

## TIME TABLE

TIME	Monday June 15	Tuesday June 16	Wednesday June 17	Thursday June 18	Friday June 19
9.00 - 9.45	Registration	Lowengrub	Papageorgiou	Thiele	Papageorgiou
9.45 - 10.30	Mauri	Lowengrub	Papageorgiou	Thiele	Papageorgiou
11.00 - 11.45	Mauri	Plapp	Thiele	Anderson	Mauri
11.45 - 12.30	Mauri	Plapp	Thiele	Anderson	Mauri
14.30 - 15.15	Lowengrub	Lowengrub	Anderson	Papageorgiou	
15.15 - 16.00	Lowengrub	Lowengrub	Anderson	Papageorgiou	
16.30 - 17.15	Plapp	Thiele	Plapp	Anderson	
17.15 - 18.00	Plapp	Thiele	Plapp	Anderson	

## ADMISSION AND ACCOMMODATION

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through our web site: <http://www.cism.it> or by post.

A message of confirmation will be sent to accepted participants. If you need assistance for registration please contact our secretariat.

The registration fee is 600,00 Euro.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered board and/or lodging in a reasonably priced hotel. Requests should be sent to CISM Secretariat by **April 15, 2009** along with the applicant's curriculum and a letter of recommendation by the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

The Deutscher Akademischer Austausch Dienst (DAAD) and the Deutsche Forschungsgemeinschaft (DFG) offer support to German students. Please contact:

DAAD, Kennedyallee 50, 53175 Bonn  
tel. +49 (228) 882-0  
e-mail: [postmaster@daad.de](mailto:postmaster@daad.de)  
web site: <http://www.daad.de/de/kontakt.html>

DFG, Kennedyallee 40, 53175 Bonn  
tel. +49 (228) 885 2655  
e-mail: [ing4@dfg.de](mailto:ing4@dfg.de)  
web site: <http://www.dfg.de>

Information about travel and accommodation is available on our web site, or can be mailed upon request.

*For further information please contact:*

CISM  
Palazzo del Torso - Piazza Garibaldi 18  
33100 Udine (Italy)  
tel. +39 0432 248511 (6 lines)  
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e-mail: [cism@cism.it](mailto:cism@cism.it)



## MULTIPHASE MICROFLUIDICS - THE DIFFUSE INTERFACE MODEL

*Advanced School  
coordinated by*

**Roberto Mauri**  
Università di Pisa  
Italy

**Udine, June 15 -19, 2009**

## MULTIPHASE MICROFLUIDICS - THE DIFFUSE INTERFACE MODEL

The aim of this course is to formulate and apply the diffuse interface model for one-component, two-phase fluids and for liquid binary mixtures, to model multiphase flows in confined geometries. Multiphase flows are generally modeled assuming that the different phases are separated by an interface, that is a surface of zero thickness. Imposing that the condition of local equilibrium is satisfied, all physical properties are allowed to change discontinuously across the interface. Naturally, that results in a free boundary problem, which means that one of the main problems of this approach is to determine the position of the interface. In microdevices, an additional difficulty is encountered, as most lengthscales of the systems are

comparable to the real interface thickness; this problem arises also in modeling drop coalescence and break up and moving contact angles. In these cases, it is more reasonable to use a different approach, proposed at the end of the 19<sup>th</sup> century by Rayleigh and Van der Waals, where interfaces have a non-zero thickness, i.e. they are "diffuse", so that all quantities, such as density or composition, vary continuously.

The equations of motion are derived, showing how additional stresses, so called Korteweg stresses, arise naturally as reversible body forces, that tends to minimize the free energy of the system. In addition, constitutive relations for the diffusive fluxes are proposed, that insure that the problem is well posed, that is the

rate of change of the total energy of the system equals its energy dissipation.

Several case studies will be presented to demonstrate the advantages of the diffuse interface method in modeling multiphase flows in microdevices, as compared to the classical two-phase flow approach. Among the examples that will be presented, here we mention the following problems:

a) mixing, spinodal decomposition and nucleation of macroscopically quiescent regular mixtures; b) deformation, coalescence and break-up of fluid volumes under shear flows; c) drop movement through an interface and from a moving nozzle; d) film ruptures and coarsening in dewetting;

e) heat transfer enhancement due to phase change; f) chaotic mixing in microfluidics; g) spontaneous emergence of complex structures during growth far from equilibrium.

A considerable emphasis will be devoted to the advanced numerical modeling schemes that have been developed so far, stressing the computational difficulties encountered in implementing the diffuse interface method. In particular, stability problems will be analyzed, showing how they can be overcome.

The course is addressed to doctoral students, young researchers as well as practicing R&D engineers, dealing with multiphase flows and, in general, interested in microfluidics.

## PRELIMINARY SUGGESTED READINGS

Van der Waals, J.D. 1893. The thermodynamic theory of capillarity under the hypothesis of a continuous variation of density [Translated by J.S. Rowlinson in *Journal of Statistical Physics*, Vol. 20, p. 200-244 (1979)].

Anderson, D.M.; McFadden, G.B.; Wheeler, A.A. 1998. *Diffuse Interface Methods in Fluid Mechanics*. Annual Review of Fluid Mechanics Vol. 30, p. 139-165.

