joining clearly does not occur at telomeres.

If this speculative model for the connection between telomeres and damaged DNA is correct, might the MRT-2 protein facilitate telomere function as a direct consequence of its checkpoint activity? Ahmed and Hodgkin[1] suggest that the telomere must be recognized as a double-strand break by checkpoint proteins before telomerase can act on it. For instance, MRT-2 (and its counterparts in other organisms) could contribute to strand-specific processing of the telomere, which is thought to be essential in maintaining chromosome ends[10]. Similar processing at double-strand breaks, also activated by checkpoint proteins[11], would be followed by a different set of events, leading instead to fusion of broken ends (Fig. 1).

Such a mechanism suggests that the cell uses an elegant economy when it handles DNA termini. However, we still do not know what activity dictates whether a processed end becomes a telomere or a fused DNA molecule. So the telomere puzzle — which was presented to us by Barbara McClintock almost 60 years ago[9] — has yet to be completely solved. ∎

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Phase transitions

Jumping between liquid states

Paul McMillan

Crystalline solids can exist in different forms — polymorphs — with different structures and bonding patterns. Such polymorphs are usually stable under different conditions. For example, carbon occurs naturally as two different polymorphs, graphite and diamond, which are stable at different pressures and temperatures. The transformation between graphite and diamond is classified thermodynamically as a first-order phase transition, in that the structure and energy change abruptly at the transition. First-order phase transitions in noncrystalline materials — for example, the abrupt condensation of a gas to a liquid — are also well known.

The existence of liquid (rather than solid) polymorphs is only just beginning to be recognized. For a long time, the idea of a first-order transition between two liquids was not considered seriously, because of the view that liquids have rapidly changing structures that vary smoothly with temperature and pressure. Growing evidence for first-order transitions in liquids has come from analysis of their physical properties and from computer simulations[1,2]. On page 170 of this issue, Katayama *et al.*[3] describe a direct structural study of liquid phosphorus under high pressure, using synchrotron X-ray diffraction. Simply by increasing the pressure, the structure of liquid phosphorus jumps suddenly from a relatively open molecular structure to a new polymeric form with higher density.

To place the results of Katayama *et al.* in context we need to understand the melting behaviour of certain liquids. Crystals are normally denser than their corresponding melts, so the melting temperature increases with increasing pressure (that is, the melting slope is positive). Important exceptions to this rule include silicon and water ice, which have a negative melting slope. Several other crystalline elements and compounds show maxima in their melting curves as the pressure increases[4].

Such unusual behaviour is understood in terms of a 'two-state model', in which low- and high-density states (associated with different atomic arrangements) coexist within the liquid. As pressure is applied, the relative proportion of high- to low-density states increases. The result is that the liquid density at high pressure can exceed that of the crystalline state, and the slope of the melting curve becomes negative. Thermodynamic analysis shows that the two-state behaviour passes into two-phase behaviour below a certain temperature[1,4], in so far as the two phases have different thermodynamic properties, such as energy or entropy (the degree of disorder). So by applying pressure to the liquid below this critical temperature, a first-order transition between two different liquid phases is expected to occur.

The case of water is interesting. Experiments reveal a transition between low- and high-density forms of amorphous ice, leading to the suggestion that a pressure-driven phase change might occur in the liquid[2,4,5]. 'Normal' water corresponds to the high-density liquid, which explains why ice floats on it. The low-density, highly viscous liquid has yet to be observed experimentally, but it exists in computer simulations. Other pressure-induced transformations between low- and high-density liquids have been seen in glassy systems that have an open structure (for example, SiO_2)[1-4]. But glasses are not in thermodynamic equilibrium, so such transformations do not correspond to true phase transitions from one stable liquid to another. A second liquid phase has been seen in supercooled molten Y_2O_3-Al_2O_3 (ref. 6). But two phases had not been directly observed in a stable


Nuclear polarization

More spins for protons

Protons have an intrinsic spin or angular momentum that becomes important when the proton interacts with other polarized particles or with an electromagnetic field. Particle physics experiments with polarized protons require high magnetic fields (2.5 to 5 tesla) and extremely low temperatures (0.3 to 1 K) to reach 70% polarization. In contrast, magnetic resonance imaging techniques that operate at room temperature and magnetic fields of 1 tesla only achieve 0.0003% polarization. The production of polarized protons in a modest magnetic field (0.3 tesla) at liquid-nitrogen temperatures (77 K) has now been reported by Iinuma *et al.* (*Phys. Rev. Lett.* **84**, 171–174; 1999).

