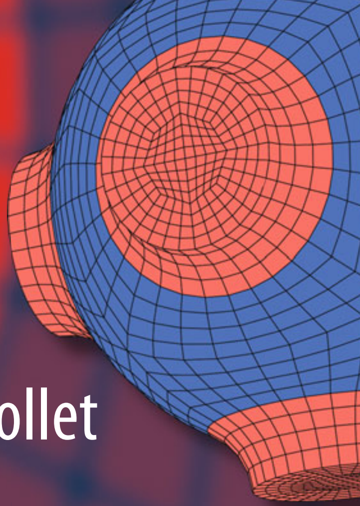
Advanced Structured Materials



Holm Altenbach · Joël Pouget
Martine Rousseau · Bernard Collet
Thomas Michelitsch *Editors*

Generalized Models and Non-classical Approaches in Complex Materials 1

Springer

Advanced Structured Materials

Volume 89

Common engineering materials reach in many applications their limits and new developments are required to fulfil increasing demands on engineering materials. The performance of materials can be increased by combining different materials to achieve better properties than a single constituent or by shaping the material or constituents in a specific structure. The interaction between material and structure may arise on different length scales, such as micro-, meso- or macroscale, and offers possible applications in quite diverse fields.

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Dedicated to the memory of a great creative spirit, G.A. Maugin

Foreword

Gérard A. Maugin

Gérard A. Maugin born at Angers (France) on December 2, 1944, married to Eleni Zachariadou in 1978, passed away in Villejuif (France) on September 22, 2016, 7 p. m.

He had retired from the University of Paris VI since 2010. His longstanding scientific activity in Continuum Mechanics and Continuum Physics is well known in the Community of Mechanics. In these fields he enjoys a well-established reputation. His interests covered almost all disciplines of Continuum Mechanics and his studies have been addressed fundamental problems of mechanics and electromagnetism and applications as well.

One of his first papers (1965) is concerned with *The Race Tidal Power Plant*, a topical subject in the current engineering applications. A few years later he published a series of papers in the Comptes Rendus de l'Académie des sciences, Paris (1970-71), on the macroscopic description of magnetic media in the relativistic framework. His striking versatility in scientific research, which emerged since the very beginning of his career, cannot be unnoticed. In April 1971 he defended his PhD dissertation thesis on micromagnetism, supervisor Prof. Cemal A. Eringen from Princeton University. The Princeton University Press has published the thesis with the title *Micromagnetism and Polar Media*, 1-294, (1971). Four years later, in May 1975, Prof. Maugin achieved his "habilitation" (Doctorat d'Etat en Sciences Mathématiques) in Paris, supervisor Prof. Paul Germain de l'Académie des sciences.

By 1975, Gérard Maugin already had a ripe scientific *curriculum studiorum* in Mechanics and Physics: 45 papers published in the most well known scientific journals of mechanics and mathematics (Ann. Inst. Henri Poincaré, J. of Physics, J.

of Mathematical Physics, General Relativity and Gravitation, J. de Mécanique and others).

His favourite topics in this period are the behaviour of electromagnetic materials in the relativistic framework and in the Galilean approximation as well. Specifically, the behaviour of deformable dielectrics, ferro-magnetic and ferri-magnetic bodies are examined and explored in such frameworks.

His training in relativity and in electromagnetism presumably developed in his mind a specific sensitivity toward the mathematical description of Continua with coupled-fields, Continua with structures and/or Microstructures.

In 1980 Gérard Maugin published the paper *The method of virtual power in Continuum Mechanics: Application to Coupled Fields*, Acta Mechanica, 35, 1-70, (1980). The energetic approach therein proposed represents one of the most powerful methods for describing complex materials from the viewpoint of continua. The method also provides the proper tools, with which to attack problems of structured continua, both, from the theoretical viewpoint and from the standpoint of applications. The method of virtual power, such as expounded in the aforementioned paper, is formulated in its most general form and is applied to electromagnetic materials in their various aspects (thermo-elastic dielectrics with polarisation gradients, dielectrics with quadrupoles, ferromagnets, liquid crystals in external electromagnetic fields, et cetera). This contribution of Prof. Maugin stands as a referential point to many searchers in continuum mechanics.

