

Biogeography

Springboards for springtails

Peter D. Moore

Travel to overseas destinations is possible even for certain tiny land invertebrates. Although they cannot fly, the ocean is not an insuperable barrier because they can survive for longish periods in sea water.

For small, flightless terrestrial organisms, the world is littered with barriers to dispersal. Deserts, oceans and mountain ranges present apparently insuperable limits to migration and spread for animals that are only a few millimetres in size and cannot fly. But from work by S. J. Coulson and colleagues¹, published in *Functional Ecology*, it seems that some soil arthropods can survive long enough in sea water to permit them to travel to distant lands. Assumptions about the causes of biogeographical distribution patterns among such organisms now need to be reconsidered.

Disjunct distributions are relatively common in soil arthropods, as in the case of the springtail *Tetracanthella arctica* (order Collembola), a dark blue, flightless insect, just 1.5 mm long, that lives mainly among mosses on the soil surface and feeds on plant detritus and fungi. It is found in isolated locations through the Arctic, ranging from Spitzbergen, Iceland and Greenland to northern Canada, but also occurs in alpine habitats in the Pyrenees, the Tatra Mountains and the Carpathians². Its isolation in the European mountain sites is best explained by the survival of relict populations after the end of the last glaciation: a presumed extensive distribution in glacial times would have contracted and become fragmented as warmer conditions spread and forest became abundant. But the scattered distribution of this springtail in the Arctic regions could be explained in several ways, including carriage on ice floes, or by larger, more mobile animals (particularly birds), or on drifting chunks of sea-borne turf or driftwood.

On 14 November 1963, an undersea volcanic eruption off the south coast of Iceland led to the formation of a new island, Surtsey, which provided a unique opportunity for observational studies in transoceanic colonization by terrestrial organisms. In 1975, Sturla Fridriksson³ published a summary of this work and recorded that six species of Collembola had reached Surtsey within 10 years of its formation. *Tetracanthella arctica* was not among them, despite being present on some of the Westman Islands only 15 km away. Such small soil organisms as the springtails, however, are evidently capable of quite rapid colonization over distances of several kilometres.

Coulson and his colleagues¹ adopted an experimental approach to the question of dispersal potential. They subjected five

species of Collembola and one mite to a variety of seawater conditions to test whether these terrestrial organisms can survive in the sea, even in the absence of driftwood or other materials. Many springtails have hydrophobic, unwettable cuticles that enable them to survive on water surfaces. Subjecting such species to 16 days on the surface of agitated sea water showed that they could indeed survive this long. Three out of the five species tested (including *T. arctica*) displayed over 80% survival. In a separate experiment, *T. arctica* and the mite *Camisia anomia* were submerged by pushing them below the surface with a paintbrush. They continued to be active, and 75% of the mites survived over a 15-day period. Only 12% of the springtails did so. Yet prolonged survival of even a small proportion of these organisms — which reproduce parthenogenetically, without the need for males — could permit their wide dispersal and subsequent establishment.

The implications for studies of springtail dispersal are considerable. Coulson and Birkemoe⁴ previously demonstrated that some species can survive at a temperature of -22°C for over four years, so the incorpora-

tion of sea-transported springtails into pack ice is entirely possible and could lead to their far-flung travel in the Arctic. Even without the aid of ice, the movement of floating or sunken springtails between land masses such as Norway and Svalbard is quite possible if they can survive for over two weeks in the open ocean.

Distribution patterns of soil invertebrates are of biogeographical interest in a variety of situations. Work in the tropics, for example, has indicated⁵ that termite biogeography and biodiversity might be a reliable indicator of tropical rainforest persistence through the Quaternary, the past 1.6 million years or so. Such hypotheses depend upon the concept of relict, non-mobile populations of an organism, which in turn is underpinned by the assumption of poor dispersal capacity. For termites, the fact that only specialist individuals in a population can start new colonies further limits the mobility of these species, but the revelation of unsuspected methods of travel in a seemingly static animal should always stimulate reflection. ■

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Sonoluminescence

Inside a micro-reactor

Detlef Lohse

Gas bubbles in a liquid can convert sound energy into light. Detailed measurements of a single bubble show that, in fact, most of the sound energy goes into chemical reactions taking place inside this 'micro-reactor'.

'Single-bubble sonoluminescence' is the remarkable phenomenon that describes how a gas bubble in liquid, exposed to a strong, standing sound wave, collapses and emits light. First observed 12 years ago¹, the basic physics of the process seems to be understood². That there is strong and crucial chemical activity inside the sonoluminescing bubble had already been hypothesized³ and indirectly confirmed^{4,5}. Now Didenko and Suslick⁶ (page 394 of this issue) have performed the first direct measurements of the reaction rates inside an individual bubble as it sonoluminesces. Energy-wise, it seems that a sonoluminescing bubble should be viewed not as a light bulb, but rather as a high-temperature, high-pressure, miniature reactor.

The process of sonoluminescence is shown in Fig. 1, overleaf. First, at low sound pressure, the micrometre-size bubble expands, increasing its volume by a factor of 1,000. When the pressure increases again, the bubble eventually collapses dramatically, shrinking to a radius that corresponds to solid-state densities. The compression drives up the temperature of the gas inside the bubble — through this 'adiabatic' heating the bubble interior is thought to reach around 10,000–20,000 K. Consequently, the gas becomes partly ionized and the recombination of electrons and ions leads to the emission of light.

