tate answers, but rather suggests ideas. For example, the overall colour-charge neutrality of three-quark baryons and quark–antiquark mesons explains why they have special status as stable objects. So QCD sanctions the semi-empirical approach of the quark/bag model, much as quantum theory validates the chemists' models of valence and bonding.

But it is important, and perhaps more exciting, that beyond endorsing old working assumptions, QCD suggests new questions and possibilities. Notably, QCD predicts each of the alternative body plans described earlier. Such beasts ought to exist, and they probably do. Unfortunately, particles or resonances observed in the laboratory do not come tidily labelled 'glueball', 'centauron' or 'quarktet'. Although candidate glueballs and centaurons have been vigorously advocated, other more conventional interpretations have not yet been firmly excluded.

The new work[1] concerns a family of resonances known as 0^{++} mesons, with names such as $\sigma(660)$, $f_0(980)$ and $a_0(980)$. 0^{++} refers to the spin (0), parity (even or +) and charge conjugation parity (+). (I won't try to explain these technicalities here.) The numbers in parentheses are the approximate masses of the resonances in megaelectron volts. (In these units, the electron mass is 0.5 and the proton mass is 938.) Here, a_0 actually refers to a related trio of particles, a so-called isotriplet.

If we attempt to explain the f_0 and a_0 particles within the conventional meson body plan, then we must combine either an up or a down quark with either an up or a down antiquark, using special, rather complicated wavefunctions. But then one would expect to find another heavier meson of the same kind, made from the heavier strange quark and its antiquark, whereas the σ is found to be lighter. On the other hand, the quarktet picture provides a very pretty, though slightly intricate, explanation of the observed pattern, based on the fundamental forces between quarks[6,7].

Such arguments[8] are already quite suggestive, but Alford and Jaffe have raised the discussion to a new level, by formulating and performing a crucial (numerical) experiment. In pure QCD, the 0^{++} particles decay rather rapidly into pairs of 'pseudoscalar' mesons (π, K, η), which complicates their study and interpretation. So Alford and Jaffe study a slightly modified version of QCD, in which the masses of the quarks are taken to be larger than their real-world values, where this can't happen. They also 'improve' on reality by removing the possibility of quark–antiquark annihilation, thereby sharpening the distinction between mesons and quarktets. They find that pairs of pseudoscalar mesons feel attractive forces, which will cause them to form stable bound states whose qualitative properties (spin, parity and mass) match those of the observed 0^{++} particles. As each pseudoscalar is a quark–antiquark meson, the combination is a quarktet!

More accurate and extensive work is required to prove that the bound states really do form, and to verify that nothing untoward happens when we swap modified for real QCD. If everything checks out as expected, then in the search for exotic hadrons it seems that, after voyages into realms of extravagant energy and strangeness, we "arrive where we started, and know the place for the first time"[9]. ■

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Ancient DNA

Neanderthal population genetics

Matthias Höss

Authenticity is all in research on ancient DNA. Experience has taught us that even the most exciting claims of the retrieval of ancient DNA are not worth much if they cannot be independently reproduced. Hence the importance of a paper on page 490 of this issue, in which Ovchinnikov *et al.*[1] describe the extraction, amplification and sequencing of DNA from 29,000-year-old archaeological bone material of a Neanderthal recovered from the Mezmaiskaya Cave in the northern Caucasus (see map on page 490). This is the second time that such a claim has been made, the first being in 1997 (ref. 2). The paper by Ovchinnikov *et al.* is probably the more important of the two, for it provides invaluable corroboration for the authenticity of Neanderthal DNA sequences. Moreover, sequences of the DNA from a second Neanderthal offer more detailed insight into the contentious evolutionary relationship between Neanderthals and modern humans.

Research into ancient DNA enjoys high

Box 1 Studying ancient DNA

Research on ancient DNA developed in the mid-1980s from molecular evolutionary research, with the aim of extending phylogenetics (studies of evolutionary relationships) and population genetics to extinct species and populations.

Mitochondrial DNA (mtDNA) is used mainly for research into ancient DNA. Such DNA has advantages for evolutionary research in general. In addition, the large number of copies of mitochondrial genes (up to 1,000 times more copies of mitochondrial DNA are available per cell, compared with single-copy nuclear genes) makes mtDNA a better option when hunting for surviving ancient DNA molecules.

The polymerase chain reaction (PCR) is the most important tool in this field. The exponential DNA amplification provided by this technique is highly efficient and, in theory, a single DNA molecule can be amplified to provide enough material for sequencing. Without PCR, it would be impossible to study the sequences of ancient DNA molecules.

However, contamination of samples by modern DNA molecules is a severe problem, in part because of the efficiency of PCR. Because only tiny amounts of target (ancient) DNA molecules tend to be retrieved, even low levels of contamination with modern DNA will distort the result. Human remains are particularly difficult to work with, owing to the difficulty of identifying contaminating, generally human, sequences.

Water and oxygen, which cause hydrolysis and oxidation of DNA, respectively, are the main causes of DNA decay over time. Any burial conditions that limit or exclude water and/or oxygen will improve the survival of DNA in archaeological samples. Low temperatures during the burial period also seem to increase the chance of DNA survival, by slowing its breakdown by hydrolysis and oxidation. The age limit for successful retrieval of DNA depends to a large extent on the burial conditions. So far, the upper limit seems to be around 100,000 years.

