Instruments

Insoluble Monolayers: Preparation, characterisation and use in functional surfaces and nanotechnology

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Why ?

- Thin organic films of a thickness of a few nanometers (a monolayer) are the source of high expectations as being useful components in many practical and commercial applications such as sensors, detectors, displays, coatings and electronic circuit components
- Nowadays materials can be synthesized almost without any limitations with desired functionality ⇒ Combined with LB enables the production of electrically, optically and biologically active components on a nanometer scale
- Powerful technique for mimicking molecular binding, transport and interactions in biological membranes
- Not only restricted to organic materials anymore – solid nano- and microparticles and fibers has been used as film forming materials

Why ?

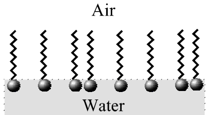
- Promising deposition technique for monolayers due to its advantages compared to other techniques i.e.
  1) Enables precise control of the monolayer (thin film) thickness and packing density,
  2) Homogeneous deposition over large areas
  3) Enables multilayer structures with varying layer composition
  4) Deposition can be made on any kind of solidsubstrate
- Enables also the study of interactions between materials on a molecular level

Basic concepts in Langmuir and Langmuir-Blodgett technology

Insoluble Monolayers

- Make use of the ability of surfactants to lower the surface tension of water based subphases
- There exists a wide range of surfactants with an amphiphilic nature which drastically lower the surface tension of water
- Surfactants with longer hydrocarbon chains than 14-16 are practically insoluble in water
- These amphiphilic substances can with the help of a volatile and water insoluble solvent easily be spread on a water surface to form an insoluble monolayer at the air/water interface: Langmuir film

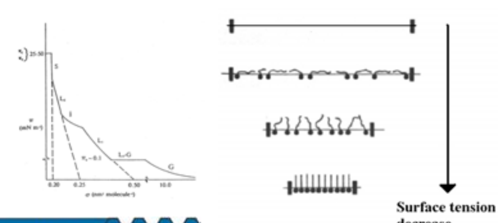
Air



Surface pressure, π

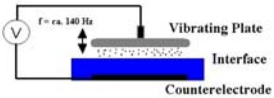
- Surface pressure is the decrease in surface tension of a water subphase when a monolayer is spread and compressed on the air-water interface

$\pi = \gamma_0 - \gamma$, γ_0 = surface tension of subphase without any monolayer
γ = surface tension of subphase with monolayer present

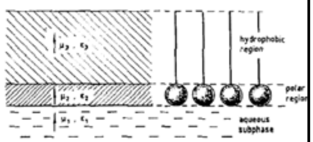


Surface potential, ΔV

- Caused by changes in the orientation and accumulation of dipole moments at the air-water interface

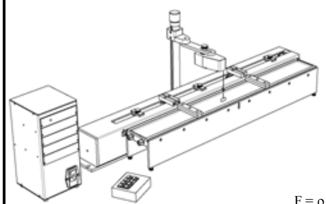


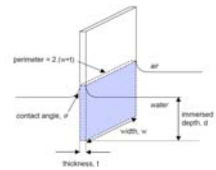
$$\Delta V = \mu_n / \epsilon\epsilon_0 A$$



Langmuir film balance

- Balance + movable barriers in a feedback loop
- Wilhelmy plate electrobalance measures the surface pressure, simultaneously as the barriers reduces the available surface area.



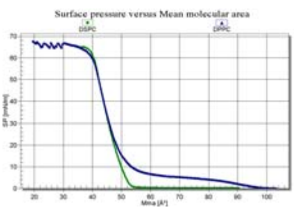


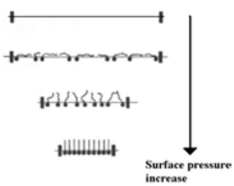
$$F = \rho_p g l_p w_p t_p + 2\gamma(t_p w_p)(\cos) - \rho_l g t_l w_l h_l$$

$$\Pi = -\Delta\gamma = -[\Delta F / 2 (t_p+w_p)] = -\Delta F / 2w_p \text{ , if } w_p >> t_p$$

Compression isotherm

- The recorded data are usually plotted as Surface pressure versus Mean Molecula Area, which results in the compression isotherm





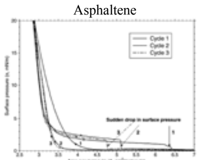
Compression isotherm

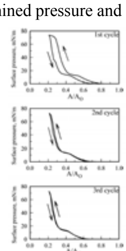
- The phase behaviour of the monolayer is mainly determined by:
  - The physical and chemical properties of the amphiphile
  - The subphase temperature and pH
  - The subphase composition i.e. salt concentration, type of salt, small molecules, biomolecules...
  - Compression speed
- An increase in the chain length increases the attraction between molecules, condensing the π-A-isotherm. On the other hand, if an ionazible amphiphile is used the ionisation of the head groups induces repulsive forces tending to oppose phase transitions.

