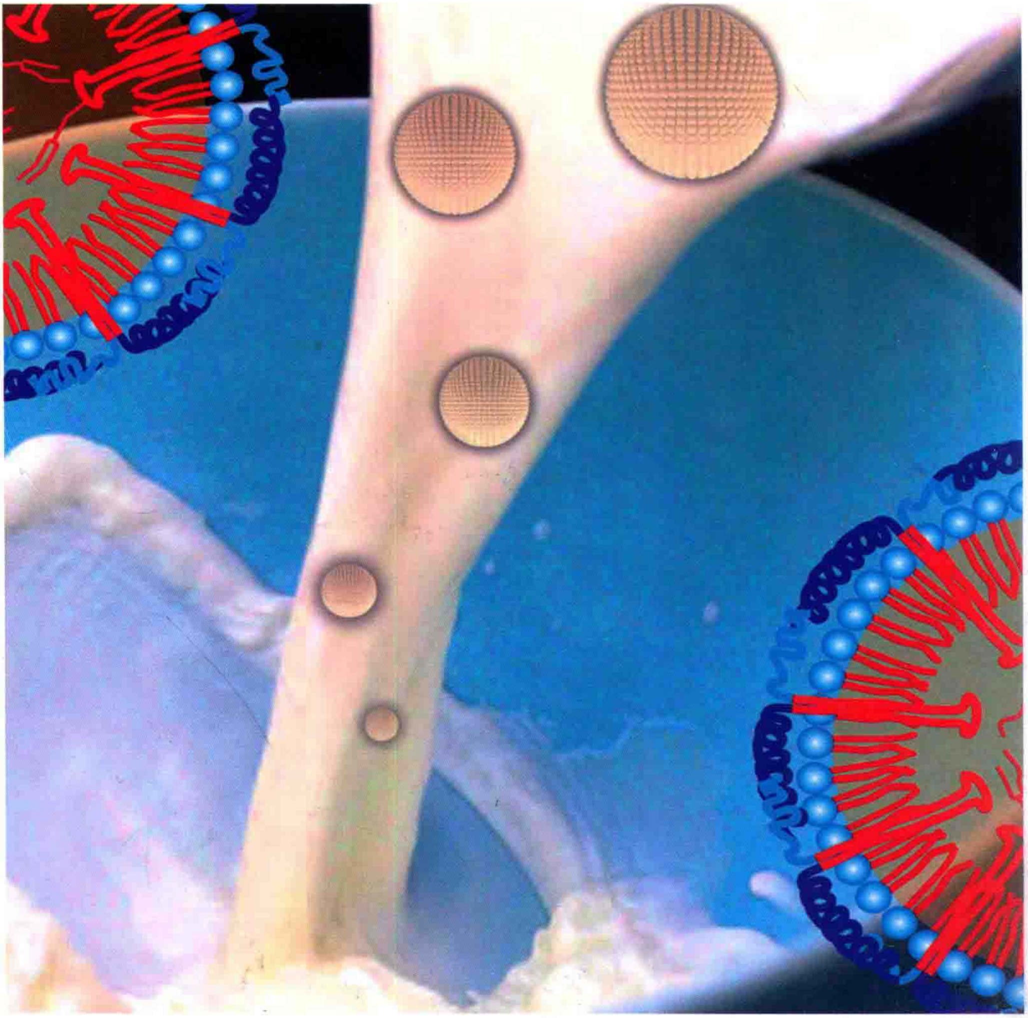
Faraday Discussions Vol 158

Soft Matter approaches to Structured Foods



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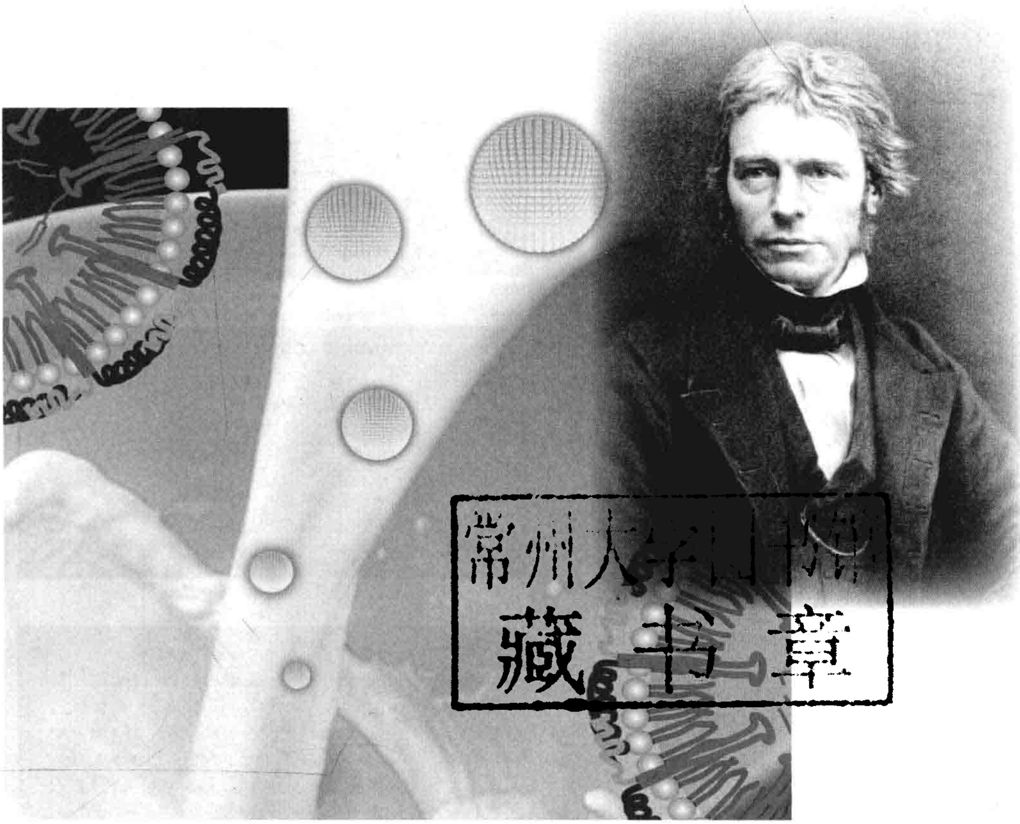
Soft Matter approaches to Structured Foods

Hof van Wageningen, the Netherlands

2–4 July 2012



FARADAY DISCUSSIONS

Volume 158, 2012

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Soft Matter Approaches to Structured Foods

Faraday Discussions

