in these mutants should provide insights into the workings of the organizer.

Other organizer-specific genes in the mouse have been or are being investigated with gene-targeting techniques. Mutations in *HNF3β* are embryonic lethal and cause marked gastrulation defects[13,14]. The defects are severe but variable; in some embryos fore- and midbrain structures are missing, indicating that in $HNF3\beta^{-/-}$ embryos the development of the head, as well as that of the trunk, is affected. Double-knockout *Gsc* mice die neonatally because of defects in the head neural crest, the main body axis being mostly unaffected; the *Gsc* phenotype might be compensated for by a related gene present in the mouse genome (G. Yamada and M. Blum, personal communication). Other mutations in the organizer-specific genes that have been found in the *Xenopus* studies should crop up among the patterning mutants identified in the genetic screens carried out recently in the zebrafish.

With so many genes involved in the formation of the head and trunk organizers, it is very likely that interactions and redundancies will be found. For example, mRNA microinjection experiments in *Xenopus* indicate that *Xlim-1* and *Gsc* have synergistic effects on notochord formation[6], and that *chordin*, but not *noggin*, can be activated by *Gsc* and *Xnot*[9]. So we can expect to find both parallel and convergent pathways in the organizer. The challenge in the near future will be to cross mouse strains to obtain double mutants in organizer-specific genes to uncover how these genes interact. It seems that unravelling the molecular nature of Spemann's organizer will be a laborious but rewarding task — considering the number of players identified so far, however, it might also be prudent to continue fishing for new genes in the *Xenopus* dorsal lip. ☐

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FLUID DYNAMICS

Turbulence and intermittency

J. C. Vassilicos

TURBULENCE, that ubiquitous phenomenon, is the puzzling blend of order and disorder that occurs in fluid flows of high Reynolds number, this measuring the ratio of nonlinear inertial forces to the linear dissipative (viscous) forces of friction within the fluid flow. Currently, research into turbulent flows is much concerned with identifying measurable, model-independent quantities that can objectively quantify aspects of the structure and geometry of the turbulence. Over the past few years[1–3], Castaing and colleagues have been developing a new measure of intermittency (or spottiness) of the turbulence that is both model-independent and can be determined over a wide range of Reynolds numbers. Now, they have devised an experimental set-up which can cover a considerably greater range of Reynolds numbers than in any previous experiment, and in doing so, they have discovered a transition from one geometry of turbulence to another[4].

Section through a turbulent water sheet, visualized with fluorescing dye and laser sheet (a plane of laser light). Reprinted from ref. 13.

Intermittency is pervasive in our world. Were the heavy car traffic in Bangkok not intermittent, pedestrians would be unable to cross the city's busy roads. Yet they cross these roads so frequently and so illegally that traffic lights have become irrelevant. In financial markets too, periods of trading frenzy are followed by periods of quiescence, and on closer examination the periods of high volatility are found to be themselves made of subperiods of relative quiet and other subperiods of relative bursts[5]. At the beginning of this century, the hydrologist H. E. Hurst discovered that, given the frequency of single floods and single droughts of the Nile, two successive floods and two successive droughts occur slightly more often than they 'normally' should. This implies an intermittency in time where years characterized mostly by floods are followed by years characterized mostly by droughts. This phenomenon of intermittency also implies a deviation from normal (here meaning gaussian) probability distributions.

Gaussianity and space-filling properties are recurrent themes in mathematics and important reference concepts in turbulence research. In two seminal papers in 1941 (see ref. 6), Kolmogorov deduced from first principles (the evolution equations of Navier–Stokes) that small-scale isotropic turbulence is non-gaussian; and he showed that if the energy dissipation of turbulence fluctuations is space-filling then the probability distribution of relative turbulent velocities (the difference between the velocities at two different points in the flow at a distance r from each other) is self-similar. This self-similarity means that the probability distribution of relative velocities is the same irrespective of the 'resolution' r.

However, experimental observations and measurements of turbulent flows have repeatedly indicated, since Batchelor and Townsend's first observations of intermittency in 1949, that the turbulence and its energy dissipation are not space-filling — they are intermittent in space — and that the probability distribution of relative turbulent velocities is not self-similar[7]. Measurements of the flatness factor, or kurtosis, of the distribution of relative velocities in a variety of turbulent flows (such as isotropic turbulence behind a grid, or the wake left by a cylinder) show that the flatness factor increases as the resolution r decreases. This demonstrates that the probability distribution of relative turbulent velocities is not self-similar and resembles a gaussian distribution less and less at smaller scales r. Oddly enough, the same holds true in financial markets[5] for the probability distribution of price changes over a timescale or 'resolution' τ. As τ decreases the kurtosis of price changes over that time increases.

Two parallel avenues of research have recently opened in the study of turbulence. One is to understand the spatial structure of turbulence intermittency, and the other is to identify objective measures of different aspects of intermittency, degrees of space-filling and self-similarity that are both model-independent and robust to variations in Reynolds number. A third avenue, which arises from the confluence of the other two, is to relate these measures to the spatial structure (geometry) of the turbulence.