Compression isotherms - Hysteresis

- Can be used to evaluate how well the monolayer material can retain its configuration during its expansion after a compression, or how mixed monolayers behave by squeezing out smaller molecules
- Monolayer compressed to a predetermined pressure and then decompressed

Asphaltene



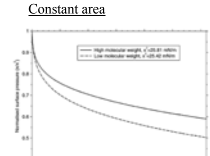


DPPC

Compression isotherms – Relaxation isotherms (Stability)

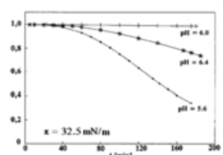
- Monolayer compressed to a predetermined pressure and then kept at this
- Monolayer compressed to a predetermined pressure at a certain area and then kept at constant area

Constant area



Comparison of relaxation isotherms for high- and low-molecular-weight asphaltene monolayers relaxed at a surface pressure of $\pi^0 \approx 25$ mN/m at 20.0 °C.

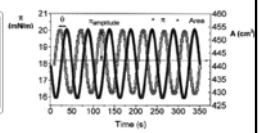
Constant pressure



The kinetic stability curves for stearic acid monolayers on $CdCl_2$ at three different pH values.

Compression isotherms – Oscillating barriers (interfacial elasticity)

- Monolayer compressed to predetermined surface pressure after which the barriers is started to oscillate
- Visco-elastic parameters of the monolayer can be obtained by using the oscillating barrier method (dilational properties)



$E^* = E' + iE'' = |E| \times \cos\phi + i|E| \times \sin\phi$

$|E| = \gamma_A / [A_A/A_{mean}]$

$|E| = \pi_{amplitude} / \ln A_{amplitude}$

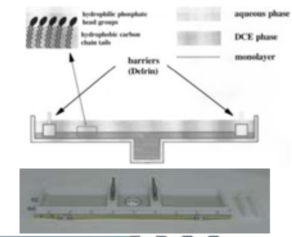
$\pi_{amplitude}$, θ →

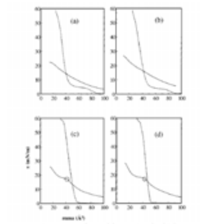
$E_d = |E| \cdot \cos\theta$
$E_v = |E| \cdot \sin\theta$
$\tan\theta = E_d/E_v$

Compression isotherms – Water/Oil

- Isotherms measured at water-oil interface resembles more closely real life situations

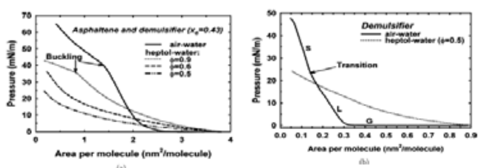
Dichloroethane/Water





Compression isotherms – Oil/Water

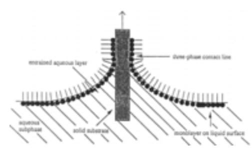
- Isotherms measured at oil-water

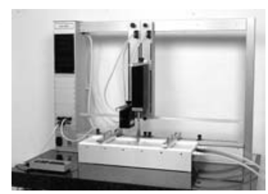


Comparison of pressure–area (π–A) isotherms of asphaltene ($x_d = 0$) and demulsifier ($x_d = 1$) monolayers, at the heptol–water and air–water interfaces: (a) asphaltene monolayers at heptol–water interfaces for $\phi = 0.5$, 0.6, and 0.9 and at the air–water interface; (b) demulsifier monolayers at the heptol–water interface for $\phi = 0.5$ and at the air–water interface.

LB Deposition

- The floating monolayer or Langmuir film can also be deposited on a solid substrate for building up highly organised multilayers of the used monolyaer material: Langmuir-Blodgett films
- Done by successively dipping a solid substrate up and down through the monolayer while simultaneously keeping the surface pressure constant by a computer controlled feedback system between the electrobalance measuring the surface pressure and the barrier moving mechanism





LB deposition

- The LB deposition is traditionally carried out in the "solid" phase. The surface pressure is then high enough to ensure sufficient cohesion in the monolayer
- The surface pressure value that gives the best results depends on the nature of the monolayer and is usually established empirically (10-40 mN/m)
- When the solid substrate is hydrophilic (glass, SiO_2 etc.) the first layer is deposited by raising the solid substrate from the subphase through the monolayer, whereas for a hydrophobic solid (HOPG, silanized SiO_2 etc.) the deposition is started from air
- The quantity and the quality of the deposited monolayer on a solid support is measured by a so called transfer ratio, t.r. This is defined as the ration between the decrease in monolayer area during a deposition stroke, A_l, and the area of the substrate, A_s. For ideal transfer the t.r. is equal to 1

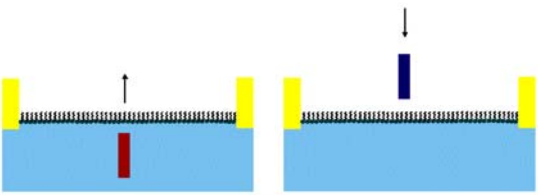
LB deposition

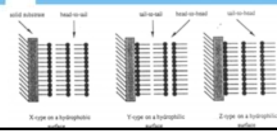
- Several parameters affect what type of LB film is produced:
  - Nature of the spread film
  - Subphase composition, pH and temperature
  - Surface pressure during the deposition
  - Deposition speed
  - Type and nature of the solid substrate
  - The time the solid substrate is stored in air or in the subphase between the deposition cycles

