Martine Ben Amar

Laboratoire de Physique Statistique, Ecole Normale Supérieure,
24 rue Lhomond, 75231 Paris Cedex 05, France
Born on July 20, 1954

Professional Preparation

- **Université Pierre et Marie Curie, France**
  Second Ph.D. in Physics, June 1984. Thesis title: *"Modèle théorique en photoémission des systmes atomiques dans le domaine de l'ultraviolet lointain. Application à l'Argent, à l'Iode et au Xénon.."*
- **Université Pierre et Marie Curie, France**
  First Ph.D. in Physics, May 1979. Thesis title: *"Etude théorique de la photoionisation du nickel aux énergies inférieures à 80 eV."*
- **1979: Agrégée de l'Université**
- **1973–77: Ecole Normale Supérieure, France**

Professional Status

- 2003- Professeur de classe exceptionnelle de l'Université Pierre et Marie Curie (Paris).
- 1993-2003 : Professor of University de l'Université Pierre et Marie Curie (Paris).
- 1999-2000 Invited Professor at MIT, Department of Mechanical Engineering (McCarthy Chair)
- 1993-1997: Junior Member of l'Institut Universitaire de France
- 1987-1993: Assistant Professor (Ecole Normale Supérieure,Paris)
- 1977-1987: Teaching assistant (Ecole Normale Supérieure,Paris)

Research Interests:

Nonlinear Theory in hydrodynamic and morphogenesis

- Instabilities of growth limited by diffusion: dendritic growth, viscous fingering, Saffman-Taylor instabilities, fractal growth. in particular proof of the singular role of surface tension in selection problems, exact solution for growth in radial geometry, relation between Laplacian and fractal growth.
- Dynamic of the moving contact line and wetting. In particular: Model for the spreading of nematic liquid crystal derived from lubrication theory of the Leslie model. Theory of cusps for drops sliding on an inclined plane, critical exponents for drops in evaporation.
- Elastic instability: fracture and crumpling. Criterium for path instability of fracture in mode I, threshold determination. Theory for crumpled paper. .
- Complex fluid rheology : Hydrodynamic models for confined complex fluids : non newtonian, polymeric, surfactant, suspensions. Adhesive and transport properties.
- Physics of the cellular membrane: elastic instabilities of inhomogeneous lipidic membranes with liquid ordered domains like rafts. Model for rafts ejection with proteins like PLA2 ,osmotic shoks or lipo-proteins.
- Morphogenesis and growth of soft tissues: theory for shapes of living tissues in the framework of exact elasticity including volumetric growth. Application to shell samples (solid tumor,

invagination) and plates (leaves, flowers, skin tumors). Present research on the website: www.phys.ens.fr/ muller/siteweb/

Publications and books

Over 90 peer-review journal publications Growth and form: Non linear aspects, edited by M. Ben Amar,P. Pelc and P. Tabeling (plenum 91) Physique Nonlinaire et morphognse: M. Ben Amar et Arezki Boudaoud, en prparation , collection: Echelles chez Belin.

Teaching

- Head of the Master Program : “Systmes dynamiques et statistiques de la matire complexes”. Approximatively 70 students per year.
- Head of the Master Program at the Ecole Normale Supérieure students “Physique des liquides et matière molle”: Approximatively 20 students per year.
- Head of the multi-universities Research Federation “Dynamique des systmes complexes” for the universities: UPMC, Paris VII, ESPCI, ENS (2005-2008, 2008-2012).

Selected Publications

- 1) **M. Ben Amar and B. Moussallam**,
  Numerical Results on Two-Dimensionnal Dendritic Solidification.
  Physica D**25**(1-3), 155-164 (1987).

- 2) **M. Ben Amar and Y.Pomeau**,
  Theory of Dendritic Growth in a Weakly Undercooled Melt.
  Europhys. Lett.**2** (4) , 307 -314 (1986).

- 3) **M. Ben Amar and E. Brener**,
  Theory of pattern selection in three-dimensional nonaxisymmetric dentritic growth.
  Phys.Rev.Lett **71** (4),589-592 (1993)

The problem of selection for the needle-crystal growing steadily in an infinite bath of undercooled melt was posed since the publicaton of Ivantsov solution in 1947. Ivantsov showed that there exists a continuum of possible parabolae in 2D, paraboloids in 3D with all the possible velocities, when surface tension was set to zero. The idea that surface tension may be the key parameter to select a possible solution was formulated by Ivantsov but this problem remains unsolved even numerically up to the 80. It turns out that this free-boundary problem involves the diffusion equation with two boundary conditions of Dirichlet and Neuman type and that the velocity appears as a non-linear eigenvalue. Contrary to the Saffman-Taylor problem where the analyticity allows to simplify the formulation via conformal mappings, in the dendritic growth problem, the solution requires the treatment of a strongly non-linear integro-differential equation, the integral coming from the diffusion Green's function. In paper [1], we solve numerically this eigen-value equation and we explicit our algorithm. Moreover, we prove , by Laplace transform, that the regular pertubation series which is possible to calculate explicitly order by order does not give any information on the selection problem. This paper prepared the second paper in the list [2] where we proved analytically that the selection process requires a singular perturbation analysis in the complex plane. For that, it was necessary to analitically extend the equation in the complex plane, catch the transcendental corrections on the imaginary axis via a WKB treatment and identify the selection mechanism to the cancellation of these transcendental contributions. This treatment was established in 2D at low undercooling. It has been followed by many contributions from other groups who tried to find alternative methods. For our group, it was the beginning of extensions to arbitrary undercooling or arbitrary experimental situations like the coupling between heat and impurities, effect of convection and so on... The fact that the selection results from the existence of an anisotropic surface tension automatically restrict this treatment to 2D since the non-axisymmetric needle-crystal shape was unknown in absence of capillary. It is why it takes approximatively 7 years to solve the problem in 3 dimensions. In [3], we first establish the non-axisymmetric modes linearly and we show that the capillary effects selecunst the velocity of the crystal but also the amplitude of these modes. The treatment performed at weak surface tension allows to determine completely and analytically the shape of the 3D crystal with all modes of anisotropy.