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A General Discussion on Soft Matter Approaches to Structured Foods was held in Wageningen, The Netherlands on 2nd, 3rd and 4th July 2012.

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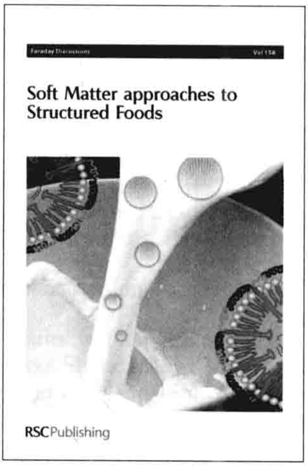

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Soymilk oleosomes or oil bodies, a typical example of food microstructures and natural emulsions (photo by Natalie Russ, oleosome figure by David Baßler and Thomas A. Vilgis).

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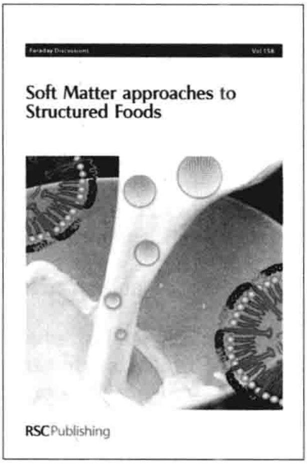