Classical LB deposition

- Vertical deposition

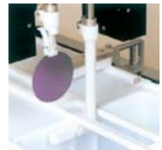
Hydrophilic substrate | Hydrophobic substrate

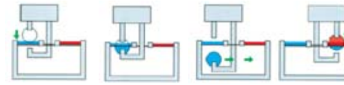


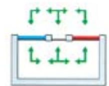


Alternate LB deposition

- Special case of normal LB deposition – 2 different monolayer materials can be deposited in any configuration

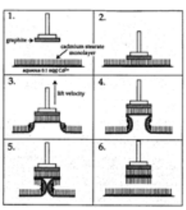




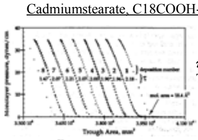


Horizontal deposition

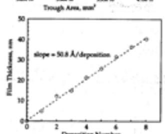
- Sometimes vertical deposition unwanted
- Alternative is horizontal deposition (Langmuir-Schaeffer)
- Basically the same preparative procedures as for vertical depositions



<u>Cadmiumstearate, C18COOH-Cd</u>



π = 35 mN/m
T.R. = 2.06 ± 0.1

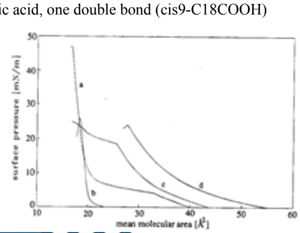


Instruments

Utilizing the Langmuir and Langmuir-Blodgett films

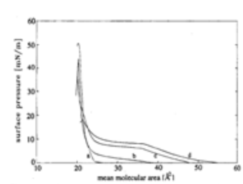
Compression isotherms

- Differences in chain conformation:
  a) Stearic acid ($C_{18}COOH$)
  b) Petroselaidic acid, one double bond (trans6-C18COOH)
  c) Elaidic acid, one double bond (trans9-C18COOH)
  d) Oleic acid, one double bond (cis9-C18COOH)

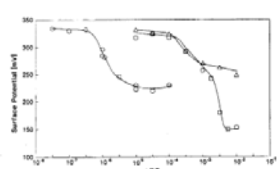


Compression isotherm + ΔV

- Effect of added salt in subphase:
  – Petroselaidic acid, one double bond (trans6-C18COOH)



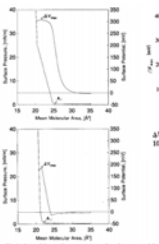
The π/A isotherms of petroselaidic acid on (a) 5×10^{-6} M, (b) 5×10^{-7} M, and (c) 10^{-7} M $TbCl_3$ and (d) pure water (pH = 2).



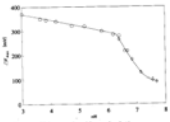
ΔV_{max} vs salt concentration for (a) petroselaidic acid on (○) $TbCl_3$, (□) $MnCl_2$, and (△) $CdCl_2$ solutions at pH = 5.7.

Compression isotherm + ΔV

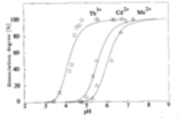
- Effect of different pH with constant salt concentration:
  - Stearic acid (C18COOH)



Variations of the surface pressure and surface potential isotherms with pH for stearic acid on 10^{-4} M $MnCl_2$: (a, top) pH = 5.65; (b, bottom) pH = 6.85.



ΔV_{max} vs pH for stearic acid on subsolution 10^{-4} M $MnCl_2$: ○, no buffer; ●, $H_2PO_4^-$–HPO_4^{2-} buffer.



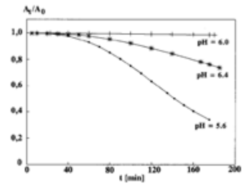
Degree of dissociation, α, of stearic acid as a function of pH on (a) 0.5 × 10^{-4} M $TbCl_3$, (b) 10^{-4} M $CdCl_2$, and (c) 10^{-4} M $MnCl_2$.

$$[H^+] = K(\alpha^{-1/\nu} - \alpha^{(\nu-1)/\nu}), \quad 0 < \alpha < 1$$

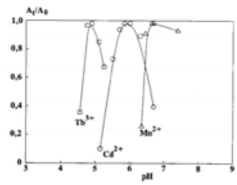
$$K = (\nu K_a^{\nu} K_s [M^{\nu+}] \Gamma_0^{\nu-1})^{1/\nu}$$

Compression isotherm - Stability

SA on subphases with constant concentration of different ions but different pH



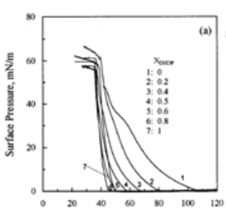
The kinetic stability curves for stearic acid monolayers on $CdCl_2$ at three different pH values.