- **M. Ben Amar**,
  Exact self-similar shapes in viscous fingering.
  Phys. Rev.A **43**(10), 5724-5727 (1991).
- **M. Ben Amar**,
  Viscous fingering in a wedge.
  Phys. Rev.A **44**(6), 3673-3685 (1991).

This couple of papers is devoted to the existence of self-similar fingers in radial growth. In Laplacian growth, it is known, at least from experimental observations, that radial growth is an unstable process and that circular interfaces develops instability at short times due to the increase of the characteristic size compared to the capillary length. Quasi self similar fingers in ficticious sectors appear which grow, up to a typical size for the finger radius, then again destabilize and repeats itself . This cascade of events called tip-splittings gives a structure which has been called fractal at long times. In the first paper, I have found exact self-similar solutions for viscous fingers growing in a wedge for arbitrary value of the angle of the wedge, in absence of capillarity. These solutions, which are completely analytic have been the starting point of mathematical papers of the Oxford and Nottingham group of complex analysis. In the second paper, I show that a finger can grow in a self similar way if surface tension is added, but such solution ceases to exist after a typical time. This is the explanation for the tip-splitting event. This break-down and characteristic time depends on the capillarity but also of the value of the sector.

- **M. Adda Bedia and M. Ben Amar**,
  Stability of quasi-equilibrium cracks under uniaxial loading.
  Phys. Rev. Let. **76**(9), 1497-1500 (1996).

With a student, I have established analytically a criterium of instability for the path of fracture in coupled modes in the quasi-static regime. This threshold of instability results from a perturbation analysis, classical in fluid mechanics but which remains rather uncommon in mechanics of solids. This method gives much more quantitative predictions that the so-called Cotterel and Rice criterium, at least when compared to experiments.

- **A. Boudaoud, P. Patricio, Y. Couder and M. Ben Amar**,
  Dynamic of singularities in a constrained elastic plate.
  Nature **407** (6805), 718-720 (2000).

With two students , I have applied the theory of crumpling that we have developped with Y. Pomeau to half a cylinder in order to interpret experimental results obtained in the Y.

Couder laboratory. A cylinder is a developpable surface and so can be compared to a sheet of paper from the point of view of the elastic deformations. We have studied experimentally, numerically and theoretically the bending of the metallic sheet, initially cylindrical, then the crumpling under the action of a localized force. The coupling between elastic singularities have been analyzed in details as the role of plasticity.

- **J.M. Allain, C. Storm, A. Roux, M. Ben Amar and J.F. Joanny**,
"Fission of a multiphase membrane",
P.R.L. **93** (15),158104-1,158104-4 (2004)

In a series of papers devoted to the physics of the cell membrane, I have studied the possibility of segregation of lipids and formation of aggregates called sometimes "rafts". In our cells, these rafts, which are rich in cholesterol, have motivated a lot of biological studies due to their possible implication in rather common diseases. Here, we explain why inhomogeneities on a tube of membrane induces the fission of these tubes. Lipidic membrane tubes play an important role inside our cells, especially in the intra-cellular traffic. In model experiments with artificial membrane tubes extract from vesicles, it turns out that, due to the extremely small size of the radius of membrane tube, the walls between domains is fragile since these walls are strongly distorted by the mismatch between elastic coefficients. This mismatch explains why we cannot observe inhomogeneous tubes of membrane. I have explained the time scale for rupture by a theory of nucleation: this experimental time scale of order the second cannot be explained by the elastic or viscous time scale of order 10^{-8}

- **E. Sultan, A. Boudaoud and M. Ben Amar**,
"Evaporation of a thin film: diffusion of the vapour and Marangoni instabilities"
Journ. Fluid. Mech **543**,183-202 (2005)

This paper concerns the hydrodynamics of thin films put on a substrate in a situation of evaporation, treated with a two-sided approach: it means that the heat diffusion was considered simultaneously in the vapor and the film, but also vapor diffusion was considered in the atmosphere. It is the most complete treatment of such an instability which is usually restricted to only one phase. We have established a threshold for the apperance of undulations of the films and compare to an experiment made in College de France on alcanes. We have found a hierarchy between the alcanes which corresponds to the experimental results. Finally, a weakly non linear analysis (not trivial due to Hilbert transforms characteristic of diffusion treatment) shows that the instability is super-critical.

- **M. Ben Amar and A. Goriely**,
"Growth and instability in elastic tissues",
Journ. Mech.and Phys. Solids, **53/10**, 2284-2319 (2005)

We have established the formalism of growth in soft tissues using exact elasticity. We have shown that, independtly of the loadings, volumetric growth induces stress inside the elastic samples in most of the growth situations. Only for isotropic and constant growth rates in vacuum, growth is free of stresses. In all other cases: spatially dependent growth processes or constant but anisotropic growth, the volumetric growth induces stresses. As soon as stress is created, since elasticity is variationnal, buckling instabilities may occur to minimize the elastic energy. We consider more precisely the case of a growing shell (a situation close to a solid tumor) and we have studied in detail the possibility of shape bifurcations.