tration of glucose by an intraperitoneal or intravascular route may thus uncover more striking abnormalities in glucose tolerance in these animals. In addition, glucose may be lost in the urine as a result of renal malfunction. Functional alterations in these or other organ systems may be associated with adaptations to the altered metabolic milieu or to pathological changes resulting from altered blood flow due to the cardiac hypertrophy described. Direct evaluation of glucose utilization by individual tissues *in vivo* and *in vitro*, evaluation of food intake, and measurement of urinary glucose levels and renal haemodynamics will undoubtedly answer some of these questions.

Further characterization of these mice may yield interesting data on their ability to compensate for metabolic defects during development. Indeed, as suggested by Katz *et al*., further investigation of the compensatory mechanism by which these animals cope without GLUT4 may provide insight into mechanisms that can be exploited in the treatment of human type II diabetes. ☐

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POLYMER SCIENCE

Gourmet macromolecules

Philip Ball

THE difference between synthesis in small-molecule organic chemistry and in polymer chemistry has traditionally been much like the difference between dinner at the Ritz and a school meal. One is exquisitely and individually prepared step by step; the other is mass-produced by throwing the ingredients into a single pot and boiling for an hour. Lest polymer chemists be offended by this comparison, it should be pointed out that of the two reasons for the gastronomical differences, only one applies to polymer synthesis: it is not that the culinary skills of polymer chemists are any the less, but that their clients are less discerning. What matters, if one is producing a polypropylene shopping bag, is not that each molecule has an identical size and structure, but that the crude bulk determinants of the mixture, such as viscosity and molecular-weight distribution, be reproducible.

Several symposia at a recent meeting of chemists*, however, underscored the fact that polymer chemists can now serve up concoctions scarcely less impeccable than those of natural-product chemists. New synthetic strategies are providing opportunities to dictate the architecture of macromolecules to an extent that their mass spectra show the sharp single peak of an almost unimolecular sample rather than the gaussians and skewed-gaussians of old.

Dendrimers — macromolecules whose many-branched tendrils radiate out from a central core to create a globular morphology — have been much acclaimed already (see, for example, H. W. Gibson, *Nature* 371, 106–107; 1994; D. A. Tomalia and P. R. Dvornic, *Nature* 372, 617; 1995). New applications of these molecules continue to suggest themselves — they might, for instance, act as nanoscale single-molecule probe tips for near-field fluorescence microscopes (R. Kopelman, Univ. Michigan).

But great things are also predicted for the highly nonlinear hyperbranched polymers formed by the condensation of branched monomers of the type AB_x (J. Fréchet, Cornell Univ.; C. Hawker, IBM Almaden). Predicted by Paul Flory in the 1950s, the first example of these macromolecules was reported in 1988. In terms of macromolecular organization they occupy a middle ground between the precisely controlled dendrimers and the more or less uncontrolled conventional linear polymers. Because in general not all of the x B groups on every monomer will be condensed with an A group of another monomer, the residue of reactive B groups makes hyperbranched polymers of possible value as functional polymers (for example, as adhesives); but whereas dendrimers display their reactive groups solely at the surface of the macromolecules, in hyperbranched polymers these groups may be buried within the globular architecture, leaving the polymer stable but with the potential to be thermally activated into a reactive form.

The earliest hyperbranched polymers contained threefold branch junctions based on AB_2 monomers, but very high degrees of branching can now be achieved by using controlled stepwise ('living') polymerization to make oligomeric 'macromonomers' with x ranging from 4 to 8 (Fréchet). Living polymerization methods, which have evolved largely over the past two decades, are surely amongst the most valuable tools to have entered the polymer chemist's kitchen. The chains of living polymers grow strictly by sequential addition of monomers to a reactive chain end, which is stabilized so as to prevent the chain termination or chain transfer processes that, in traditional free-radical or condensation polymerizations, result in broad molecular-weight distributions and a mixture of products.