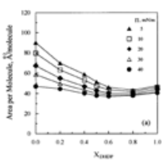


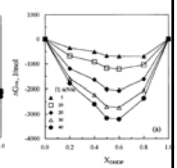
The stability of stearic acid monolayers vs. pH on $TbCl_3$, $CdCl_2$ and $MnCl_2$ subphases. The time t at which A_t/A_0 was determined was 100 min for the Tb subphase and 175 min for Cd and Mn subphases. The surface pressure was 32.5 mN m^{-1} for the subphases containing divalent ions and 30 mN m^{-1} for the Tb subphase.

Compression isotherms - Thermodynamics

- Mixing of monolayer materials; Dipalmitoylphosphatidylcholine (DPPC) and dihexadecyl phosphate (DHDP). Lipids used for liposome preparation.





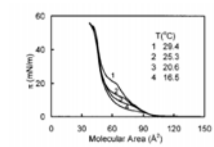


$$A_{ex} = A_{12} - A_{id} = A_{12} - (X_1 A_1 + X_2 A_2)$$

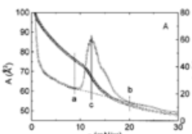
$$\Delta G_{ex} = \int_0^{\Pi} [A_{12} - (X_1 A_1 + X_2 A_2)]\, d\Pi$$

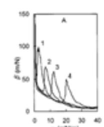
Compression isotherms - Thermodynamics

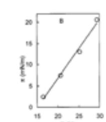
- DPPC: Temperature dependence and compressibility



$$\beta = -\frac{1}{A}\left(\frac{\partial A}{\partial \pi}\right)_T$$

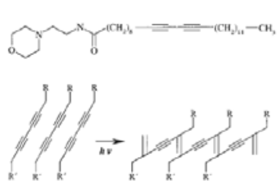


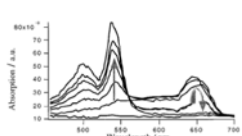




Monolayer Polymerization

- UV induced polymerization of diacetylenes

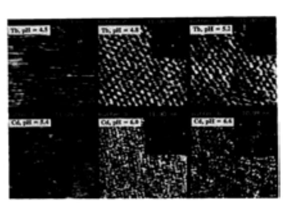




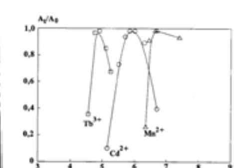
Consecutive in situ absorption spectra of the photopolymerization of a monolayer of EMPDA at the air/water interface at a subphase being thermostated to 5 °C. The absorption curves were taken at illumination times of 0, 2, 4, 7, 15, and 25 s and 3 min.

Deposition - Stability

- Quality of deposited film improved by tuning the stability of monolayer



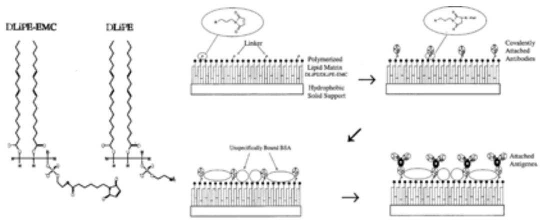
The AFM top view images for Tb and Cd stearate deposited at three different pH values.



The stability of stearic acid monolayers vs. pH on $TbCl_3$, $CdCl_2$ and $MnCl_2$ subphases. The time t at which A_t/A_0 was determined was 100 min for the Tb subphase and 175 min for Cd and Mn subphases. The surface pressure was 32.5 mN m^{-1} for the subphases containing divalent ions and 30 mN m^{-1} for the Tb subphase.

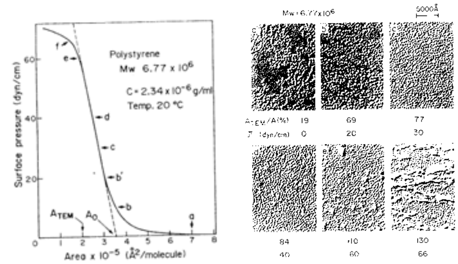
Deposition - Biomembranes

- Polymerized monolayer with functional group for covalently immobilize antigens



Deposition - Microparticles

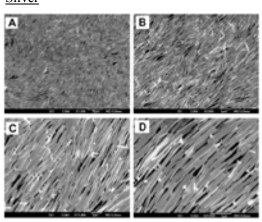
- Polystyrene particle deposition



Deposition - Nanowires

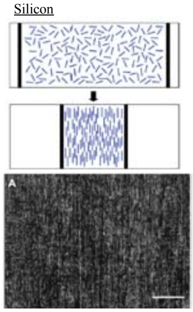
- Nanowire deposition with LB technique

Silver



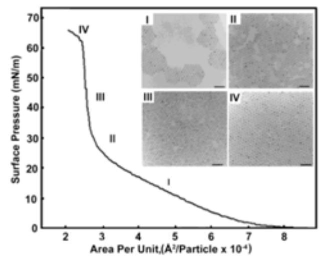
Scanning electron microscopy images (at different magnifications) of the silver nanowire monolayer deposited on a silicon wafer.