Finally, the resurrection of extinct species is, and will stay, impossible. The reason? Only small, insufficient amounts of ancient DNA can ever be recovered, even under ideal conditions. **M.H.**

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publicity. It is perhaps the combination of modern molecular techniques and ‘old-fashioned’ archaeology that catches the interest of the scientific community and general public alike. This fascination sometimes clouds critical judgement. But this area of research, like all others, must meet with standards that ensure the authenticity and reproducibility of any given result. This has not always been so. Several of the most spectacular claims — such as the retrieval of DNA sequences from 15-million-year-old plant compression fossils[3], from 80-million-year-old bones of putative dinosaur origin[4] and from insects of up to 130 million years in age trapped in amber[5–7] — could not be reproduced in any other than the original laboratories, and so are of limited value[8–11].

The relationship between Neanderthals and humans remains enigmatic, so the retrieval of Neanderthal DNA has been one of the major goals of researchers in the field of ancient DNA. The age of later Neanderthal populations is well within the range compatible with reliable retrieval of ancient DNA (such retrieval is possible from samples up to 100,000 years old). However, it appeared from several studies (for example, ref. 12) that the work done with ancient human remains was close to the technological limit of what is possible. This is mainly because of the difficulty of distinguishing target sequences from contaminating modern, in this case human, DNA (Box 1).

So it came as no surprise that the publication of the first successful retrieval of DNA from a Neanderthal, from the Feldhofer Cave in Germany[2], was greeted with caution. Although the paper was widely regarded as being of technically high quality, the remote possibility remained that the published sequence was an artefact or the result of contamination. The need for DNA sequences from a second, unrelated Neanderthal specimen was clear, as echoed in most reviews of that paper. And this is where the importance of the work of Ovchinnikov *et al.*[1] lies.

Ovchinnikov and colleagues sequenced Neanderthal mitochondrial DNA and found that it is closely related, but not identical, to that described previously. Like the first paper[2], the study of Ovchinnikov *et al.* is convincing in itself. The authors used all the state-of-the-art controls to monitor artefacts and contamination, including having the sequences verified by another laboratory. However, only the combination of the papers allows us to appreciate fully their individual worth. The identification of two Neanderthal DNA sequences, from different specimens found in locations far apart, that are closely related but not identical, rules out the possibility that either sequence is an artefact or the product of contamination. By verifying each other, the two papers provide the most reliable proof so far of the authenticity of ancient DNA sequences.

Can we learn anything from this new Neanderthal DNA sequence about the relationship between modern humans and Neanderthals? The new sequence shares with the Feldhofer one the same surprising feature: it is no more closely related to DNA from modern European populations than to sequences from any other modern human population. This argues against the idea that modern Europeans are at least partly of Neanderthal origin. Although the two sequences were taken from specimens at geographically distant locations, the number of differences between the sequences indicates that these two individuals were from a single gene pool. Furthermore, the variation between the two Neanderthal sequences is similar to that among modern humans.

Details of the Mezmaiskaya sequence also support the suggestion[2] that there was no contribution of the Neanderthals to the pool of mitochondrial genes in modern human populations. However, this does not exclude the possibility of a contribution of nuclear Neanderthal genes. Approximate quantification of the number of mitochondrial DNA molecules found in the Feldhofer Neanderthal ruled out any hope of recovering nuclear DNA from this specimen[2], but the apparently excellently preserved Mezmaiskaya specimen might yield values compatible with retrieval of nuclear DNA.

Having achieved DNA sequencing from members of geographically distant Neanderthal populations, it would be interesting to do the same for populations that are far apart on the timescale. A specimen dated closer to the upper time limit of Neanderthal distribution (about 230,000 years ago) would be a tempting choice for DNA retrieval.

The quality of the molecular data retrieved so far from Neanderthal specimens is compelling. If this is how research on ancient DNA is going to proceed, then we are truly on our way to Neanderthal population genetics. ■

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Daedalus

Direct illumination

The best monochromatic microwave sources are those efficient cavity-resonator valves, the klystron and the magnetron. The wavelength they emit is determined by the size of their cavity. These days, silicon microengineering can create and shape objects and cavities with dimensions around a wavelength of light. So Daedalus is now planning micro-klystrons and micro-magnetrons to generate bright monochromatic light.

It should be simple enough to form a proper cavity in silicon, and coat it with low-resistance metal to make it a good resonator. The main problem is making an electron beam fine enough to enter the cavity. A conventional cathode would be far too coarse. Fortunately, point sources for electron beams already exist, for field-ion and electron microscopes. With luck they could be formed by the same photofabrication used to make the cavity.

A single photoklystron would be a wonderful point source of light, but very feeble as a lamp. A DREADCO team is designing an array of many hundreds of photoklystrons sculpted on a single silicon wafer. Integrated circuitry on the same wafer will apply control and power voltages to the klystrons of the array. The whole thing will be sealed in an evacuated glass envelope from which the generated light can escape.

Integrated-circuit mass production is so cheap that the photoklystron lamp could well be competitive with its fluorescent and filament rivals. If the klystrons on the wafer were all different, so that each radiated its own frequency, the resulting lamp could be almost perfectly white, ideal for domestic illumination. Even better, it would be a cold white, with no infrared. And as a resonant device, the lamp should be highly efficient, far brighter per watt than its rivals.

If all the photoklystrons in the lamp were identical, it would be perfectly monochromatic, an ideal spectroscopic source. Like a conventional klystron, it could be tuned over a useful range by varying the voltage applied to its electrodes. A series of such klystron lamps could span the visible and infrared bands seamlessly, right out to the millimetre region. Physicists would at last be released from the inflexible, untunable grip of the laser.

David Jones

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