Wave propagation was also one of his favourite topics of interest. To this topic he devoted his attention and his studies since the very beginning of his studies. Due to the interesting results achieved in applied problems of wave propagation, he was awarded by a scientific prize, the Prize of Mechanics Doisteau-Blutet of the French Academy of Sciences in 1982. His interest in wave propagation never ceased nor decreased in the subsequent years, even when his main efforts were focused on other fields. As a result of the expertise that he had acquired in this field, Gérard Maugin was invited to deliver a course on *Physical and Mathematical Models of Nonlinear Waves in Solids*, in Udine, at the International Centre for Mechanical Sciences (CISM), in 1993. Springer-Verlag will publish the lecture notes of this course in the series CISM Courses and Lectures. Afterward, he also published the book *Nonlinear Waves in Elastic Crystals*, Oxford University Press (1999).

This specific attention to the dynamical problems in continua is often transferred to his graduate students. Some of them investigated the possibility of "soliton-propagation" in structured materials, under his advice. Interesting and unexpected results are shown in evidence by their studies, with the help of numerical techniques.

Gérard Maugin not only provided his students with an excellent professional training in Continuum Mechanics and Physics he also transferred to his students and co-workers enthusiasm in research along with motivations and scientific curiosity. These qualities represent the primary source of his prolific scientific activity.

An impressive number of papers and many books and monographs (published by Springer-Verlag, McGraw-Hill, Elsevier, Oxford University Press UK, Cambridge University Press UK) emerge from his Curriculum and numerous awards and honours.

A detailed list can be found on the website:
http://www.dalembert.upmc.fr/home/maugin/.

Gérard Maugin was a member of the editorial board of many scientific journals, among them

- International Journal of Engineering Science from 1976 to December 1995,
- Wave Motion since 1986,
- Journal of Thermal Stresses,
- Journal of Technical Physics of the Polish Academy of Science,
- International Journal of Applied Electromagnetics and Mechanics - one of its founders in 1990,
- Applied Mechanics Reviews - Associate Editor since 1985,
- Journal of Non-equilibrium Thermodynamics,
- Egyptian Journal of Mathematics,
- Archives of Applied Mechanics (formerly Ingenieur-Archiev),
- Yugoslav Journal of Mechanics,
- Archives of Mechanics of the Polish Academy of Science,
- ARI - Associate Editor since its creation 1997,
- Proceedings of the Estonian Academy of Science since 1997,
- Mechanics Research Communications - one of the five Editors since July 1999, and
- the Marocain Revue de Mécanique Appliquée et Théorique.

He held a membership in scientific societies (in most of the cases as member of the executive committee or of the advisory board)

- Society of Natural Philosophy (SNP), USA,
- Society of Engineering Science, (SES), USA, Life member,
- Society for Industrial and Applied Mathematics (SIAM), USA,
- American Physical Society (APS), USA,
- American Mathematical Society (AMS), USA,
- Acoustical Society of America (ASA), USA,
- Gesellschaft für angewandte Mathematik und Mechanik (GAMM), Germany,
- International Society for the Interaction of Mathematics and Mechanics (ISIMM) - Member of the Executive Committee 1986-1990, 1997-2001,
- Société Française d'Acoustique (SFA), France,
- Association Française de Mécanique (AFM), France, and
- EUROMECH Society (European Society of Mechanics),

and was appointmented as consulting editor (for Springer, John Wiley & Sons, Kluwer, Oxford University Press) or as expert for research contracts and grants (in USA, Canada, UK, Belgium, France and other countries). In addition, he acted as a Series Editor of the CRC Series on Continuum Modelling and Discrete Systems (CRC, Boca Raton, Florida, USA) and Applied Electromagnetics and Mechanics (Elsevier, then I.O.S. Press, The Netherlands).

He was a visiting professor and visiting scientist at Princeton, Belgrade, Warsaw, Istanbul, at the Royal Institute of Technology in Stockholm, at the TU Berlin, Rome, Tel Aviv, the Lomonosov University, Kyoto, Darmstadt and Berkeley. In 2001 he received the Max Planck Research Award, was the 1991/92 Fellow of the Berlin Institute for Advanced Study, and in 2001 received an honorary doctorate from the Technical University of Darmstadt. In 1982 he received the mechanics Prize of French Academy of Sciences and in 1977 the Medal of the CNRS in physics and engineering. He was a member of the Polish Academy of Sciences (1994), of the Estonian Academy of Sciences and was awarded an honorary professorship by the Moscow State University. In 2003, he received the A. Cemal Eringen Medal.

