CORRECTED 13 SEPTEMBER 2004; SEE LAST PAGE

Rh-related proteins are expressed—RhBG in the basolateral plasma membrane and RhCG in the apical plasma membrane (*5*). Regulated excretion of NH_4^+ by the kidneys is a crucial mechanism for controlling systemic pH (*7*). Synthesized in the proximal tubule, NH_4^+ accumulates in the renal medulla by active transport from the loop of Henle. The final step in NH_4^+ excretion involves rapid NH_3 diffusion across the collecting duct epithelium in parallel with active H^+ secretion. Although it has been assumed that NH_3 diffuses into the collecting duct lumen through the lipid bilayer, the structure of AmtB predicts that the entry of NH_3 is mediated by the Rh-related proteins expressed there. It remains to be seen whether NH_3 penetration through these proteins may be a point where systemic acid-base balance is regulated, or whether Rh-related proteins are involved in clinical disorders such as renal tubule acidosis.

Another site where rapid ammonia transport may be critical to homeostasis is the liver where RhBG is present (*8*). NH_4^+ is produced during the catabolism of amino acids and is also delivered to the portal circulation by intestinal bacteria that break down urea. NH_4^+ is a neurotoxin and must be efficiently cleared from the portal blood by hepatocytes and converted to urea and glutamine to prevent serious systemic consequences. Central nervous system dysfunction occurs if NH_4^+ concentrations are elevated as seen in hepatic encephalopathy, a common but ominous manifestation of advanced liver failure. RhBG is expressed selectively in the pericentral hepatocytes, just before the portal blood is delivered to the systemic circulation. Thus, RhBG may be important to the process that normally clears the last vestiges of ammonia from the portal blood.

The structural determination reported by Khademi *et al*. provides great insight into the important process of gas transport. As with the transport of water, glycerol, and other uncharged solutes, the phenomenon of gas transport now has a molecular identity and an advanced level of understanding. Thus, physiologists may now be able to ask specific scientific questions about ammonia transport with great precision.

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PHYSICS

Visualizing the Dynamics of the Onset of Turbulence

Friedrich H. Busse

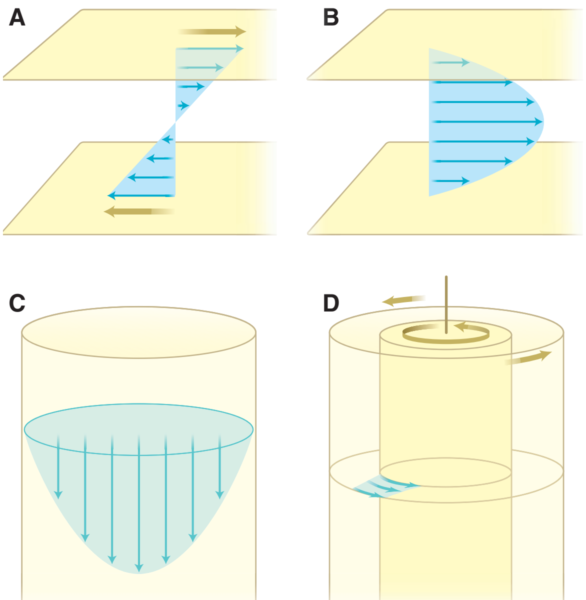
The transition to turbulence in fluid flow is an everyday experience. As a faucet is slowly opened, the initially laminar flow of water changes into an irregular chaotic flow. As a result, friction is much increased and, for the same discharge, a higher pressure head must be applied than in the laminar case. This transition is of fundamental importance in engineering problems dealing with fluid flows. On page 1594 in this issue, Hof *et al.* (*1*) present the first observation of a basic dynamical property of the transition.

The study of the onset of turbulence has a long history. In 1839, Hagen first noted the existence of two distinct flow regimes in the discharge from pipes (*2*). Some 50 years later, Reynolds (*3*) realized that the transition between these regimes only depends on a dimensionless number, $Re = UD/\nu$, where U denotes the mean velocity averaged over the circular cross section of the pipe, D is its diameter, and ν is the kinematic viscosity of the fluid.

In pipe flows, disturbances of finite amplitude are responsible for the transition to turbulence. Reynolds noticed as much when he reported that the transition was delayed to higher values of Re when a particularly smooth entrance region of the pipe was used. However, theoretical studies can treat easily only infinitesimally small disturbances, and this is one reason why theoretical understanding of the transition to turbulence in shear flows has been slow to emerge. For laminar flow in a channel between parallel plates, such analysis suggests that laminar flow should become unstable at $Re = 7696$, but experiments indicate a much lower value of ~1500 for the transition (*4*). For flow between two parallel plates sliding relative to each other with speed U (plane Couette flow) and for flow through a circular pipe (see the figure), the discrepancies are even larger: No growing infinitesimal disturbances could be found theoretically at any Reynolds number.

With today's powerful computers, it is not difficult to simulate turbulent fluid flows at Reynolds numbers of several thousands. Good agreement between statistical properties of turbulence in experiments and in numerical simulations has been found (*5*), but a detailed understanding of the transition process is still lacking.