Silicon

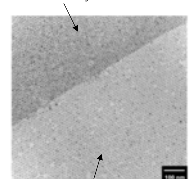


Deposition - Nanoparticles

- Fe_2O_3 nanoparticle deposition with LB technique



Double layer

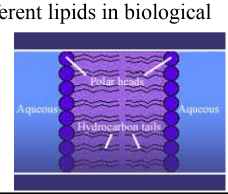


Monolayer

Practical/Commercial Applications?

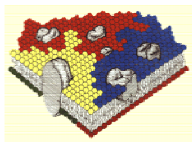
Basic properties of biomembranes

- Monolayers simple models of biological membranes
- Main components of mammalian plasma membrane and cell membranes are different lipids; phospholipids, sphingolipids, cholesterol etc.
- Studies with monolayers can help understanding the behaviour and role of different lipids in biological membranes



Interaction of biomolecules with membranes

- Basic research topics to understand and control the mechanism and interactions at molecular level
- Implications to biotechnology, pharmaceutical & cosmetic industry
  - Biocompatible surfaces
  - Incorporation of biomolecules in artificial membranes
  - Surface epidermal cell interacations
  - Drug delivery
  - Enzyme interactions
  - Respiratory Distress Syndrome (RDS)



Sensors

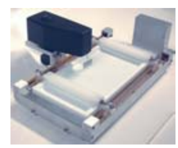
- Chemical sensors of LB films are developed for gas, bio, food, beverage etc applications.
- Gas and volatile organic compoound (VOC) sensors requires large surface to bulk ratio. This gives higher signals for lower concentrations of gas and can improve reversibility of the detection process. LB layers are ideal candidates for these sensors.
  - Gas sensors have been developed for example for NO_x, SO_2, CO, Cl_2, NH_3 etc.
  - VOC sensors have been developed for example for acetic acid, citric acid, glutamic acid, ethanol, n-butyl acetate, hexanal, saxitoxin, sucrose quinine etc.
- Biosensors should be able to use small ammount of analytes which is possible with LB film based sensors as they are nanoscale layers. Furthermore, the LB technology have been proven to enable controlled oriented immobilization of active biomolecules by using linker lipids or streptavidin-biotin-lipids.
  - Immunological assays; antibody-antigen reactions
  - Detection of biotin functionalized biomoleules

Technological Applications

- The capability of fabricating dimensions to mono-molecular tolerances and their ability to incorporate different molecular architecture give LB films some unique advantages for technological applications.
  - Optical waveguides and signal processing devices based on thin organic films are being developed for computing and communications applications due to their nonlinear optical properties and fast respons times
  - Organic photoactive and/or conductive layers are being developed for organic light emitting diodes, organic solar cells, liquid crystal displays, optical information storage, optical switching etc...
  - CdS and TiO_2 nanoparticles are studied due to their excellent photocatalytic properties.
  - Magnetic nanoparticles (magnetite Fe3O4 and maghemite Fe2O3) are of great interest for applications in information storage systems, catalysts, ferrofluids, and medical diagnostics.
  - Nanoparticles and –wires are are being used as templates for nanoscale photoresists
  - Hybrid materials of clays and amphiphilic cations are being studied for ion-exchange materials and catalysis applications

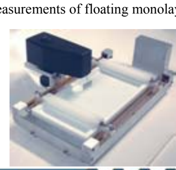
KSV LB Trough Models

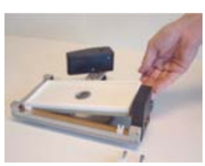
- MiniMicro
- Minitrough
- KSV2000



KSV MiniMicro

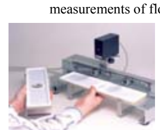
- The smallest miniaturized Langmuir/Langmuir-Blodgett trough on the market
- Standard trough size; 170 mm (l) x 80 mm (w) x 5 mm (d) = 68 ml, other trough sizes by request
- Transportable and quick setup; exchangable troughs for modularity
- Full size software enabling all most common Langmuir film studies from compression (expansion) isotherms, isobars, dilational elasticity and Langmuir-Blodgett deposition
- Maximum substrate size for deposition; 25 mm (w) x 30 mm (l)
- Compatible with major thin film characterization techniques; Brewster Angle Microscopy, Fluoresence Microscopy, UV-Vis, IRRAS and Synchrotron beam line measurements of floating monolayers

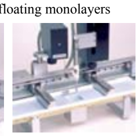


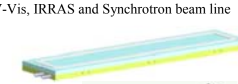


KSV MiniTrough

- The most sold Langmuir/Langmuir-Blodgett trough system in the world
- Cost efficiency without compromize
- Standard trough size; 330 mm (l) x 75 mm (w) x 5 mm (d) = 125 ml, other trough sizes by request
- Low volume (from 15 ml), oil/water, microscopy, enzyme kinetics trough options
- Full size software enabling all most common Langmuir film studies from compression (expansion) isotherms, isobars, dilational elasticity and Langmuir-Blodgett deposition
- Maximum substrate size for deposition; 35 mm (w) x 60 mm (l)
- Compatible with major thin film characterization techniques; Brewster Angle Microscopy, Fluoresence Microscopy, UV-Vis, IRRAS and Synchrotron beam line measurements of floating monolayers







