

## TIME TABLE

TIME	Monday June 29	Tuesday June 30	Wednesday July 1	Thursday July 2	Friday July 3
9.00 - 9.45	Registration	Ogden	Steinmann	Ogden	Dorfmann
9.45 - 10.30	Maugin	Ogden	Steinmann	Ogden	Dorfmann
11.00 - 11.45	Maugin	Dorfmann	Maugin	DeSimone	Ogden
11.45 - 12.30	Ogden	Dorfmann	Maugin	DeSimone	Ogden
14.30 - 15.15	Ogden	Steinmann	DeSimone	Dorfmann	
15.15 - 16.00	Maugin	Steinmann	DeSimone	Dorfmann	
16.30 - 17.15	Steinmann	DeSimone	Dorfmann	Maugin	
17.15 - 18.00	Steinmann	DeSimone	Discussion	Maugin	

### 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 29, 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)

Centre International des Sciences Mécaniques  
International Centre for Mechanical Sciences

ACADEMIC YEAR 2009  
The Broglio Session

# MECHANICS AND ELECTRODYNAMICS OF MAGNETO- AND ELECTRO- ELASTIC MATERIALS



*Advanced School  
coordinated by*

**Ray W. Ogden**  
University of Glasgow  
UK

**David J. Steigmann**  
University of California  
USA

**Udine, June 29 - July 3, 2009**

## MECHANICS AND ELECTRODYNAMICS OF MAGNETO- AND ELECTRO-ELASTIC MATERIALS

The theory of electromagnetic continua has received considerable stimulus in the last few years because of the rapid development of elastomeric and polymeric materials that can respond dramatically to the application of an electric and/or magnetic field. Such materials, often referred to as 'smart materials', are being used in a variety of applications, ranging from high-speed actuators and sensors, and active car suspensions and vibration isolators, to artificial muscles, and other biomedical applications. The key point is that the mechanical properties of the materials can be changed rapidly and substantially by externally applied electric or magnetic fields. Thus, the coupling between mechanics and electromagnetism is both strong and highly nonlinear. The coupling in the material response is typically achieved and optimized

by distributing within an elastomeric matrix nano- or micron-sized ferrous particles. Crosslinking may occur, for example, in the presence of an applied field, whereby particles form chain-like structures aligned along the applied field direction. The material is then characterized by two families of preferred directions, which can be utilized to produce highly controllable smart materials. Mathematical and computational methods pervade research, development, testing, and evaluation problems encountered by researchers in the field of smart materials, and associated modelling issues have a fundamental role in the analysis of problems that arise in such complex materials. The purpose of the course is to present a state-of-the-art overview of the continuum theory of both electro- and magneto-sensitive

materials capable of large deformations, particularly elastomers and polymers. This will include discussion of the underlying physics and of the mechanical properties of magneto- and electro-sensitive elastomers, nematic elastomers and gels, and computational formulations related to the modelling of these materials from the point of view of material properties and, in particular, control of their mechanical properties will be treated in detail. The presentations will include carefully crafted overviews of the fundamental formulation of the three-dimensional theory from several points of view. They will also include solutions to boundary-value problems which are amenable to experimental verification, and the numerical implementation of solution strategies that take coupling between

field and deformation effects into account. A further aspect of the course will be discussion of stability of equilibria in the presence of electromagnetic coupling together with extensions of the classical energy criterion of elastic stability based on thermodynamical considerations. Additional topics will include extensions of the concept of material, or 'configurational' forces, the theory of incremental fields and small-amplitude waves, and the consistent derivation of large-deformation models of electro-magneto-elastic membranes and plates. The course is addressed to doctoral students and postdoctoral researchers in mechanical, civil and electrical engineering, material science, applied physics and applied mathematics, academic and industrial researchers and practicing engineers.

### PRELIMINARY SUGGESTED READINGS

Vu, D.K.; Steinmann, P.; Possart, G. 2007. Numerical modelling of nonlinear electroelasticity. *Int. J. Num. Meth. Engng.* 70, 685-704.