For configurations other than plane parallel flow, theoretical studies have been more successful. For example, when the circularly symmetric flow between differentially rotating coaxial cylinders becomes unstable, axisymmetric vortices are formed, the amplitude of which increases smoothly with the Reynolds number. This is a typical example of a supercritical bifurcation (*6*), in



Simple laminar shear flows. (**A**) Plane Couette flow; (**B**) channel flow (Poiseuille flow); (**C**) pipe flow; (**D**) circular Couette flow.

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contrast to the unstable subcritical bifurcations that occur in plane parallel shear flows in the absence of rotation.

For plane Couette flow and pipe flow, theoretical studies have not found evidence for bifurcation at finite values of *Re*. Nevertheless, the belief in the existence of relatively simple solutions describing states of fluid flow distinct from the basic states of plane Couette flow or pipe flow has persisted. These solutions must be expected to be unstable; therefore, numerical methods are usually not capable of producing them, just as experiments do not exhibit them.

One way of accessing these solutions is by considering the plane Couette or pipe flow problem as a special case of a more general problem, with an additional parameter as a function of which instabilities or bifurcations can be found. The desired solutions are searched by following one or the other of the bifurcating solution branches through secondary bifurcations. For plane Couette flow, the small-gap limit of circular Couette flow provides such an additional parameter in the form of the mean rate of rotation (*7*), which vanishes only in the special case of plane Couette flow. Alternatively, one may consider plane Couette flow between horizontal plates, the lower of which is heated, and the upper of which is cooled. The basic state of flow is not changed by this procedure, but additional instabilities driven by thermal buoyancy become available (*8*). Or an artificial forcing can be applied to gain a point of bifurcation from which a solution branch can be followed to the place of vanishing forcing (*9*). This method has been applied to the case of pipe flow (*10*, *11*).

With these methods, steady solutions are obtained for plane Couette flow and traveling wave solutions for pipe flow. These "tertiary solutions" are separated from the basic states by two bifurcations. They are thus characterized by two wave numbers, in the streamwise and in the transverse directions.

A dominant component of the tertiary solutions are the roll-like eddies with axes parallel to the mean flow. These rolls redistribute momentum and tend to flatten the profile of the mean flow. As a result, the slope of the profile close to the solid boundary steepens, thereby increasing viscous stress. To obtain the same mass flux through the pipe as in the laminar case, a higher pressure gradient is thus needed. Similarly, in the plane Couette case, a stronger force must be applied to keep the plates moving relative to each other with velocity *U*.

The two-dimensional roll-like eddies would decay if they were not sustained by the three-dimensional components of the tertiary solutions. Streamwise oriented roll-like structures or "streaks" are commonly observed in wall-bounded turbulent shear flows, but the relationship to the tertiary solutions is tenuous at best. There has been little hope to observe the latter solutions in the laboratory because they are almost always unstable.

It thus came as a surprise when Hof *et al.* (*1*) observed the predicted patterns of tertiary solutions in their experiments. Using special disturbances in carefully prepared pipe flow (*12*) and sophisticated visualization techniques, they demonstrate that the tertiary solutions can be realized at least as a transient phenomenon. They find surprisingly close agreement between experimentally observed structures and their theoretical counterparts (*1*).

The puzzle of the visibility of unstable solutions may be explained as follows. The changing state of fluid flow can be considered as a trajectory in the high-dimensional solution space of the basic equations of motion. The tertiary solutions (and the more complex ones bifurcating from them) are unstable in particular directions, but they attract trajectories from most other directions. The trajectories therefore spend much of their time in the neighborhood of those solutions before they are ejected. These solutions may thus be regarded as virtual traffic arteries, which become visible as they attract parcels of momentum and transport them for a while until they deliver them to another artery and decay.

The achievement reported by Hof *et al.* (*1*) stems from a collaboration between engineers, physicists, and mathematicians. It opens the door not only to a full understanding of the transition problem, but also to possibilities for influencing and controlling transitions, with far-reaching engineering implications. The new results also demonstrate that it is never too late to attack an old problem, especially if it is done as an interdisciplinary effort.

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CHEMISTRY

Multidimensional Snapshots of Chemical Dynamics

Albert Stolow and David M. Jonas

Chemical reactions involve the concerted motions of both atoms and electrons as bonds rearrange on the way from reactant to product. Elementary models use a single, one-dimensional (1D) reaction coordinate to describe motion across a transition state separating reactants from products. However, internal molecular motions along other coordinates tend to prevent molecules from following this lowest energy reaction coordinate. These other motions are not mere energetic reservoirs that may aid or deter motion along the reaction coordinate. Rather, they are intimately involved in the complex flow of electronic charge and vibrational energy during reaction. Recent advances in femtosecond (10^{-15} s) laser and detector technologies are enabling a new generation of experiments that provide true multidimensional views of the dynamics of chemical reactions (*1*).

One emerging approach is based on time-resolved diffraction from crystals that have been photochemically excited by a femtosecond pulse of light, allowing multidimensional measurements of the ensuing atomic motions. For example, Moffat (*2*) and Anfinrud and co-workers (*3*) have performed time-resolved crystal diffraction experiments that yield the time-dependent positions of all atoms during a biochemical photoreaction. The reaction is initiated by a 100-picosecond pulse of light and then probed by measuring the diffraction pattern

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