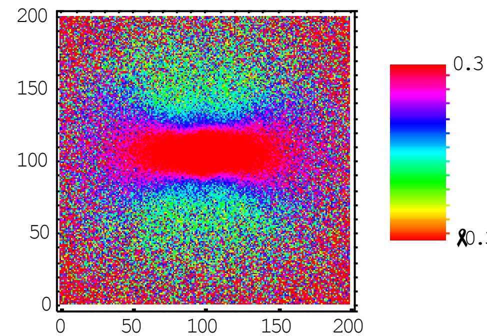




g=0.91



g=0.71



g=0.55

(Patterns with crossed polarizers from F. Jaillon, Lyon).

Standard approach : Stokes parameters

Müller matrix depends on scattering properties of medium and on geometry. It contains contributions from different scattering orders.

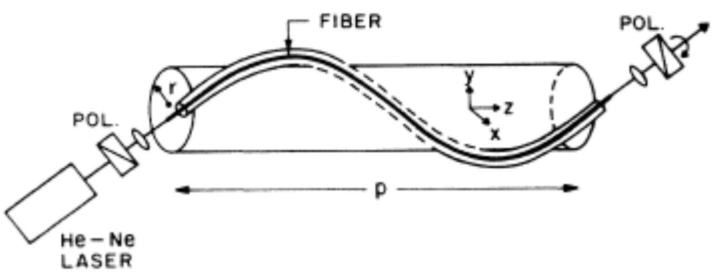
Geometrical phase

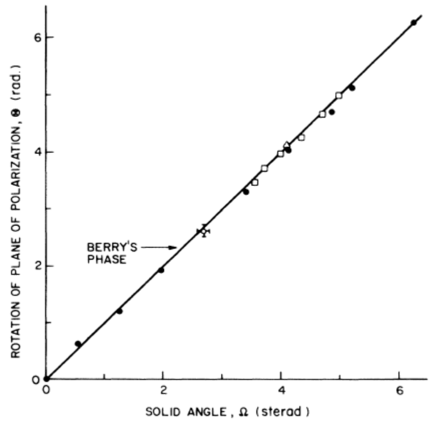
Adiabatic evolution of a system described by
an hamiltonian $H(\vec{R}(t))$ with $\vec{R}(T)=\vec{R}(0)$ (Berry 1984).

- Dynamical phase (depends on $\vec{R}(t)$)
- Geometrical phase (independent of $\vec{R}(t)$)

Example: a spin which turns around a magnetic field $\vec{B}(t)$ in a direction which is slowly varying : analogous to light polarization when the wave vector $\vec{k}(t)$ is slowly varying.

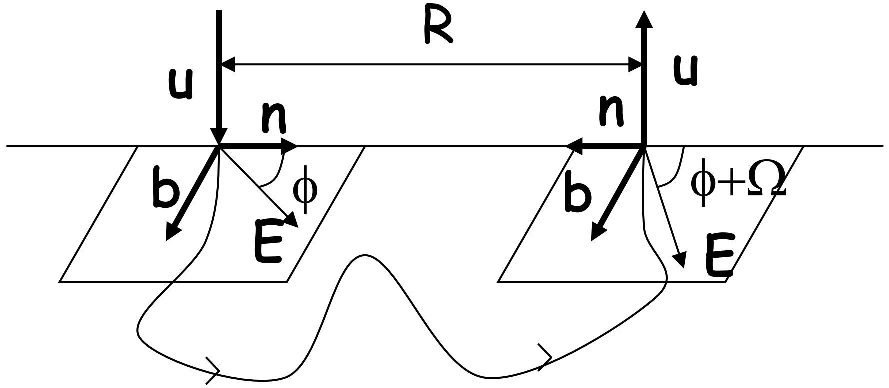
Experimental evidence: Tomita (1986)





Changing the pitch of the helix modifies Ω
A wavelength independent effect

Application to multiple light scattering
Case of forward-peaked scattering



We have obtained cross shaped patterns with a contrast :

