ABSTRACTS: AMSI-MASCOS LECTURER 2007/08 - PROFESSOR INGO MÜLLER

Thermodynamics and Kinetic Theory of Rubber

In most bodies the elastic deformation is due to a change of internal energy and there is only a small contribution of entropy, or none. This is different for rubber: In a rubber rod the elasticity is purely entropic, with no essential contribution of energy. Simple experiments and elementary thermodynamics prove that fact.

Therefore rubber elasticity is amenable to simple arguments from statistical thermodynamics. That theory provides a thermal equation of state – a stress-strain relation -- for rubber which, historically, has provided the basis for non-linear elasticity, and polymer physics.

During the lecture an interactive movie is shown which demonstrates the role of a polymer molecule as an entropic spring.

References:

[1] I.Müller, P.Strehlow, *Rubber and Rubber Balloons*, Springer Lecture Notes on Physics, Springer Verlag, Heidelberg (2004)
[2] I.Müller, W.Weiss, *Entropy and Energy – a Universal Competition*. Springer Verlag, Heidelberg (2005)

Socio-thermodynamics

-- Integration and Segregation in a Population

Segregation of social or ethnic groups in a population is an ubiquitous phenomenon which is generally thought of as being detrimental to the commonweal. Therefore a scientific study is indicated so as to reveal the underlying motifs and, perhaps, to control them.

There is a strong phenomenological similarity between a segregated society and the miscibility gap of a solution or an alloy. This research attempts to uncover the underlying kinship between phase separation in a solution and segregation in a society. Both may be viewed as thermodynamic – or socio-thermodynamic – equilibria with homogeneous Gibbs free energies – or socio-chemical potentials.

In order to make the arguments specific, a model of game theory has been adapted for the purpose of describing the comportment of a population. The model is one of hawks and doves who compete for the same resource and may assume different competitive strategies depending on availability and price of the resource.

A proper understanding of the analogy between sociology and thermo-dynamics requires the formulation of socio-thermodynamics, complete with first and second laws, and well-defined counterparts for pressure and volume, for temperature and energy, and for heating and working.

The evaluation of the theory reveals that segregation may be considered as a survival strategy for a population in bad times, because in a segregated society the gain per bird is bigger than in a homogeneously mixed society whatever its strategy.

Reference:
[1] I.Müller, Socio-thermodynamics – Integration and Segregation in a Population. *Continuum Mechanics and Thermodynamics* 14 (2002)

Entropy and Energy -- a universal Competition

Irreversibility imposes a teleological character on thermodynamic processes. In the simplest case, an adiabatic body, the entropy growth until it reaches a maximum. But under isothermal, -- rather than adiabatic --, conditions it is the free energy

$$F = E - T\,S,$$

which tends to a minimum. For low temperature T, where the entropic term with S may be neglected, the free energy tends to a minimum, because the energy E becomes minimal. But for high temperature, where the energetic term may be neglected, the free energy becomes minimal, because the entropy becomes maximal. In general it is neither the energy which achieves a minimum in equilibrium, nor the entropy which becomes maximal. The two tendencies reach a compromise, and the free energy becomes minimal.

Three examples for this competition are given: • the planetary atmosphere, • phase transitions, and • the Haber-Bosch synthesis of ammonia. Phase transitions are illustrated by an interactive movie showing the vapour-liquid-solid transition of seven atoms.

References:
[1] I.Müller, W.Weiss, *Entropy and Energy – a universal Competition.* Springer Verlag, Heidelberg, (2005)

Thermomechanics of Shape Memory Alloys-- Phenomena, Simulation and Applications

The phenomena and some applications of shape memory alloys will be presented in a movie. The phenomenon is due to an austenitic-martensitic phase transition and therefore it may be treated with thermodynamic methods, properly adapted to the case of a hysteretic solid-solid transition in alloys. The thermodynamics of shape memory alloys will be presented on three levels:

A purely thermodynamic theory of the phase transition is formulated with an additional ingredient for the consideration of the pseudo-elastic hysteresis.

A kinetic theory of the transition provides some insight into the transition considered as an activated process. Given two out of three possible inputs as functions of time – such as load and temperature --, the remaining one – e.g. deformation -- may be calculated as a function of time.

A molecular 2-dimensional simulation demonstrates how the lattice structure transforms and how twinning occurs. A statistical thermodynamic treatment of the molecular model provides reasonably good predictions for the transition temperatures.