KSV 2000

- The cost effective, full size modular and open design Langmuir/Langmuir-Blodgett trough system
- Expands from a full size conventional Langmuir film balance to a high performance Langmuir film deposition system or to a fully equipped alternating multilayer Langmuir-Blodgett instrument; MiniAlternate Option (trough volume 1 L instead of 6 L)
- Compatible with all the special trough options of the KSV MiniTrough
- Standard trough size; 580 mm (l) x 150 mm (w) x 7 mm (d) = 610 ml
- Full size software enabling all most common Langmuir film studies from compression (expansion) isotherms, isobars, dilational elasticity and Langmuir-Blodgett deposition
- Maximum substrate size for deposition; 100 mm (w) x 100 mm (l)
- Compatible with most thin film characterization techniques; Brewster Angle Microscopy UV-Vis and IRRAS measurements of floating monolayers



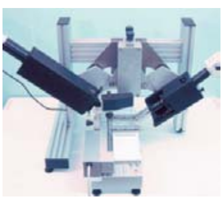
Langmuir film characterisation methods

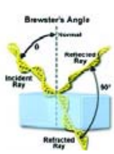
BAM

PM-IRRAS

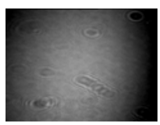
ISR

Brewster Angle Microscope, BAM
KSV Optrel BAM300

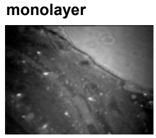




film absent



formation of monolayer



resolution – 2 μm

angle of incidence 45-75 degree

Use of BAM – morphology of monolayer

- Gibbs adsorption isotherm
- crystallization

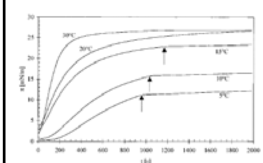
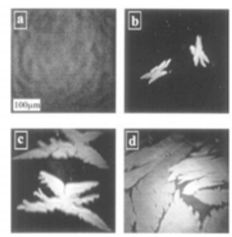


Figure 2. π(t) adsorption kinetics of 1.5 × 10^{-5} M aqueous DHBAA solution at different temperatures: 1−5, 2−10, 3−15, 4−20, and 5−30 °C. The appearance of the phase transition point and its coordinates are a function of the temperature *T*.

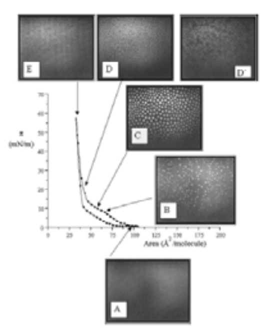


D. Vollhardt, V. Melzer, *J.Phys.Chem.B,* 101**(1997)**3370.

Use of BAM – morphology of monolayer

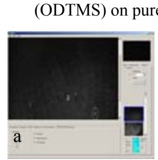
Dipalmitoyl phosphatidyl glycerol (DPPG)

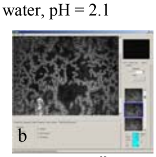
J. Minones Jr., P. Denarowicz Łątka, J. Minones, J.M. Rodriquez Patino, E. Iribarnegaray, *J.Coll.Interf.Sci.,* 265**(2003)**380.

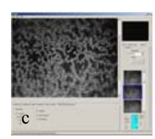


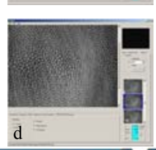
Use of BAM - monolayer polymerization

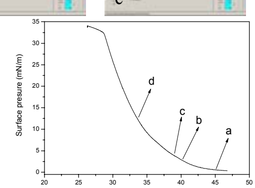
- Condensation polymerization, Octadecyltrimethoxysilane (ODTMS) on pure water, pH = 2.1





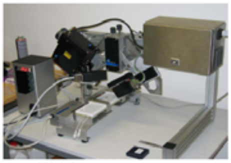


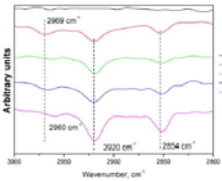




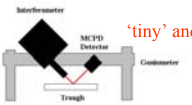
(Polarization modulation) - Infrared Reflection Absorption Spectroscopy, **PM-IRRAS**

New!!





air/water *or* air/solid



'tiny' and easy to use!

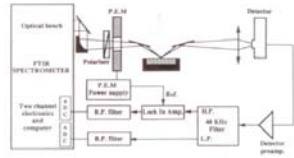
Resolution – 8 cm^{-1}

Spectral range 800 - 4000 cm^{-1}

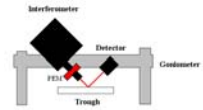
Angle of incidence 40-85 degree

PM-IRRAS

- Optical techniques widely used in surface characterization
- Advantage of optical techniques that they are non-invasive
- Molecular scale analysis of thin films at air-water, air-solid, and even liquid-solid interfaces
- Enables quantitative analysis of film properties



Traditional approach



KSV´s approach

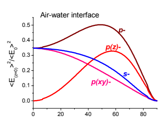
IRRAS vs PM-IRRAS

IRRAS

- Reference spectrum taken without a sample (e.g. clean subphase) is used to resolve sample´s response from instrument´s spectrum