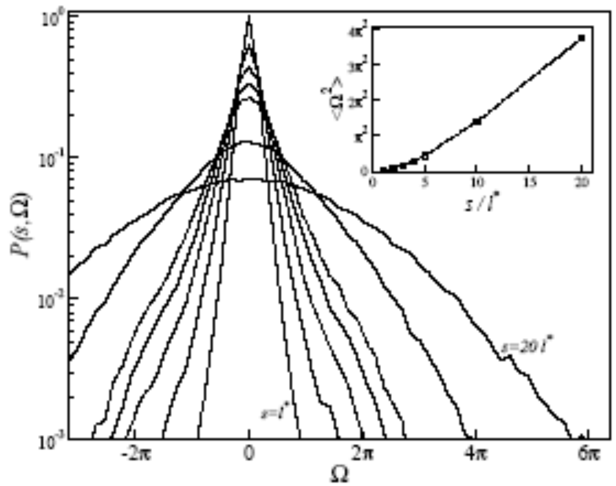
$$C(R) = \frac{1}{I_0(R)} \int P(s,R) \langle \cos(2\Omega(s)) \rangle ds$$

- Distribution of geometrical phase is gaussian for s>> ℓ^*

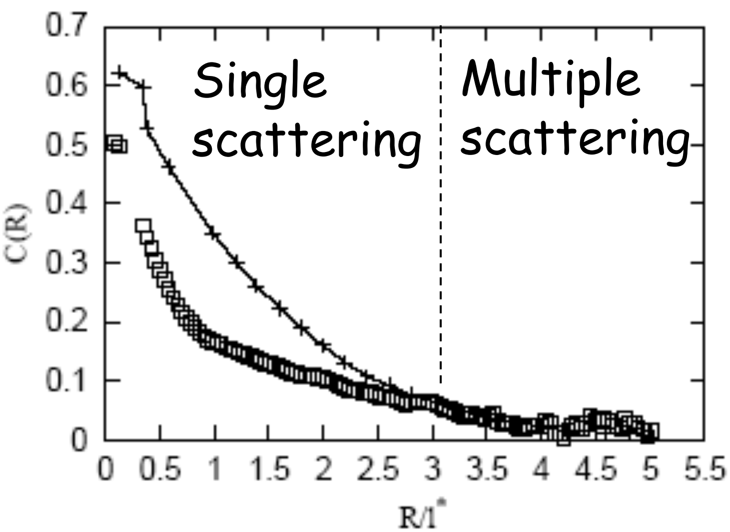
- Linear polarization decays on a length scale ℓ_p analogous to absorption length scale

$$\langle \cos 2\Omega \rangle = \exp(-\frac{s}{\ell_p})$$

Distribution of geometrical phase Ω (Monte Carlo simulations)



Experiment: colloïdal suspension (g=0.91)



D. L., V. Rossetto, F. Jaillon, H. Saint-Jalmes
Optics Letters, **29** 2040 (2004).

Polarization resolved diffuse wave spectroscopy (DWS)

Analysis of fluctuations of speckle intensity $g_2(t) = \langle I(t)\,I(0)\rangle$

Correlation function of electromagnetic field

$$g_1(t) = \sqrt{1 - g_2(t)} = \int P(s)\exp(-2\frac{t\,s}{\tau_0\,\ell^*})\,d\,s$$

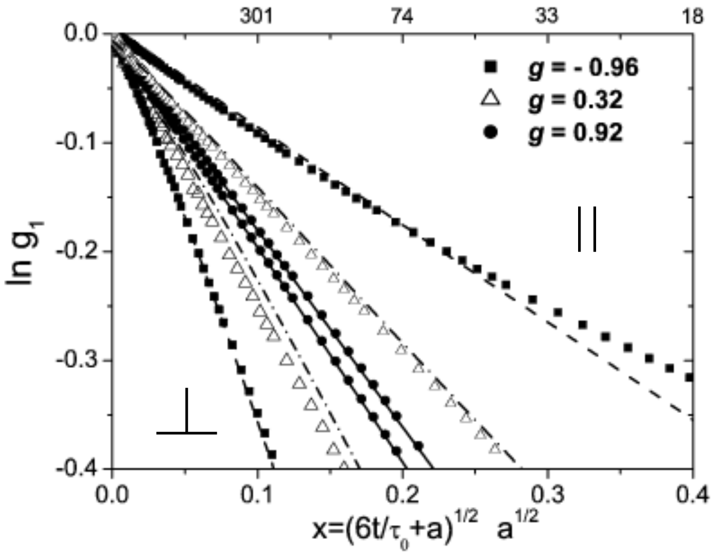
Short paths -> long decay time of correlation function