References:
[1] I.Müller, S.Seelecke, Thermodynamic Aspectrs of Shape Memory Alloys. *Mathematical and Computer Modelling* 34 (2001)
[2] O.Kastner, *Zweidimensionale molekular-dynamische Untersuchung des Austenit-Martensit Phasenübergangs in Formgedächtnislegierungen*. Dissertation, TU Berlin. Shaker Verlag (2003)

Bi-axial Deformation of a Rubber Sheet

-- a Case of "Buckling in Tension"

A square rubber sheet, bi-axially loaded in tension with equal loads will retain its square shape only for small loads, because for bigger loads the square shape is unstable. This observation was originally made by E.A.Kearsley under the assumption that rubber is a Mooney Rivlin material. The effect is considered in this lecture from several different points of view. Thus we obtain a paradigmatic case of instability that demonstrates such phenomena as • bifurcation, • broken symmetry, • hysteresis, and • catastrophic break-through.

References:
[1] E.A.Kearsley, Asymmetric stretching of symmetrically loaded elastic sheet. *International Journal of Solids and Structures* 22 (1985)
[2] I.Müller, P.Strehlow, *Rubber and Rubber Balloons.* Springer Lecture Notes on Physics, Springer, Heidelberg (2003)
[3] R.C.Batra, I.Müller, P.Strehlow, Treloar's biaxial tests and Kearsley´s bifurcation in rubber sheets. s*Mathematics and Mechanics of Solids* 10 (2005)

Heat Conduction between concentric cylinders in rarefied gases

-- an Application of Extended Thermodynamics

In a dense gas Fourier heat conduction between concentric cylinders leads to a logarithmic temperature field. The solution becomes singular near the inner cylinder, if its radius tends to zero. This is different in a rarefied gas, where higher moments must be taken into account. The simplest case is the case of thirteen moments, which can be solved analytically.

It turns out that the singularities in the temperature field disappear in the 13-moment theory. Also the entropy flux is no longer given by the quotient of heat flux and temperature, a fact which suggests that the mean kinetic energy of the atoms does not determine temperature any longer: There is a *thermodynamic temperature* which differs considerably from the kinetic one, except in equilibrium, of course.

Furthermore, it turns out that a rarefied gas cannot rotate rigidly, if there is heat conduction.

References:
[1] I.Müller, T.Ruggeri, Stationary heat conduction in radially symmetric situations – an application of extended thermodynamics. *Journal of Non-Newtonian Fluid Mechanics* 119 (2004)
[2] E.Barbera, I.Müller, Inherent frame dependance of thermodynamic fields in a gas. *Acta Mechanica* 184 (2006)

[3] E.Barbera, I.Müller, Secondary heat flow between confocal ellipses. *Journal of Non-Newtonian Fluid Mechanics* (submitted)

Rubber Balloons

-- Prototypes of Hysteresis

Rubber balloons are characterized by a non-monotone pressure-radius relation which presages interesting non-trivial stability problems. A stability criterion is developed and exploited in order to show that the balloon may be stabilized at any radius by loading it with a piston under an elastic spring, if only the spring is hard enough.

If two connected balloons are subject to an inflation-deflation cycle, the pressure-radius curve exhibits a fairly simple hysteresis loop. More complex hysteresis loops appear when more balloons are all inflated together. And if many balloons are inflated and deflated at the same time, the hysteresis loop assumes the form reminiscent of pseudo-elasticity. Stability in those complex cases is determined by a simple suggestive argument.

References:

[1] W.Kitsche, I.Müller, P.Strehlow. Simulation of pseudo-elastic behaviour in a system of rubber balloons. In: *Metastability and Incompletely Posed Problems*, S.Antman, J.L.Ericksen, D.Kinderlehrer, I.Müller (eds.) IMA Volume No.3, Springer Verlag, New York (1987)
[2] I.Müller, P.Strehlow, *Rubber and Rubber Balloons,* Springer Lecture Notes on Physics, Springer Verlag, Heidelberg (2004)

The terroristic Nimbus of Entropy – and other fanciful Stories

from the early history of thermodynamics

The founders of thermodynamics in the 19th century did not find it easy at all to make themselves heard by the scientific community of the day. And it did not help that they themselves did not grasp fully what they had found. That situation provided ample opportunity for misunderstanding which to us, now, in the 21st century, is quite amusing.

At the same time the pioneers of thermodynamics – however imperfect the understanding of their discoveries was -- revolutionized science by the discovery of energy and entropy, the dichotomy of natural forces, of which the first one is deterministic and the second one random. They revolutionized everyday life by utilizing energy and by creating methods for the production of fuel. And they rendered traditional philosophy redundant.

References:

[1] I.Müller, W.Weiss, *Entropy and Energy – a Universal Competition*. Springer Verlag, Heidelberg (2005)
[2] I.Müller, *A History of Thermodynamics -- the Doctrine of Energy and Entropy* Springer Verlag, Heidelberg (2007)