Vu, D.K.; Steinmann, P. 2007. Theoretical and numerical aspects of the material and spatial settings in nonlinear electroelastostatics. *Int. J. Fracture* 147, 109-116.

Maugin, G.A. 1988. *Continuum Mechanics of Electromagnetic Solids*, North Holland.

Trimarco, C.; Maugin, G.A. 2001. Material mechanics of electromagnetic solids, in: *CISM Courses and Lectures No. 427*, Kienzler, R.; Maugin, G.A. (Eds.), *Configurational Mechanics of Materials*, pp. 129-171, Springer, Wien.

Dorfmann, A.; Ogden, R.W. 2006. Nonlinear electroelastic deformations, *J. Elasticity* 82, 99-127.

Dorfmann, A.; Ogden R.W. 2008. Nonlinear electroelastostatics: incremental equations and stability, *Int. J. Engng Sci.*, in press, available online. DOI:10.1016/j.ijengsci.2008.06.005.

DeSimone, A.; Dolzmann, G. 2002. Macroscopic response of nematic elastomers via relaxation of a class of  $SO(3)$ -invariant energies. *Arch. Rat. Mech. Anal.* 161, 181-204.

DeSimone, A.; DiCarlo, A.; Teresi, L. 2007. Critical voltages and blocking stresses in nematic gels - Dynamics of director rotation for nematic elastomers under electro-mechanical loads. *European Phys. J. E* 24, 303-310.

Steigmann, D.J. 2008. On the formulation of balance laws for electromagnetic continua. *Math. Mech. Solids* 2008, in press, available online. DOI:10.1177/1081286507080808

### INVITED LECTURERS

**Antonio DeSimone** - SISSA, Trieste, Italy  
*6 lectures on:* Nematic Elastomers and Gels (LCEs): variational models of the quasistatic response to mechanical loads; soft deformation paths as quasi-convex hulls of the sets of spontaneous strains; quasiconvex envelope of the energy density and its use in finite-element simulations; static and dynamic response to applied electric fields.

**Luis Dorfmann** - Tufts University, Medford, MA, USA  
*7 lectures on:* Extension of the basic constitutive laws, governing equations and boundary conditions for quasi-static deformations of electro-sensitive and magneto-sensitive solids to their counterparts for incremental deformations superposed on a state of finite elastic deformation; applications to stability analysis and elastic wave propagation.

**G rard Maugin** - Univ. Pierre et Marie Curie/CNRS, Paris, France  
*7 lectures on:* The basics of electromagnetics in matter, with emphasis placed on the notions of electromagnetic forces, momentum and stresses, on the general thermomechanical framework, and on applications to magnetoelasticity at different scales; the notions of internal stresses, internal variables, homogenization, ferromagnetic polycrystals and configurational forces.

**Ray W. Ogden** - University of Glasgow, UK  
*8 lectures on:* Physical background on electro-magnetic effects in polymeric materials; formulation of constitutive equations describing the interaction of mechanical and magnetic (or electric) effects for magneto-active (or electro-active) solids capable of large recoverable deformations; solution of prototype boundary-value problems.

**David Steigmann** - University of California, Berkeley, CA, USA  
*6 lectures on:*  
Replaced by  
- Dorfmann  
- Maugin  
- Ogden.

**Paul Steinmann** - University of Erlangen-Nuremberg, Germany  
*6 lectures on:* Computational aspects of the simulation of electro/magneto-elastic continua at large strains, including FEM, BEM and FEM-BEM coupling; theoretical and computational aspects of the configurational mechanics of these electro/magneto-active materials, including configurational forces and Eshelby's tensor; computational examples.

### LECTURES

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

**MECHANICS AND ELECTRODYNAMICS OF MAGNETO-  
AND ELECTRO-ELASTIC MATERIALS**

Udine, June 29 - July 3, 2009

Application Form

(Please print or type)

Surname \_\_\_\_\_

First 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 \_\_\_\_\_