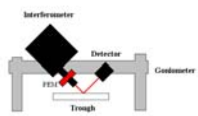
PM-IRRAS

- Utilizes the fact that light's polarization state changes in reflection thus yielding differing spectra for differing polarization states
- Since atmospheric disturbance (H20 and CO2) is isotropic, i.e. has no polarization preference, its contribution to IRRAS measurement can be greatly reduced



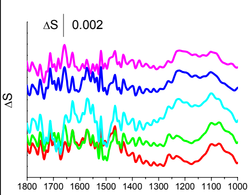
PM-IRRAS

- Usual choice is to modulate polarization between *s* and *p* –states and record spectra for both states S_s and S_p
- Define differential reflectivity spectrum $\Delta S/S = (S_s - S_p)/(S_s + S_p)$
- Isotropic disturbance is in theory cancelled out from differential spectrum
- Sample's isotropic absorption cancelled

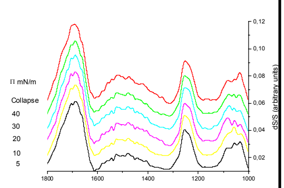


IRRAS vs PM-IRRAS of DPPC on pure water – Polar Part

IRRAS

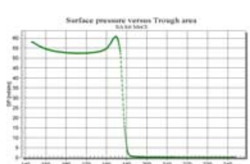


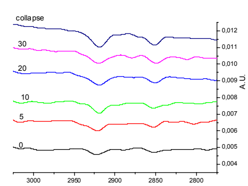
PM-IRRAS



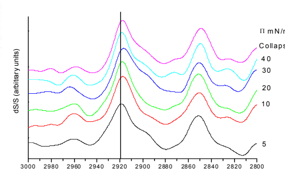
SA on $MnCl_2$ subphase

IRRAS





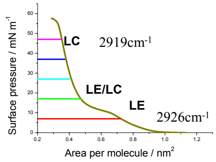
PM-IRRAS

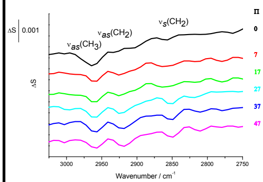


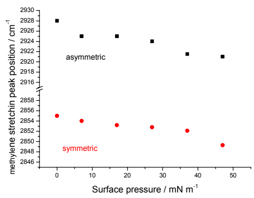
IRRAS of DPPC on pure water

Measurement angle 45 °

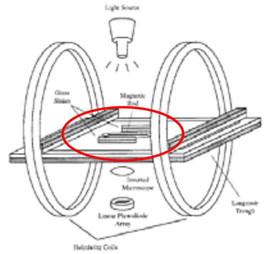
Acyl chain tilt angle ~28°

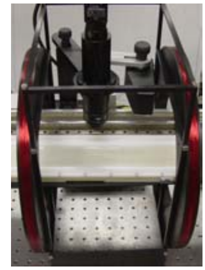






Interfacial Stress Rheometer



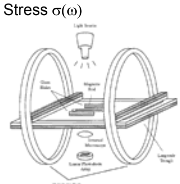


C.F. Frank, G.G. Fuller, C.W. Frank, C.R. Robertson, *Langmuir*, 15**(1999)**2450.

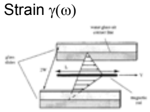
www.ksvltd.com

Interfacial Stress Rheometry – The principle

Stress $\sigma(\omega)$



Strain $\gamma(\omega)$



1) Applies a controlled stress, σ, to an interface by creating a magnetic field gradient onto a magnetic rod at the interface

2) The magnetic field causes the needle to glide at the interface inducing a simple shearing deformation

3) The resulting strain, γ, is measured in real time by imaging the position of the needle.

C.F. Frank, G.G. Fuller, C.W. Frank, C.R. Robertson, *Langmuir*, 15**(1999)**2450.

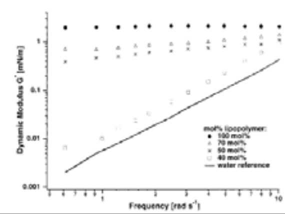
www.ksvltd.com

Interfacial Stress Rheometry – The principle

$$G_s^*(\omega) = \frac{\sigma_s}{\gamma_0} e^{i\delta(\omega)} = G_s'(\omega) + iG_s''(\omega)$$

Elastic properties   Viscous properties

- Condensation processes
- Gelation
- Polymer adsorption



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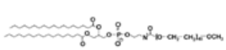
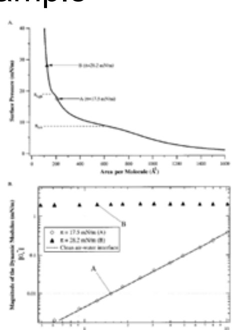
Interfacial Stress Rheometry - Example -

Phase transitions in polymer films



DSPE-PEG2000



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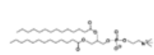
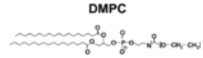
ISR – Example