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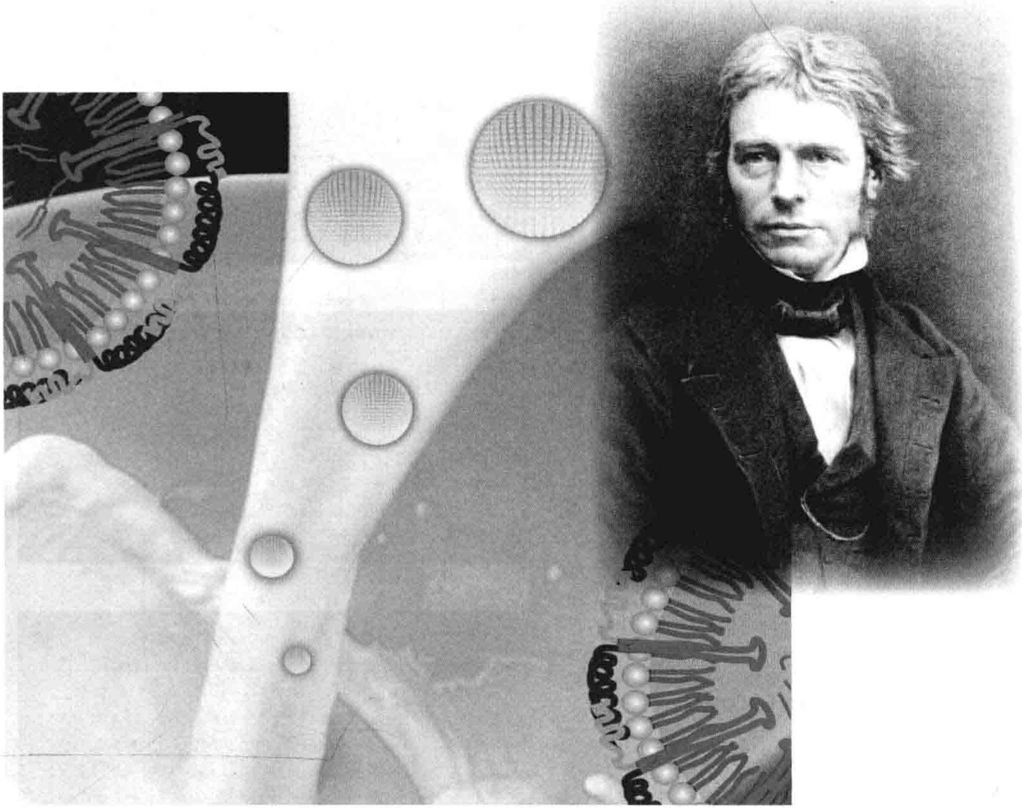

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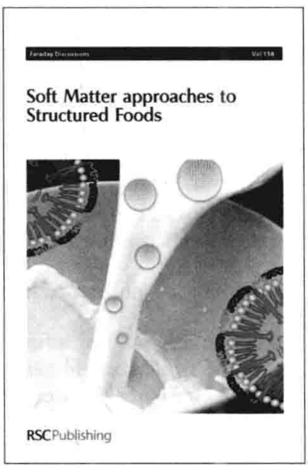

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The Graduate School

VLAG

CONCLUDING REMARKS

ADDITIONAL INFORMATION

Soft matter approaches to structured foods: from "cook-and-look" to rational food design?

Job Ubbink*[ab]

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Developments in soft matter physics are discussed within the context of food structuring. An overview is given of soft matter-based approaches used in food, and a relation is established between soft matter approaches and food technology, food creation, product development and nutrition. Advances in food complexity and food sustainability are discussed from a physical perspective, and the potential for future developments is highlighted.

Introduction

Over the last few decades, the application of physics, physical chemistry and materials science in food science and technology has experienced a rapid expansion. Foods, food ingredients and their transformations are increasingly being considered from the perspective of soft matter science and the awareness that various developments in fundamental physics are relevant for food development is on the rise. This includes aspects relating to food processing, storage and consumption and the physiology of digestion.[1–6]

While highlighting the emphasis in food development on structure building, the notion of "structured foods" is in fact a pleonasm. Not only are all foods structured, in a continuum of length scales from the molecular level up to the macroscopic scale of a food item, but the functional properties of a foodstuff also critically depend on at least one characteristic length scale.

The central contribution of soft matter science to food science and technology lies in the identification of relations between the critical elements of food structure and the associated physical phenomena on the one hand, and food functionality on the other hand. Potentially, soft matter approaches, including food materials science[7,8] and the physical chemistry of foods,[9] could thus strongly shape developments in the food field. For various reasons, however, the amalgamation of soft matter physics and food science and technology has not always been an easy process.

In the first place, in most foods, structure development by human intervention comes on top of a complex structure as laid down by nature. To have an impact on food development, soft matter science should therefore be able to deal with both nature- and man-induced structures and related physical properties. In this context, one should also not forget that, throughout human history, man has successfully manipulated the structure and properties of both plant and animal foods by systematic, biology-based approaches such as selective breeding.

In the second place, a central characteristic of foods is that they are complex. Foods display both a complex structure and a complex composition. Moreover, foods originate from a wide range of plant and animal sources, with major geographical

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variations, and the foods as we currently know them are strongly shaped by long-standing empirical approaches. Furthermore, the appreciation of food is strongly determined by cultural preferences, which vary enormously over the world. The challenge to soft matter physicists is thus considerable, as the different complexity layers turn food into a rather unwieldy subject for fundamental physical investigation.

Finally, it does not make much sense to study a food as a static item; its transformation by cooking, processing or other preparation methods is an essential part of the game, as is the breakdown during consumption and digestion of the food product. Consequently, one cannot truly decouple the physics from the technology and craftmanship, from the physiology, or even from the behavioral sciences.