Iinuma *et al.* achieve high levels of proton polarization (up to 32%) by doping their materials with a small amount of pentacene. Electrons in pentacene can be excited to higher states (S' and S_1 in the figure) with a laser beam. Around 2% of the electrons transfer from S_1 to the lowest triplet state T_0. Using microwaves tuned to the frequencies of the electron and proton spins, the electron polarization is transferred to nearby protons. Electrons in the triplet state decay into the ground state, where the proton
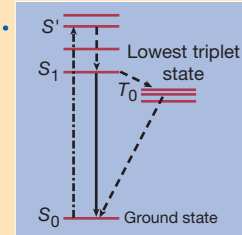
spin remains polarized.

Early experiments at liquid-nitrogen temperatures polarized just 13% of the protons (the theoretical limit is 73%). Iinuma *et al.* trebled this using a powerful pulsed dye laser (rather than a nitrogen laser) to optically excite the electrons to the first excited state of pentacene. The authors suggest that their technique might enhance the sensitivity of NMR at higher temperatures as well as having an impact on particle physics. **Sarah Tomlin**

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simple liquid until the work of Katayama *et al.*[3].

Previously, Brazhkin and colleagues observed large changes in the electrical conductivity of simple liquids (iodine, sulphur and selenium) at high pressure, which were attributed to liquid–liquid phase transitions[4,7]. But these changes could equally well occur in a two-state regime within a single liquid phase[4]. Katayama *et al.*[3] provide a method to determine which type of thermodynamic behaviour is associated with changes in liquid properties as the pressure varies. They use synchrotron X-ray diffraction methods to study directly the structure of liquid phosphorus at high pressures and temperatures. They observe at a pressure near one gigapascal, a sharp transition between the molecular liquid present at atmospheric pressure and a high-density polymeric form. The two forms coexist within a narrow pressure range, as determined by the composite X-ray spectrum, and the transition could be reversed by lowering the pressure — providing direct evidence for a pressure-driven structural transition in the liquid above the melting point.

The evidence now available indicates that first-order phase transitions do occur in the liquid state, and that the phenomenon is probably widespread[1–4]. We must revise our conventional picture of liquids as entities with continuously varying averaged structure. Instead, each liquid is constrained by distinct 'configurational landscapes' that are explored within a given range of density (or pressure)[8]. Liquid polymorphs with different structures and physical properties have landscapes that are separated by high-energy barriers that determine the first-order nature of liquid–liquid transitions[2]. This 'configurational landscape' model may even be applied to biomolecules, in which transformations between unfolded and folded structures of proteins may be modelled by analogous phase transitions[8].

Multiple liquid–liquid transitions may occur for a given substance as the pressure is varied[1,4,7]. At the lowest density, the liquid–gas transition is then the 'final' member of a suite of such transitions. The experiments of Katayama *et al.*[3] point the way not only to structural investigations of liquid polymorphs, but also to gaining a broader understanding of relationships between liquids and gases, by providing direct confirmation that pressure-driven transitions between different liquid phases do occur. An even more intriguing possibility is that first-order transitions may occur between gases. A 'normal' gas is already recognized as distinct from an ionized plasma. Perhaps transitions between non-ionized gaseous phases might occur at extremely low temperatures and at low densities. ■

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Palaeontology

Fossil fish up for election

Meemann Chang

The bony fishes (osteichthyans) were the progenitors of tetrapods, without which none of us would be here. So we have good reason to be interested in bony-fish evolutionary history. The group is divided into the ray-finned and lobe-finned fishes, and recently discovered early bony-fish specimens have a mixture of characters of each type. Moreover, these specimens show some features formerly thought to be present only in the more primitive cartilaginous fishes (chondrichthyans — sharks and rays) and an extinct group called placoderms. So palaeontologists have been puzzling over which group the new forms should be assigned to, and how all of the various groups are related to each other.

