cells. Perhaps the faeces came from an Indian with a bleeding intestine.

PRO: Because myoglobin comes only from heart and skeletal muscle, myoglobin was not detected in 20 'control' faeces from other Puebloan archaeological sites, nor in modern faeces from 29 healthy individuals and 10 patients with blood in their faeces. The myoglobin-specific antibody used does not detect the related blood protein haemoglobin[1].

CON: Okay, you've proved one case of cannibalism, but it's still a rare aberration. Instead of denigrating Indians by looking for proof of bad behaviour, why don't you look for proof of good behaviour[4]?

I ask instead, why is the evidence for cannibalism — which suggests that this practice was once widespread — now so desperately denied? I can think of at least four reasons. First, because Westerners abhor cannibalism, some of us cannot believe that other societies practised (or still practise) it. But many behaviours accepted by one society are abhorred by another. The horror of my New Guinea friends when I described circumcision, US treatment of the elderly, and US funeral customs matched Westerners' horror at cannibalism. Some widespread Western practices are far more destructive than cannibalism. There are good reasons why cannibalism might have been customary in some societies but abhorrent in others[5].

Second, because Westerners abhor cannibalism, Western missionaries and government officers who encounter a society practising cannibalism immediately forbid it. So it is no surprise that there are few first-hand accounts of cannibalism by twentieth-century Westerners: would you invite someone to watch you doing something if it would get you arrested? Once Western control is established, cannibalism quickly dies out.

Third, those Westerners who obtain evidence of cannibalism are condemned as slandering the non-Western society reported as having practised it — condemned not only by anthropologists offended at perceived insults to 'their' people whom they study, but also by the cannibals' descendants who have absorbed Western values.

Finally, any society has practices considered acceptable in private but inappropriate to practise in public, in the presence either of anyone else (for example, sex or defecation) or of non-clan members (for example, initiation rites or cannibalism). The abundance of New Guinea babies, my knowledge that babies are conceived by sexual intercourse, and second-hand accounts persuade me that New Guineans practise sex, but I have no first-hand observations of it even after many years there. When I read how vigorously cannibalism's critics deny its existence in the absence of first-hand observations by anthropologists, I find myself imagining a conversation among asexually reproducing extraterrestrials who have conquered the Earth.

PRO: Abundant second-hand evidence convinces me that humans engage in a ritual, too horrible to describe, involving misuse of the urine-producing organs. Our leaders execute humans suspected of performing the ritual.

CON: Have you observed this awful practice yourself?

PRO: No, never. But I have incontrovertible evidence: immunologically detected seminal protein recovered from the vagina of a female human mummy.

CON: This is just one possible interpretation of one aberrant finding. There are other possible interpretations. Why must you denigrate humans by seeking evidence for bad behaviour, instead of studying good behaviour? ■

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Chemistry

The smallest fullerene

Martin F. Jarrold

A flat graphite sheet can be made from carbon atoms arranged in hexagons. Inserting pentagons into the sheet will cause it to pucker and curve; adding just twelve pentagons creates enough curvature, in principle, to make the sheet wrap up and link together to form a spherical shell (a fullerene) or even a closed tube. The deciding factor is how the pentagons and hexagons are arranged. The archetypical fullerene, C_{60}, is a sphere with all 12 pentagons evenly distributed over its surface, each one completely surrounded by a ring of hexagons. This highly symmetric geometry is possible only with precisely 60 atoms. Some other fullerenes have icosahedral (12-fold) symmetry, but it is quite rare[1]. C_{180}, with two rings of hexagons around its 12 pentagons, can adopt icosahedral symmetry. So, in principle, could C_{20}. A C_{20} fullerene has no hexagons, just twelve pentagons. This is the smallest fullerene that can exist, although it had never been seen until now. On page 60 of this issue, Prinzbach *et al.*[2] claim to have prepared not only the C_{20} fullerene, but also the equally elusive 'bowl' isomer of C_{20} (Fig.