This introductory lecture is not intended as a general review of the field; its aim is rather to present a broad, personal sketch of the relation between physics and food. In this, I will often emphasize the food context rather than the physics, as I believe that increased awareness of elements relating to food preparation and processing, consumption, nutrition and sustainability may provide further incentive to the development of soft matter science of food and enhance its impact. Central to my discourse will be the following questions with a bearing on soft matter approaches in the food context:

1. How did – accidental or purposeful – efforts to food structuring impact what we eat, and how we eat?

2. What is the impact of soft matter science on the structuring of foods, prepared industrially as well as artisanally?

3. Does one need a dedicated physical science to deal with food-related issues? To which extent can principles, concepts and even quantitative results be transferred from more fundamental physical disciplines?

4. What future impact may we expect from soft-matter approaches towards food structuring? How will it impact food creation? Will it help in resolving societal challenges related to food, in particular those with a bearing on nutrition, health, and the sustainability of food production and consumption?

Even though in the following sections, I will regularly return to these questions, I will not be able to provide adequate answers but to a few loose elements. I, however, trust that in the remainder of this Discussion meeting, light is shed on some of the important issues in the soft matter science of food and nutrition, and that novel avenues are presented to advance our understanding of the physics of foods.

Soft matter approaches

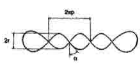
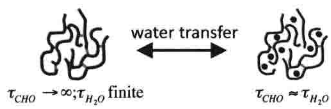
Even if one limits oneself to the purely physical aspects of food, one will find that the field of soft matter physics of foods is very wide. This is because, in foods, most of the phases and states encountered in soft materials occur. Foods are particularly rich in examples of soft matter, comprising both phases exhibiting long-range order as well amorphous states. Central to the soft matter physics of food is that foods exhibit a complex free energy landscape (Fig. 1), which is characterized by many shallow free energy minima. Furthermore, it almost invariably turns out that in their most desirable form, foods are metastable: they either occupy a local free energy minimum, or are quenched into a state of fairly high free energy, but slow dynamics.

In foods, phase transitions thus readily occur, induced by thermal fluctuations or driven by external perturbations. The complex but fairly flat energy landscape characteristic of foods conveniently allows for a multitude of transformations; a fact that is thoroughly exploited in both food technology and in cooking. The metastability of many foods conversely renders them highly susceptible to undesired physical transformations, leading to a decay of food quality.

Foods do not only change their properties by phase transitions. Even in quenched or otherwise constrained systems, many physical parameters may more or less quickly relax to a state of local equilibrium when subjected to an external perturbation, such as a change in water content or relative humidity. In this sense, the soft matter physics of food is similar to other fields, such as the statistical mechanics of biopolymers (Table 1).

The rich phase behavior of foods results from a complexity in composition and a large variation in the physicochemical properties of food constituents, such as shape, (chain) stiffness, propensity to form hydrogen bonds and electric charge.[9] In turn, the phase behavior of foods and food ingredients may be used to create a multitude of mesoscopic and macroscopic structures in food.[1–6] In addition, food structures are often induced by templating. In particular in food ingredients structured by nature, various metabolism-driven biophysical mechanisms actively build highly complex food structures, such as plant cell walls and cellular assemblies, which by the thermodynamics of the constituents themselves would not materialize.

Table 1 Statistical mechanics of constrained systems

	DNA supercoiling	Water in carbohydrate glasses
Identify major physical phenomena	• Chain bending & torsion • Electrostatic interactions; • Chain entropy	• Osmotic elasticity of polymer glass • Hydrogen bonding • Mixing entropy
Coarse graining		
Constraints	Topology: $\Delta Lk = \Delta Tw + Wr$	Physics: $T_g(\phi_w)$
Variables that attain equilibrium within constrained environment	superhelical radius r; linked variables p, a	water activity a_w
Minimal model	$F = F_{bending} + F_{torsion} + F_{pert}$ $F_{pert} = F_{et.stat} + F_{conf}$	• *Glass*: Sorption on heterogeneous sites • *Rubber*: Flory-Huggins solution theory
Check for consistency	• Limiting behavior towards tight supercoiling • Assumptions on parameter ranges	• Limiting behavior towards $a_w \to 0$; $a_w \to 1$
Validation	Comparison to experimental data and computer simulations	• Fitting to sorption data • Comparison to $T_g(a_w)$ by DSC • Global agreement with spectroscopic data
Refinements	Sequence-dependent bending	• Carbohydrate polydispersity • Aging of carbohydrate glass
Limits	• $\Delta Lk \to 0$ • Multivalent ions	• Prediction of dynamic phenomena • Prediction of details of molecular interaction