For colloids in brownian motion: $\tau_0{}^{-1} = k_0{}^2 D = \dfrac{4\pi^2}{\lambda^2} D$

Many other applications of DWS: micro-rheology of soft matter, granular media or biological tissues…

Polarization memory of multiply scattered light probed by DWS
MacKintosh et al. PRB 40, 9342 (1989)

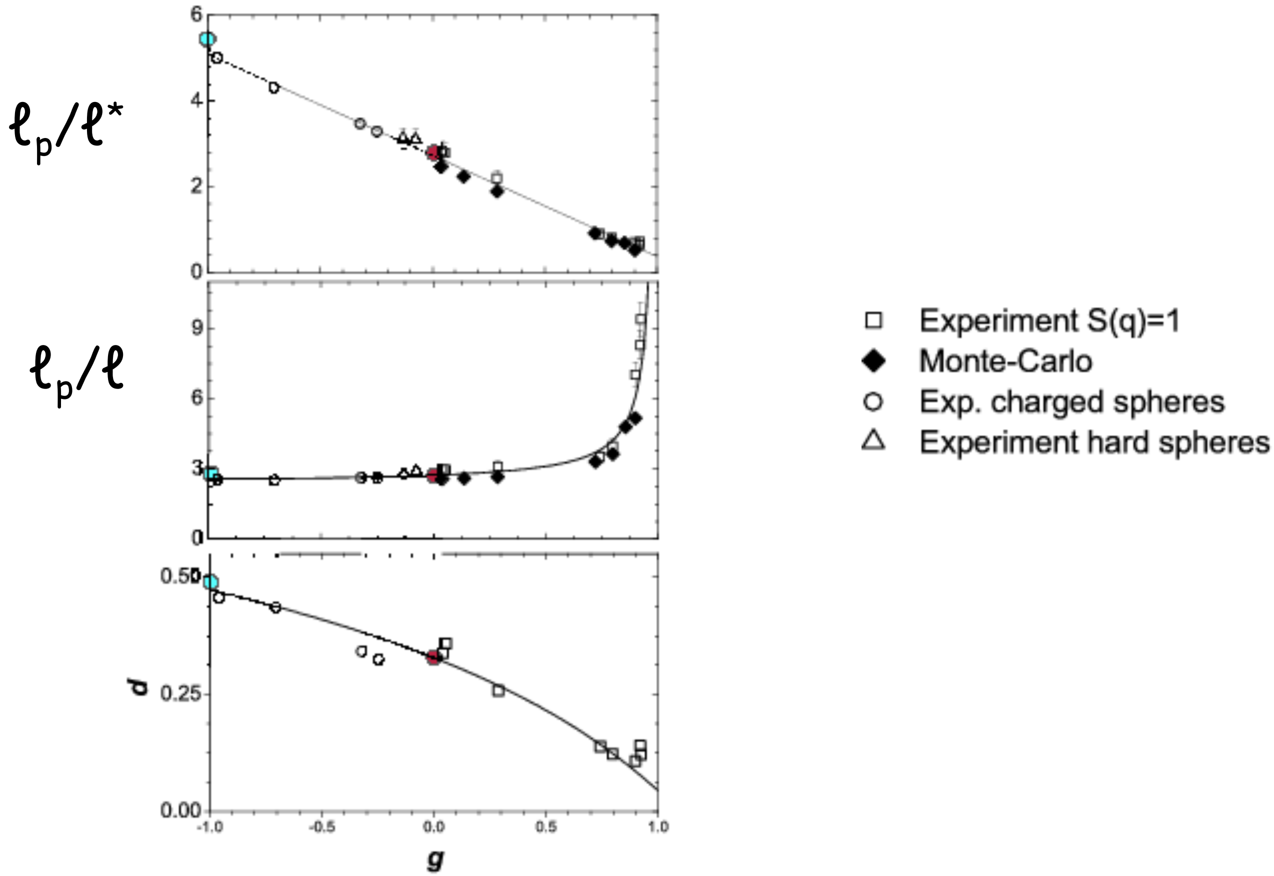
Linearly polarized light in backscattering



LF Rochas-Ochoa, D. L.,
R. Lenke, P. Schurtenberger,
F. Scheffold,
JOSA, **21**, 1799 (2004).