In an ideal living polymerization reaction, monomers are added to each of the initiator molecules at an equal rate, so that when the supply of monomer is exhausted all of the chains have more or less equal length, and the reactive chain ends remain 'living' in the sense that polymerization will resume if more monomer is added. Most living polymerization reactions have involved anionic or cationic reactive ends, stabilized by the presence of a counterion; but free-radical chain ends, stabilized by a free-radical capping agent that will bind reversibly without initiating new chains, can now also be used (Hawker) to provide a variety of controlled macromolecular architectures, such as star polymers and graft copolymers in which the star arms or grafted side chains are of equal length.

Precise control of polymer architecture is the hallmark of biology, which uses templating methods to realize this goal. The same specificity for an arbitrary but predefined monomer sequence has been accessible for some time now through the solid-state methods used to construct stretches of polypeptides or nucleic acids with particular sequences, an approach that can, in principle, be used to make chains of any length but which in practice becomes very time-consuming for chains longer than 30 or so monomers. But the speed with which, say, the 4^N possible sequences of DNA N-mers can be generated may be greatly enhanced by using photolithographic techniques to build up pixelated combinatorial arrays (S. Fodor, Affymetrix, California). By tethering these oligomers away from the substrate on polyethylene oxide strings, the arrays can be used for rapid and easy recognition of complementary sequences in free strands of DNA, fluorescently tagged so that the appropriate element of

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**National Meeting of the American Chemical Society, Chicago, 20–24 August 1995.*

the array 'lights up' when binding occurs. The primary use of these oligonucleotide arrays, now marketed commercially as biosensor-style chips, may be as a convenient way to write down sequence information in a form that would allow easy comparison of one genome against another.

Co-opting natural polymerization machinery to express purely synthetic genes is now possible (D. Tirrell, J. Beecher, Univ. Massachusetts at Amherst, see *Nature* **367**, 323; 1994) by using recombinant DNA technology to incorporate artificial sequences, prepared by solid-state methods, into *Escherichia coli* plasmids. The fruits of this new approach are now starting to fall: for example, hybrid enzymes that are expressed with a ready-made synthetic polypeptide region that confers a useful materials property, such as self-organization into films or electrochemical activity.

And finally, controlling the microscale morphology of polymers, rather than their macromolecular structure, can provide new microsculpted materials: examples range from patterned polymer sheets formed by letting capillary forces draw the monomers into a micropatterned mould (G. Whitesides, Harvard Univ.; see *Nature* **376**, 581; 1995) to macroporous functionalized polymer monoliths for use in chromatography and bioreactors (Fréchet) to crosslinked, hollow microspheres of haemoglobin (M. Wong, Univ. Illinois). The latter, formed by ultrasonication of a solution of haemoglobin, could act as oxygen carriers, with similar sizes and flow characteristics to erythrocytes, in artificial blood. ☐

Philip Ball is an associate editor of Nature.