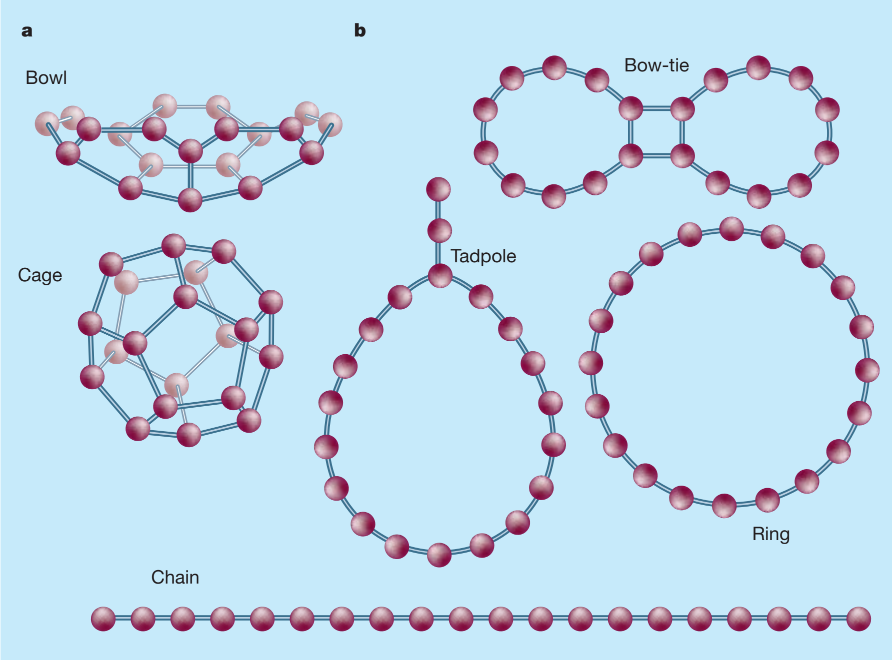

Figure 1 **Isomers of C_{20}.** a, **The fullerene cage and bowl isomers. Prinzbach *et al.*[2] have created these structures for the first time in minute quantities. Note that the fullerene is expected to be distorted from ideal icosahedral (twelve-fold) symmetry.** b, **The ring and chain isomers, all of which have been observed previously. Several different forms of the 'tadpole' (a chain attached to a ring) and the 'bow-tie' isomers exist.**

1a). The bowl, which has a central pentagon surrounded by five hexagons, has also never been seen before.

The pentagons are the reason why carbon makes such fascinating nanostructures. But they have a dark side: they also cause strain. The best way to handle strain is to distribute the pentagons evenly, and in particular to avoid having two together. The common fullerenes, such as C_{60}, C_{70}, C_{76}, C_{78} and C_{84}, all have isolated pentagons. For fullerenes with less than 60 carbon atoms, however, there are too few atoms to avoid neighbouring pentagons. With arguably one exception, these smaller fullerenes are not stable enough to be prepared in macroscopic amounts: they have been observed only in molecular-beam experiments. In the low-pressure environment of a molecular beam, molecules essentially float around in a vacuum, so it is possible to observe reactive and unstable species that do not survive elsewhere. Early dissociation and 'shrink-wrapping' experiments[3] provided indirect evidence that fullerenes could be made in molecular beams with as few as 30 carbon atoms. However, these and other experiments found no evidence for a C_{20} fullerene cage or bowl isomer[4,5]. It turns out that C_{20} prefers to adopt less compact chain and ring geometries (Fig. 1b), all of which have been observed.

Calculating the relative energies of the different C_{20} isomers is a great theoretical challenge. The most reliable calculations give the bowl the lowest energy, with the ring above the bowl, and the cage having much higher energy still[6]. But although the C_{20} cage is theoretically less stable than the ring and bowl, Prinzbach *et al.*[2] show that it can be prepared, and survive for at least a short time, if the right precursor is used. Their precursor has the basic carbon skeleton of the fullerene cage capped with hydrogen and bromine atoms. To generate the fullerene, the capping atoms must be removed very gently so that the carbon skeleton does not get hot enough to convert into the lower-energy ring or bowl geometries. A similar scheme was used to prepare the bowl isomer from another precursor. Given that the bowl has the lowest energy, why don't all the rings just convert into bowls? The reason is entropy. There is an entropic Catch 22 in action here. The ring must be heated to overcome the activation barrier and make the bowl. But when the ring is hot enough to convert, the bowl is no longer the favoured (lowest free energy) isomer because the floppier ring has more vibrational entropy.