Experimental studies[8] and direct numerical simulations[6,9,10] of small-scale turbulence have now revealed that the vorticity of turbulence is concentrated in tubes and that most of the dissipation is concentrated around these tubes. These localized ordered flow structures are inherently linked to the non-gaussian nature of the turbulence statistics and to the observed intermittency of turbulent activity. These localized flow structures may even be individually responsible for aspects of the global (aggregate) scaling properties of the turbulence statistics[6]. Measures of power-law scalings of turbulence statistics have already been proposed[11,12] that can detect scaling laws even in flows where the Reynolds number is so low as to defeat traditional measures (such as power spectra).

In their experiment, Chabaud *et al.*[4] use the new quantitative measure of intermittency developed by Castaing and co-workers[1–3]. This measure, $\lambda^2(r)$, is derived from the variances of the probability distributions of relative turbulent velocities at different resolutions r. It is in general a function of the distance or resolution r, but is independent of r in certain circumstances when the fluctuations are space-filling. The deviation of probability distributions from normal (gaussian) distributions can, more or less entirely, be described by $\lambda^2(r)$. The r-dependence of $\lambda^2(r)$ also describes the departure from self-similarity of the probability distribution of relative velocities, and the r-dependence of the flatness factor. Moreover $\lambda^2(r)$ can be measured in practice over a large range of Reynolds numbers without having to determine accurately the actual probability distribution of the turbulence.

In their new work, Chabaud *et al.* use helium gas as the experimental fluid in a cryogenic experimental apparatus. The dissipative viscous forces in helium vary dramatically with pressure, thus permitting the study of turbulence over an unprecedented range of Reynolds numbers for the same experimental set-up. The experimenters find that $\lambda^2(r)$ has a strong r-dependence — so the turbulence is intermittent — and that this dependence is qualitatively different above and below a critical Reynolds number, so that the geometry of the intermittency changes as the critical value is crossed (from a power-law scaling above and a logarithmic dependence below).

Furthermore, this geometry seems to depend quantitatively on dissipative viscous forces at large Reynolds numbers. Until now it had prevailingly been thought that viscous forces only affect the smallest scales of the 'turbulent edifice' by diffusive attrition. The results of Chabaud *et al.*[4] indicate that dissipative viscous forces affect the entire edifice, even at larger scales, a result that has serious implications for current turbulence modelling such as large eddy simulations.

The most fundamental questions, however, remain unanswered. For example, we do not know what the full geometry or spatial structure of the turbulence intermittency is and how it undergoes transition at the critical Reynolds number. The various quantitative measures of intermittency, scaling, non-gaussian statistics and departures from self-similarity need to be related to local flow structures in the turbulence (such as vortex tubes) so that the intermittency geometry of turbulent dissipation may be understood and reduced, if possible, to a few defining parameters.

Turbulence poses a challenge that is not restricted to fluid mechanics. Its kinematics may become a model for the mathematical description of a wider class of modern problems (financial markets, traffic and so on) where the number of independent degrees of freedom is neither large enough for the methods of statistical mechanics to apply, nor small enough for the general qualitative results of low-dimensional chaos to be valid. ☐

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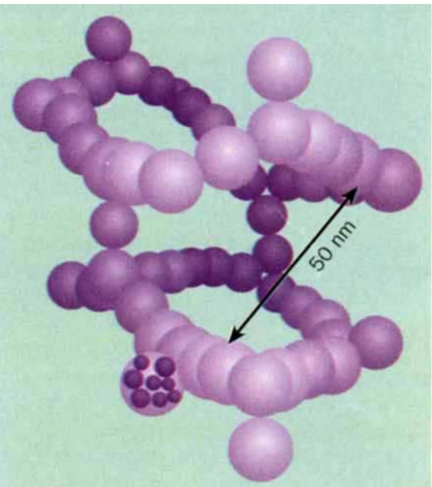
MATERIALS SCIENCE

Superexpansive gels

Jochen Fricke

AEROGELS — a low-density sponge-like form of solids such as silica — have fascinated scientists since their invention[1] in 1931, because of their potential for many and varied technical uses. Surface coatings of aerogel may find important applications in optics; they could be used as quarter-wave plates with a small index of refraction in order to reduce reflective losses. Likewise, if piezo-ceramic sensors for distance measurements are covered with a quarter-wave layer of aerogel for acoustic impedance matching they give off bursts of ultrasonic energy which are a thousandfold more intense than without. In electronics, the coatings may be used as insulating layers with low dielectric constant, allowing dielectric coupling between conductive layers to be reduced; in addition the transmission speed for signals is closer to the velocity of light in a low-density layer (mainly air, after all) than in a non-porous material.



Branching strings of silica 'beads' a few nanometres across.

Until now, almost all aerogel production has been at high pressures within an autoclave; at low pressures, odd though this seems at first, the gels collapse during processing. Now, Jeffrey Brinker and colleagues (page 439 of this issue)[2] have discovered how to do the trick at ambient pressure.

A silica gel is generally formed by polycondensation of a silica-containing precursor, such as tetramethoxysilane or waterglass. The gel consists of nanometre-sized beads of SiO_2, which agglomerate into branching chains. The 50-nm voids or pores left between the chains (see figure) are filled with liquid. The problem is that if the gel is dried in air the liquid around the perimeter of the gel body forms nanometre-sized menisci across the pores. As compressive forces are proportional to the inverse of the pore radius, the pressures exerted on the nanostructured gel can reach hundreds of bar; as a consequence the gel collapses irreversibly on drying.

Kistler opened the way to preserve the delicate gel network. His trick was to