BROWN DWARFS

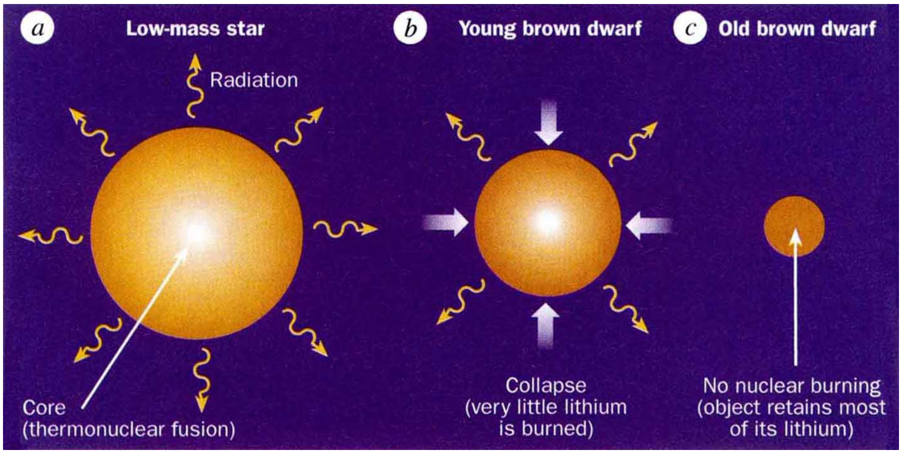
A bright future for faint stars

Lorne Nelson

WHAT distinguishes a star from a planet? Could we call Jupiter a failed star? In an attempt to answer these questions, astronomers have postulated the existence of a whole new class of astronomical objects called brown dwarfs[1,2], which, in essence, bridge the gap between stars and giant planets. On page 129 of this issue, Rebolo, Zapatero Osorio and Martín[3] present compelling evidence that they have discovered one of these elusive objects in the Pleiades star cluster. Not only does their discovery confirm the predictions of astronomers that brown dwarfs must exist, but it also opens the door to studying a class of objects that may well constitute a significant fraction of the baryonic dark matter that is thought to exist on all distance scales throughout the Universe.

To understand how brown dwarfs differ from stars and planets, consider the Sun and Jupiter. Both were formed at the same time and are self-gravitating 'gas' spheres composed primarily of hydrogen. The Sun has a mass nearly 1,000 times greater than that of Jupiter and thus it has a very different internal structure. But suppose that we decreased the Sun's mass by a factor of ten and increased Jupiter's mass by the same factor. Would we still refer to Jupiter as a planet and to the Sun as a star? What if the factor were thirty?

Clearly, the mass of an object and the process by which it formed are two of the important factors that must be considered when determining an object's classification (see figure). Stars are formed as a result of the collapse of a fragment of an interstellar gas cloud. As the star contracts, its internal temperature increases until it is able to sustain thermonuclear fusion. However, when the mass of the 'protostar' is less than ~ 0.08 solar masses, its internal temperature never becomes high enough to achieve stable hydrogen burning. Consequently, it continues to collapse (and cool) until electron degeneracy pressure halts further contraction. These objects are known as brown dwarfs and are often referred to as 'failed stars'. Giant planets also contract and cool during their evolution, but they are distinct from brown dwarfs in that they form by the cold accretion of matter in a gaseous disk rather than through the fragmentation of a gas cloud.



Schematic comparison of stars and brown dwarfs. In the low-mass star (*a*), sustained nuclear burning of hydrogen in the core prevents the star from collapsing under its own gravity. In contrast, as a young brown dwarf (*b*) contracts, its internal temperature rises but never gets high enough to sustain nuclear fusion. In an old brown dwarf (*c*), the collapse is halted by electron degeneracy pressure. The object cools continuously and becomes very faint.

As a brown dwarf cools, it becomes increasingly faint. A 0.06-solar-mass brown dwarf whose age is equivalent to that of the Sun is about 100,000 times less luminous. Although this intrinsic faintness makes them extremely difficult to detect, advances in telescope technology during the past decade have spurred rapid progress. Astronomers are using a variety of techniques to search for brown dwarfs[4], but looking for them in young clusters of stars that are relatively close to the Sun seems to be the most promising approach. Not only are young brown dwarfs much more luminous, but as the ages of clusters are reasonably well determined, the masses of brown dwarf candidates can be inferred and the validity of theoretical models can be examined.

Rebolo and colleagues discovered the apparent brown dwarf (Teide 1) in the Pleiades cluster. As the cluster is located about 400 light years away and is only about 100 million years old, it is an ideal location to search for brown dwarfs[5]. From its observed brightness and inferred surface temperature, Rebolo and colleagues conclude that Teide 1 probably has a mass of ~ 0.02 solar masses. Unlike previous claims for the existence of objects very close to the substellar limit, Teide 1 seems to have a mass that places it well below this limit. However, there appears to be a genuine discrepancy between the theoretical models and the observationally inferred properties of Teide 1. In particular, the inferred surface temperature of Teide 1 seems to be too low. The presence of molecules and possibly even grains in the atmospheres of brown dwarfs makes it difficult to calibrate the surface temperatures. At present, we cannot rule out the possibility that the mass of Teide 1 is as large as 0.07 solar masses, although even this is below the limit of 0.08 solar masses. This issue will probably be resolved when a new