- Parallel polarizers : short paths contribute more -> slower decay of g
- Predominant forward scattering -> longer characteristic path length
- Depolarization length ℓ_p is unique adjustable parameter

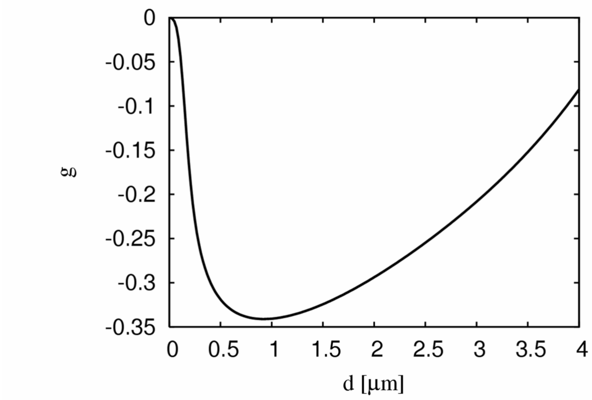
Measurement of ℓ_p and polarization degree d as function of anisotropy parameter g



- g=0, Rayleigh scattering (Akkermans 1988)
- g->1, forward-peaked scattering,
- g->-1, backward peaked scattering

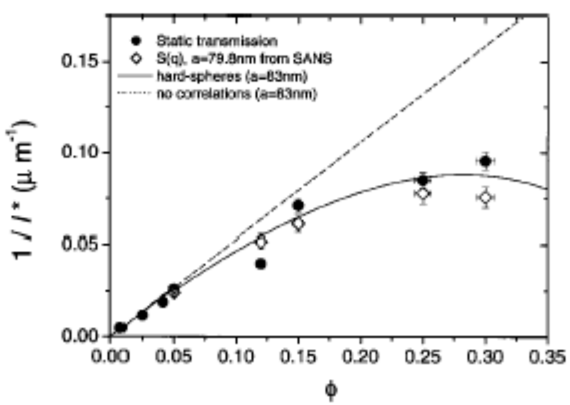
How to create a medium with negative g<0 ?

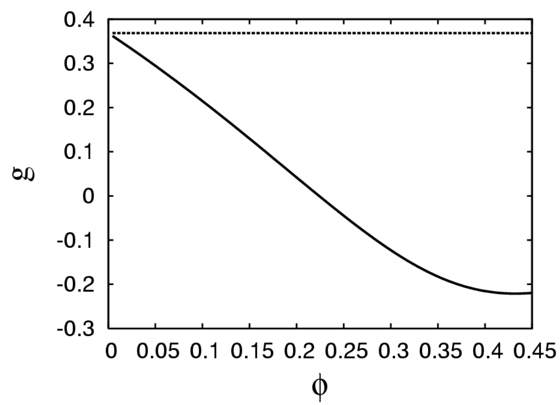
- With metallic spheres :
  Example: Mie scattering with Platinum spheres in infrared at λ=10μm,
  index of refraction m=37-41i



- In a medium with density correlations :
  By tuning these correlations through particle interactions, any value of g (with -1<g<1) is accessible.

For hard spheres





From F. Scheffold et al., PRE **65**, 051403 (2002); PRL **93**, 073903 (2004)

Conclusion

• Geometric mechanism for the loss of memory of linear polarization in multiple scattering
-> geometric depolarization

• Applications to complex fluids (or biological tissues) which scatter light predominantly in forward direction.

• Polarization resolved DWS in correlated media.
Determination of a characteristic depolarization length ℓ_p