Determining the structure of C_{20} molecules that are isolated in the gas phase is not easy. The usual structural probes available to chemists, such as NMR and X-ray diffraction, just do not work in this rarefied environment. Prinzbach *et al.* have used a technique called anion–photoelectron spectroscopy. Here, C_{20}^- anions are irradiated with a pulsed laser that detaches some of the extra electrons. The kinetic energy of the photo-detached electrons is then determined by precisely clocking their travel time over a predetermined distance. The difference between the photon energy and the energy of the fastest-moving electrons provides a measure of how strongly the extra electron is held by C_{20}^-. If the geometries of the initial anion and the resulting neutral C_{20} are slightly different, removing the electron leaves the neutral C_{20} vibrationally excited. The vibrational frequencies can then be deduced from oscillations in the photoelectron signal.

Prinzbach *et al.* show that the photoelectron spectra of C_{20}^- ions derived from the bowl and fullerene precursors are different from each other, and different from the spectrum for C_{20}^- rings generated by vaporizing graphite with a laser. There is one cautionary note, however. The vibrational frequencies determined for the precursors are not really enough to unambiguously characterize their geometries, because many different C_{20} isomers could have these frequencies. Although it is perhaps unlikely, the C_{20} ions derived from the fullerene precursor could have distorted or partly opened up in some unexpected way. This possibility can be ruled out only by the measurement of other vibrational frequencies.

Now that the bowl isomer has finally been prepared it should be possible to resolve an important issue about how fullerenes form. There are two conflicting explanations for how fullerenes are made from small carbon fragments: the 'fullerene road' and the 'pentagon road'[7]. The C_{20} bowl is the starting point of the 'pentagon road' process, by which C_{60} fullerenes are thought to grow from bowl to cup to fullerene by adding two carbon atoms at a time. The main challenge to this mechanism was the absence of the bowl isomer, which also precluded any real test of this idea. Such a test should now be possible. In the 'fullerene road' mechanism, small carbon fragments make rings, which then isomerize into fullerenes. This seemingly unlikely isomerization process has already been seen to occur for carbon clusters with more than 40 atoms. The final resolution of this and other issues will hinge on further experiments and on more extensive theoretical studies, both of which will surely be motivated by this latest development. ■

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Xenotransplantation

New risks, new gains

Jeffrey L. Platt

No field of medicine has stimulated more excitement and controversy than xenotransplantation — the transplanting of animal organs and tissues into humans. The excitement stems from the possibility that transplantation could finally be extended to all patients who need it. The controversies arise from the immunological hurdles to xenotransplantation, and from the possibility that infectious agents might be passed from the animal source to the human recipient and, potentially, more broadly in the human population. In this issue are two papers (first published in electronic form three weeks ago) that speak to this excitement and controversy. On page 86, Polejaeva *et al.*[1] describe how they have cloned pigs — a step towards surmounting the immunological hurdle. Meanwhile, on page 90, van der Laan *et al.*[2] report that pig pancreatic islet cells, transplanted into mice, can transmit porcine endogenous retroviruses to the mice.

Pigs are ideal sources of xenotransplants because they are available in large numbers and because their organs are similar in size and nature to those of humans. Polejaeva *et al.*[1] cloned pigs by a two-stage approach, which ultimately involved the transfer of nuclei from cultured adult cells to fertilized eggs from which the nuclei had been removed. This approach is similar to that used recently by Onishi *et al.*[3], also to clone pigs.

Compared with breeding, cloning is not an efficient way to propagate pigs, but it does have advantages. For example, genes might be added to, or 'knocked out' from, the genome — modifications that are easier to achieve in cultured cells than in whole animals. This technique might provide a way around the rejection of 'foreign' transplanted pig organs by the human immune system. At the moment this problem is sidestepped by damping down the recipient's immune system. But, for example, Polejaeva