As the bubble expands, gas dissolved in the liquid enters the bubble. At the point of adiabatic collapse, some of these gases are

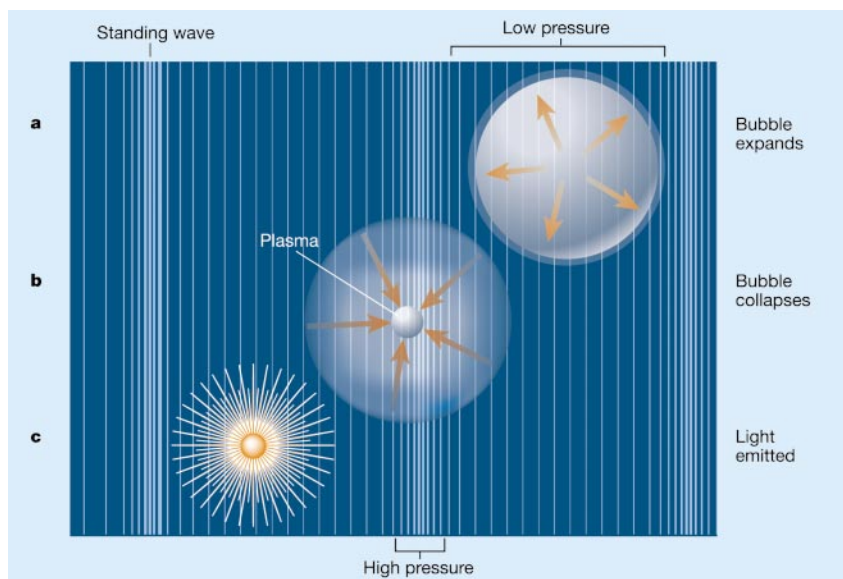


Figure 1 Glowing bubbles: a sound wave in liquid causes sonoluminescence. a. At low pressure, a gas bubble expands dramatically, until b, an increase in sound-wave pressure triggers its collapse. As the temperature inside the bubble soars to over 10,000 K, the gas becomes partly ionized, forming a plasma. Finally, c, recombination of electrons and ions results in light emission. But according to Didenko and Suslick⁶, more energy goes into chemical reactions in the bubble gas than is released as light.

trapped inside the hot bubble and start to react. For example, nitrogen molecules dissociate into nitrogen radicals and then react to form gases such as NH and NO. These highly soluble gases re-dissolve in the surrounding water when the bubble cools down. As the bubble expansion begins again, the next reaction cycle starts. Didenko and Suslick's calculations of the energy budget of sonoluminescence show that the amount of energy going into endothermic chemical reactions inside the bubble is two orders of magnitude higher than that going into light emission.

However, one complication that still remains is that the temperature inside the bubble cannot be measured directly. It has to be deduced either from the bubble dynamics (for example, by Mie scattering^{17,8}) or from the properties of the light emitted (spectral information, intensity and widths of the light pulses⁹). Either way, assumptions have to be made, whether in the modelling of the bubble dynamics¹⁰ and the thermodynamics of the heat and mass exchange between the bubble and its surroundings, or in the modelling of the plasma physical processes to predict the observable light properties.

The information obtained in these two ways should obviously be consistent in a viable theory of sonoluminescence. Even then, we can't be certain, as errors arising in the modelling of the bubble interior and light emission could compensate for each other. But Didenko and Suslick's measurements of the chemical reaction rates open up a third experimental window on the process. This extra constraint reduces the freedom in modelling, leading towards further convergence of the models.

It is astounding how many sub-disciplines of physics and chemistry have played a role in disentangling what happens in single-bubble sonoluminescence. They range from acoustics, fluid dynamics, plasma physics, thermodynamics, atomic physics and spectroscopy, to physical and analytical chemistry, chemical kinetics, dynamical-system theory and applied mathematics in general. But nuclear and fusion physics are not on the list: the final conclusion from Didenko and Suslick's results is that it is the chemical reaction rate within the bubble that limits the efficiency of bubble collapse. So 'bubble fusion' — an energy-generating fusion reaction in the high-density, high-temperature interior of the collapsing bubble¹¹ — is most unlikely.

Genetics

Inherit the wheeze

Jeffrey M. Drazen and Scott T. Weiss

A study of families containing asthma sufferers has led to the discovery of a gene that is associated with the disease. The finding brings the biological basis of asthma into sharper focus.

Asthma — a condition that afflicts hundreds of millions of people worldwide — has been recognized by physicians and lay people for more than two millennia. One would think that after all this time, and with so many affected people, we would understand the root causes of the disease. We don't; but we do know a little. Pathologically, asthma is characterized by infiltration of the airways with two specific

types of immune cells. Physiologically, the disease features both the asthma attack itself (episodic obstruction of the airways) and bronchial hyperresponsiveness — the tendency of the airways to narrow when exposed to a stimulus, such as cold, dry air, that would be innocuous in a normal person. Genetically, asthma is known to be a heritable, complex disorder (although the underlying genes have not been pinpointed) that

Although fusion may be out of reach, there are other uses for sonoluminescent bubbles. The extreme conditions inside the bubble are adjustable through external parameters such as forcing pressure or water temperature, so the bubble can be considered as a controlled high-temperature reaction chamber, offering opportunities to measure reaction rates in extreme temperature and pressure regimes. But understanding single bubbles is not enough. Before this knowledge can be applied to sonochemistry¹² — the enhancement of chemical reactions through ultrasound in a bubbly fluid — a better understanding of bubble–bubble interactions will be needed.

Just as the hydrogen atom was the basic model for larger atoms and molecules, so the single bubble is the simplest building block in the physics of a sound-driven bubbly fluid. With the detailed understanding of the hydrogen atom, atomic physics began to flourish. By analogy, now that there is a basic understanding of single-bubble sonoluminescence and the chemical activity inside the bubble, I expect also a flourishing of cavitation physics.

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