One significant development of the numerical techniques is the assumption that the diffusivity is a simple function of the mixing length[8] which can be determined by fast, linear calculations that give the dominant parameter dependences times a coefficient that is a slow function (determined through numerical turbulence calculations) of dimensionless parameters of the reactor set-up[9]. This has led to the IFS/PPPL model, named after the main institutions involved in its development. The basis for this approach has yet to be validated through detailed high-resolution turbulence calculations, and it is important that details of such calculations be published soon.

One reason we are interested in these models is to predict the performance of future devices, like ITER. To have a predictive energy-transport model requires many other components besides the turbulence-induced diffusivity. Dorland and Kotschenreuther have combined the IFS/PPPL diffusivity model with an assumed prescription for the density evolution and the boundary temperatures, and proposed it as a predictive transport model. Their results imply that ITER will fall far short of its main goal — a self-sustaining fusion reaction[4]. But other transport models, some theory-based and some empirical, have also been used to predict ITER's performance. Some are optimistic and some pessimistic; all are being tested against the existing experimental database to assess their reliability[10]. So far, the Dorland and Kotschenreuther model has not produced the best agreement or the worst.

ITER was initially planned to operate in the low-confinement mode, but all the models showed that it wouldn't then be able to achieve its goals. The regime now under consideration is the first of the advanced operation modes, the one discovered in 1982. But studying a single operation mode gives a very narrow perspective for such a device. The more advanced high-confinement regimes, with spontaneous or actively driven internal transport barriers, should be considered. They are not yet proven to be compatible with the steady state, but experiments underway may do so over the next few years.

ITER, being a large engineering project dealing with frontier physics, must be designed with enough flexibility to accommodate new physical developments. In recent years, fusion science has progressed quickly, so we must retain the ability to incorporate the advances that fusion science is making throughout the design and construction phases of ITER. □

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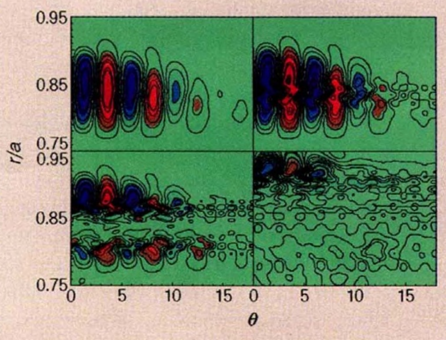
Shear calm



Plasma turbulence and transport are highly nonlinear. As a consequence, many states exist for a single set of boundary conditions, and spontaneous transitions can occur from one solution to another. The low- and high-confinement regimes are examples of two such states.

At low levels, injected power goes into heating the plasma and increasing the temperature gradient, and so increasing the turbulence level. But the turbulence increases energy transport, reducing the gradient and the confinement time — so the heating efficiency decreases with increasing power. This state is disordered and turbulent.

At higher power, above a threshold value, injected power can mostly go to heating the plasma, and, through a process of self-organization, building up a radial electric field. That induces a global $E \times B/B^2$ flow, which carries turbulent vortices along with it. A radial gradient in the field causes the flow to shear, which tends to shear the vortices and smooth out density fluctuations (the figure shows a simulated set of turbulent eddies being distorted and broken up[11]). This reduces fluctuation-induced transport[12], so confinement time is increased. B.A.C.

Daedalus

The dark is light enough

All life, the textbooks tell us, depends on the Sun. At the base of the food chain, green plants use sunlight to convert carbon dioxide into plant tissues. All higher organisms, directly or indirectly, live on what the green plants have won.

Recently, however, a genuine non-solar ecology has been discovered. The oceanic 'black smokers', those abyssal eruptions of geothermally superheated water, are far too deep for sunlight to penetrate. Yet they support a bizarre and complex ecology of specialized bacteria, tube worms and crustacea. These creatures are supposed to get their energy by oxidizing metal sulphides dissolved in the hot water.

Daedalus has other ideas. Our own motors and power stations exploit the classic thermodynamic source of useful energy, temperature differences. A black smoker creates a temperature difference approaching 400 degrees, exploitable at 60% efficiency (compared to about 10% for photosynthesis). Surely, says Daedalus, specialized organisms must have evolved to use this rich source of energy. A tube worm, for example, can be over a metre long. With one hot and one cold end, it could operate neatly as a thermal engine. But even tiny bacteria could gain energy by eddying in and out of the hot zone, thus taking themselves repeatedly round a thermal cycle.

These 'Carnot creatures' would operate by chemistry rather than physics. The high temperature would initiate a cascade of productive chemical reactions, whose waste heat would be discharged at the low temperature. No biochemist would recognize such a weird metabolism unless he was looking for it; but the search should be well worth while. For Carnot creatures could fit usefully into human industry. Many motors and furnaces throw out waste heat at hundreds of degrees. A suitable 'Carnot culture' of organisms could exploit that heat usefully, especially if their unique biochemistry could be adapted to cleaning up related metallic or sulphide pollution.

But Carnot biochemistry could be far more important than this. Many worlds, from distant 'brown dwarf' stars to the satellites of giant planets, may have internal heating but no effective 'Sun'. If Carnot life is possible, it may well have evolved in such dark and dismal places — making life abundant throughout the Universe. Indeed, our distant descendants may be able to harness Carnot biochemistry to sustain themselves on geothermal or residual brown-dwarf warmth when the Sun finally grows dim.

David Jones