I would like rather to emphasise his natural attitude as searcher and as teacher. This attitude combined with his skill in finding the proper (and often the simplest) mathematical tools, through which to expound and to clarify the physical nature of the phenomenon under consideration.

The so-called Configurational Mechanics or Material Mechanics is the “novel” field, to which Gérard Maugin devoted his main interest during the last decades. He initiated the search and the studies of configurational forces in elasticity, being concerned with the elastic energy-momentum tensor, a notion introduced by Eshelby in a few seminal papers in the fifties. It is not difficult to show that the Eshelby tensor naturally applies to defective materials and in fracture mechanics. For instance, based on this tensor, one is able to recover all known invariant integrals around a defect, including the celebrated J-integral around the tip of a crack. In addition, fracture criteria can be (and indeed, are) properly extended to elastic dielectrics and to elastic magnetised materials.

The early studies of Gérard Maugin and others in this field are also concerned with inhomogeneous materials. Specifically, Maugin and others re-proposed the Eshelby tensor in finite elasticity, basing on Noll’s notion of homogeneity and uniformity. Such an extension of the Eshelby tensor shows in evidence important physical properties and relevant geometrical features, which are hidden in the linear framework. All these features eventually address the notion of configurational force. Gérard Maugin and others suddenly realised that the notion of configurational force confers to the Eshelby stress tensor a deeper physical meaning. They also realised that the notion of configurational (or material) force could not be confined to the in-homogeneities in the elasto-static framework. Hence, the important role of this force was enquired in dynamics. One of the relevant results is the natural relationship of the material force with the so-called material-momentum, or pseudo-momentum. Such a result also represents a turning point for the introduction of the so-called configurational mechanics, which now stands on firm bases. In addition, configurational mechanics is also shown to be the natural framework for thermodynamical transformations, such as solid-phase-transitions.

The notion of configurational force becomes even more powerful in complex materials and materials with structures. Based on this notion, Gérard Maugin (with a second author) contributed to disentangling the following quarrel in liquid crystals (Int. J. Engng. Sci., 33, 1663-1678, 1995): as to whether the Ericksen stress tensor should be regarded as related to a configurational force or to the classical traction. The point is that the Ericksen tensor for liquid crystals has the form of an energy-stress tensor, just like the Eshelby stress. Hence, one could be tempted to incorrectly identify the one with the other. It is worth noticing that the quarrel involved Ericksen and Eshelby themselves, along with Kröner and other prominent people.

Eventually, the interest arises in discriminating configurational forces from traction in the more general context of structured continua. This interest becomes a crucial need in the case of electromagnetic materials. In this regard, it is worth recalling that Eshelby was initially inspired by the Maxwell stress tensor of electromagnetism. The latter however, though possessing the form of an energy-stress, is undoubtedly related to the classical traction. In order to avoid misunderstandings, one envisages the existence of two meaningful energy-stress-tensors in continua and, more specifically, in electromagnetic materials. The introduction of the material energy-stress (namely, the Eshelby tensor) provides a novel standpoint, which allows one to enlighten unclear issues or rather obscure aspects of electromagnetic materials. One of these is the proper form of the electromagnetic momentum. Basing on a criterion established by Gérard Maugin and others, one is able to distinguish between momentum and *pseudo-momentum* or *crystal-momentum*, in the language of Solid State Physics. These themes are still nowadays open to further developments. New applications of these ideas are proposed from time to time in the community of continuum mechanics, in which a steadily increasing interest is recorded on this subject.

It should be noted that Gérard Maugin delivered his knowledge and new research results immediately to the PhD and post graduated students. One of his loveliest places for lectures was the International Center of Mechanical Sciences (CISM, Udine, Italy), where he presented not only the aforementioned course on wave propagation. He was involved, for example, in the following activities:

- Non-Equilibrium Thermodynamics with Application to Solids (coordinated by W. Muschik in 1992): lectures on "Non-Equilibrium Thermodynamics of Electromagnetic Solids",
- Nonlinear Waves in Solids (coordinated by A. Jeffrey and J. Engelbrecht in 1993): lectures on "Physical and Mathematical Models of Nonlinear Waves in Solids",
- Configurational Mechanics of Materials (coordinated by R. Kienzler and G.A. Maugin in 2001): lectures on "Elements of Field Theory in Inhomogeneous and Defective Materials" and "Material Mechanics of Electromagnetic Solids" (together with C. Trimarco),
- Surface Waves in Geomechanics: Direct and Inverse Modeling for Soils and Rocks (coordinated by K. Wilmanski and C.G. Lai in 2004): 6 lectures on waves on interfaces, in thin layers on linear media, on surfaces with curvature, grating and roughness, nonlinear surface waves, propagation of surface soliton packages, interactions with nonmechanical fields,
- Generalised Continua and Dislocation Theory. Theoretical Concepts, Computational Methods and Experimental Verification (coordinated by C. Sansour in 2007): 4 lectures on defects, dislocations and the general theory of material inhomogeneities,
- Mechanics and Electrodynamics of Magneto- and Electro-Elastic Materials (coordinated by R.W. Ogden and D.J. Steigman in 2009): 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 force,

- Generalized Continua from the Theory to Engineering Applications (coordinated by H. Altenbach and V. Eremeyev in 2011): 6 lectures on electromagnetism and generalized continua, ponderomotive couple, electromagnetic microstructure, resonance couplings with classical deformation, effects on configurational forces (fracture and phase transformation).

Gérard Maugin was also greatly attracted by researches in Epistemology and the History of Science. The naissance of fundamental concepts of Mechanics and Physics and their evolution through the centuries were fascinating topics for him. Toward these topics he had developed a unique sensitivity, since he was a young researcher. To them he devoted his efforts in the last years until the end of his life by writing a history of Continuum Mechanics in the following three volumes published by Springer, Solid Mechanics and Applications Series:

- Continuum Mechanics Through the Twentieth Centuries: A Concise Historical Perspectives *(2013)*,
- Continuum Mechanics Through the Eighteenth and Nineteenth Centuries: Historical Perspectives from John Bernoulli (1727) to Ernst Hellinger (1914) *(2014)*,
- Continuum Mechanics Through the Ages: From the Renaissance to the Twentieth Century *(2016)*.

Last but not least, he offered clear and reliable explanations of over 100 keywords in Continuum Mechanics for better understanding the fundamental concepts

- Non-Classical Continuum Mechanics - A Dictionary *(2017)*.

This book was published also by Springer in the Advanced Structured Materials Series (Series Editors: Andreas Öchsner, Lucas F.M. da Silva, and Holm Altenbach) as volume 51.

His memory will endure among his many friends and in the Scientific Community of Mechanics.

Università di Pisa, Italia, January 2018 *Carmine Trimarco*

Preface

At the beginning of February 2017 the invitation letters for a special remembrance book were sent to approximately 70 friends and colleagues of the great French scientist in the field of Continuum Mechanics (or more general Continuum Physics) Gérard A. Maugin who died on September 22nd, 2016. As usual in such case that the response is 50% sending a kind reply that they will submit a paper and finally one gets 15-20 papers. In the case of Gérard the resonance was overwhelming - the editors got finally approximately 60 papers and the decision was made to publish two volumes. This is the first one including 40 papers from authors living in more than 20 countries.

The scientific interests of Gérard are well reflected by variety of subjects covered by the contributions to this book including the following branches of Continuum Mechanics

- relativistic continuum mechanics,
- micromagnetism,
- electrodynamics of continua,
- electro-magneto-mechanical interaction,
- mechanics of deformable solids with ferroïc states (ferromagnetics, ferroelectrics, etc.),
- thermomechanics with internal state variables,
- linear and nonlinear surface waves on deformable structures,
- nonlinear waves in continua,
- Lighthill-Whitham wave mechanics,
- lattice dynamics,
- Eshelbian Mechanics of continua on the material manifold,
- geometry and thermomechanics of material defects,
- material equations and
- biomechanical applications (tissue and long bones growth).

In addition, he published several papers and books on the history of continuum mechanics. This was reason that the authors of this book have submitted so different papers with the focus on the research interests of Gérard.

We have to thank all contributors for their perfect job. Last but not least, we gratefully acknowledge Dr. Christoph Baumann (Springer Publisher) supporting the book project.

Magdeburg, Paris
January 2018

Holm Altenbach
Joël Pouget
Martine Rousseau
Bernard Collet
Thomas Michelitsch

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