Pismen, L.M. 2006 *Patterns and Interfaces in Dissipative Dynamics*. Springer, New York.

Velarde, M.G.; Zeytounian, K.K. 2000 *Interfacial Phenomena and the Marangoni Effect*. Springer, New York.

Oron, A.; Davis, S.H.; Bankoff, S.G. 1997 Long-scale evolution of thin liquid films. *Rev. Mod. Phys.* 69, 931-980.

Pismen, L.M.; Pomeau, T. 2000 Disjoining potential and spreading of thin liquid layers in the diffuse interface model coupled to hydrodynamics. *Phys. Rev. E* 62, 2480-2492.

## INVITED LECTURERS

**Patrick D. Anderson** - Eindhoven University of Technology, The Netherlands

*6 lectures on:* Computational difficulties encountered in implementing the diffuse interface method. In particular, the mapping method for single-component fluid systems is designed to deal with the optimization of distributive mixing flows. Applications are found in chaotic mixing in microfluidics, self-stratifying coatings (phase-separation at interfaces) and inkjet design for fast, accurate printing or copying.

**John S. Lowengrub** - University of California at Irvine, CA, USA

*6 lectures on:* Latest development of the diffuse interphase model. Examples include modeling the motion of a drop through an interface, the dripping of a drop from a moving nozzle, deformation, coalescence and break-up of fluid volumes, phase inversion and interfacial deformation, that determine the physical (i.e. mechanical, optical, rheological, etc.) characteristics of multi-component flows.

**Roberto Mauri** - Università di Pisa, Italy

*5 lectures on:* History of the diffuse interface model with applications to one-component, two-phase fluids and liquid binary mixtures. Van der Waals theory is revisited, stressing that the diffuse interface model can be derived ab initio using irreversible thermodynamics. Numerical simulations about mixing, spinodal decomposition and nucleation of regular liquid mixtures are shown, together with heat effects.

**Demetrios T. Papageorgiou** - Imperial College, London, UK

*6 lectures on:* Stability problems involved in solving the diffuse interface system of equations. Problems on surface tension driven flows are studied using the diffuse interface approach, to investigate the stability, dynamics, and breakup of single and compound liquid jets, both in the presence and absence of surface active agents, which affect interfacial tension.

**Mathis Plapp** - Ecole Polytechnique, Palaiseau, France

*6 lectures on:* Application of the diffuse interface model the dynamics of phase transformations. Application to the spontaneous emergence of branched patterns in diffusion-limited growth. Methods of matched asymptotic expansions to relate diffuse-interface models to free boundary problems. Applications to pattern formation in fluid dynamics: viscous fingering and instabilities in ferrofluids triggered by magnetic fields.

**Uwe Thiele** - Loughborough University, UK

*6 lectures on:* Modeling the dynamics of thin liquid films. The long-wave sharp-interface limit of a diffuse interface theory is used to obtain a thin film evolution equation. The latter is analysed for homo- and heterogeneous substrates using as examples film rupture in dewetting, the pinning-coarsening transition on patterned substrates, and the depinning of driven drops. Finally, both, sharp and diffuse interface models are employed to study the structure formation in films of binary mixtures.

## LECTURES

All lectures will be given in English. Lecture notes can be downloaded from CISM web site, instructions will be sent to accepted participants.

# MULTIPHASE MICROFLUIDICS - THE DIFFUSE INTERFACE MODEL

Udine, June 15 - 19, 2009  
Application Form  
(Please print or type)

Surname \_\_\_\_\_

Name \_\_\_\_\_

Affiliation \_\_\_\_\_

Address \_\_\_\_\_  
\_\_\_\_\_

E-mail \_\_\_\_\_

Phone \_\_\_\_\_ Fax \_\_\_\_\_

**Method of payment upon receipt of confirmation (Please check the box)**

*The fee of Euro 600,00 includes IVA/VAT tax and excludes bank charges*

I shall send a check of Euro \_\_\_\_\_

Payment will be made to CISM - Bank Account N° 094570210900,  
VENETO BANCA - Udine (CAB 12300 - ABI 05418 - SWIFT AMBPIT2M - IBAN  
CODE IT83Z 05418 12300 09457 0210900).  
*Copy of the receipt should be sent to the secretariat*

I shall pay at the registration counter with check, cash or VISA  
Credit Card (Mastercard/Eurocard, Visa, CartaSi)

**IMPORTANT: CISM is obliged to present an invoice for the above sum. Please  
indicate to whom the invoice should be addressed.**

Name \_\_\_\_\_

Address \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

C.F.\* \_\_\_\_\_

VAT/IVA\* No. \_\_\_\_\_

(\*) Only for EU residents or foreigners with a permanent business activity in Italy.

**Only for Italian Public Companies**

I ask for IVA exemption (ex law n. 537/1993 - art. 14 comma 10).

**Privacy policy:** I understand that data received via this form will be used only to provide  
information about CISM and its activities, within the limits set by the Italian legislative  
decree no. 196/2003 and subsequent amendments.  
Complete information on CISM's privacy policy is available at [www.cism.it](http://www.cism.it).

I have read the "Admission and Accommodation" terms and conditions and agree.

Date \_\_\_\_\_ Signature \_\_\_\_\_