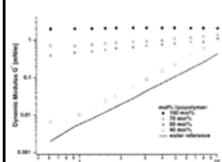
Phase transition in mixed polymer films

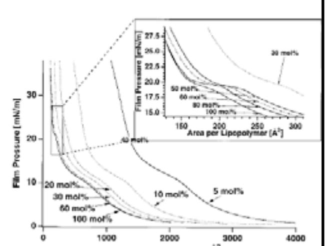


DMPC



DSPE-PEG2000



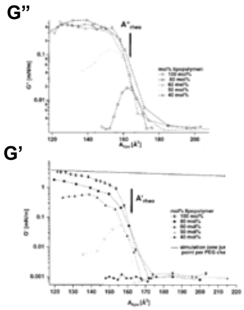


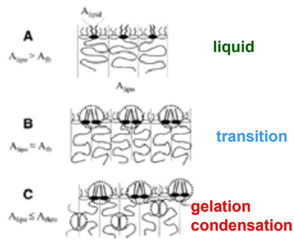
C.A. Naumann, C.F. Brooks, W. Wiyatno, W. Knoll, G.G. Fuller, C.W. Frank, *Macromolecules*, 34**(2001)**3024.

www.ksvltd.com

ISR – Example

Polymer condensation

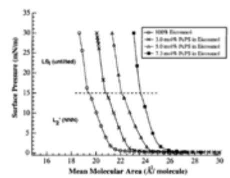




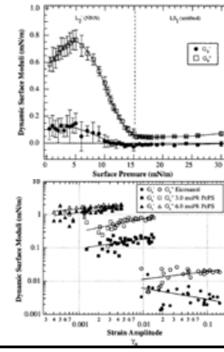
C.A. Naumann, C.F. Brooks, W. Wiyatno, W. Knoll, G.G. Fuller, C.W. Frank, *Macromolecules*, 34**(2001)**3024.

ISR – Example

Nature of phase transitions



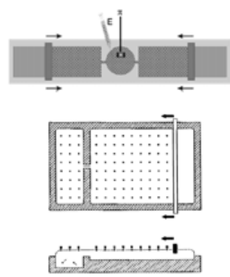
C.F. Frank, G.G. Fuller, C.W. Frank, C.R. Robertson *Langmuir*, 15**(1999)**2450.

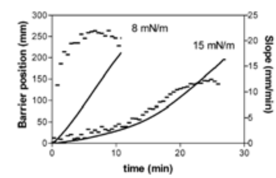


Customized/Special designs

Zero order trough

- Studying zero order reactions (enzyme kinetics)



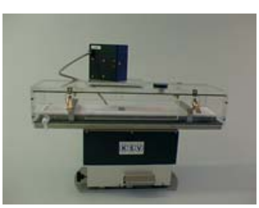


Reaction progress for the hydrolysis of PC10 monolayer at 8 or 15 mN/m by 10.6 μg of PLA2.

Instruments

Synchrotron trough – Gracing Incidence X-ray Diffraction (GIXD)

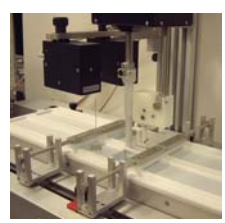
Example



Big Dipping trough 30×30 cm²

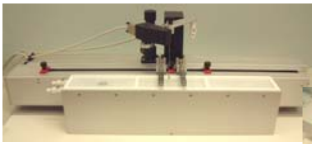
Mini Alternate for KSV2000 and KSV5000

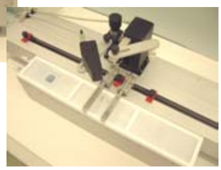
- 1.5 L of subphase only
- max. substrate size 45 × 45 mm²



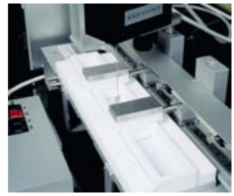
An alternate trough for 6” Wafers has also been done !!!

Fromhertz trough





Interfacial trough – Oil/water

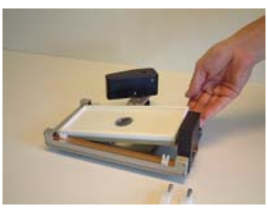


Trough with electrode in the subphase

Example 1

Example 2

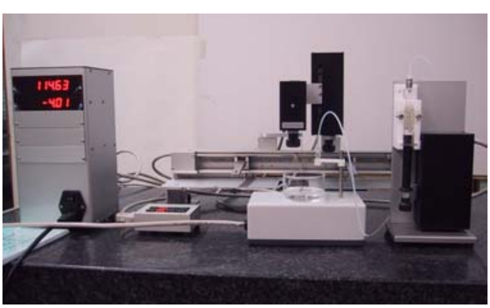
MiniMicro trough



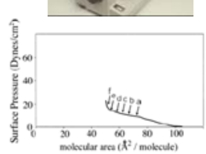
Big Dip Coater

6" wafer Alternate Dipping trough

Converting Minitrough to a CMC measuring tensiometer



Fluorescence microscopy



L-DPPC