On page 185 of this issue[1], Basden *et al.* report on another bony-fish fossil that comes from southeastern Australia and is designated AM101607. It looks ray-fin-like, but it also exhibits some characters previously found only in lobe-finned fishes and others found only in chondrichthyans and placoderms. Last year, Zhu *et al.*[2] discussed another fish of this kind, *Psarolepis*, from China and Vietnam, which had been earlier described by Yu[3] and is more lobe-fin-like in appearance. Both *Psarolepis* and AM101607 are from the Early Devonian period, about 400 million years ago, and so are among the oldest bony fishes known. The respective authors[1,2] each propose that the specimen they describe is a candidate to be a member of the basal group (the 'ancestor') of bony fishes, but Basden *et al.*[1] consider that their fish is the more promising contender.

Specimen AMF101607 consists only of a large portion of a braincase, but its three-dimensional preservation reveals many anatomical details. In several respects it resembles two well-preserved ray-finned fishes, *Mimia* and *Moythomasia*, from the Late Devonian (about 350 million years ago) of western Australia[4]: similarities lie in the ornamentation of the dermal bones; in the pattern of the skull roof (Fig. 1a, b), and of the sensory canal and pit line; and in the structure of the lateral wall of the orbito-temporal region of the braincase. It also has some characters in common with *Psarolepis* and other lobe-finned fishes. Other characters, however, are shared with ray-finned fishes and chondrichthyans, rather than lobe-finned fishes (the postorbital process; the broad spiracular groove; and the lateral commissure joining the base of the orbito-temporal region of the braincase). But, most strikingly, AMF101607 has some features never found in either lobe-finned or ray-finned fishes, such as an eyestalk.

Eyestalks are rod-like structures that grow out of the inner wall of the orbit and have a flat, rounded knob at the end which abuts against the eyeball[5]. They were thought to be unique to chondrichthyans and placoderms, where they (and the endocranium as a whole) are cartilaginous and can be seen in full only in recent sharks and rays (Fig. 2a). In placoderms, now represented only by fossils, the cartilaginous endocranium is frequently lined with a thin layer of calcified cartilage. In these fishes, the eyestalk itself is not preserved. Even its base, which is part of the endocranium, has been found in only a few taxa, such as *Jagorina* and *Macropetalichthys*[6], where it is evident as a stub (Fig. 2b). In most cases there is only a hole in the inner wall of the orbit at the site for eyestalk attachment[7] (Fig. 2c).

It seems that the minerals filling the base of the eyestalk in Basden and colleagues' specimen were etched out during acid preparation of the fossil, and there is only an opening left in the inner wall of the orbit. Yet the rim of the opening is clearly everted,
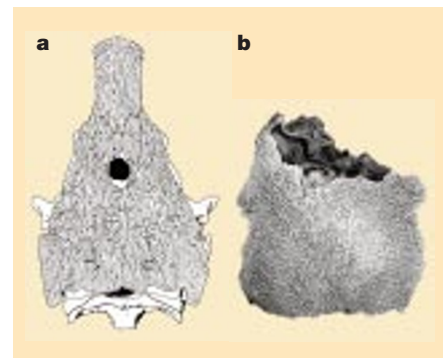

Figure 1 **Similar patterning of the skull roof of Devonian fossil ray-finned fishes from Australia.** a, *Mimia,* from the Late Devonian[4]. b, **The new specimen AMF101607 from the Early Devonian, as described by Basden *et al.*[1].**