switching on nuclear events.

What these messengers are is still a mystery, but $Ins(1,4,5)P_3$ and diacylglycerol must be likely candidates because of their involvement in neuromodulation. A role for calcium has already been implicated in PC12 cells where there is a rapid increase in *c-fos* transcription following the addition of agents that open voltage-dependent calcium channels[11]. Long-term potentiation of synaptic transmission between neurones in the hippocampus has been used as an experimental model for memory. Because both calcium and protein kinase C have been implicated in the acquisition of long-term potentiation there already is some experimental evidence for the involvement of such messenger systems in memory[12]. The photoreceptors of *Hermissenda* provide another experimental model for memory where the closure of potassium channels by protein kinase C is an essential component of the plastic change that occurs during associative learning[13]. The virtuosity of this dual signalling system is truly remarkable: not only does it control the second-to-second activity of most cells, but it can apparently extend its performance to controlling the long-term plastic changes that underly cell growth and the acquisition of memory. □

Michael Berridge is in the AFRC Unit of Insect Neurophysiology and Pharmacology, Department of Zoology, University of Cambridge, Cambridge CB2 3EJ, UK.

Particle physics

Glueball sightings premature

from Frank Close

HAS a glueball at last been positively identified? Aihara *et al.* (*Phys. Rev. Lett.* **57**, 51; 1986) seem to think so; their measurement of the lack of electromagnetic coupling of the iota particle leads them to conclude that the iota is the long-sought bundle of gluons. Certainly the iota has been most people's favourite candidate for some years but a definitive test has been awaited. The present claim comes from data which are some 40 per cent better than an earlier experiment by the 'TASSO' collaboration in Hamburg (Althoff *et al. Z. Phys.* **C29**, 189; 1985), but this group did not risk such a positive claim, and the evidence is perhaps not as clear-cut as the new data of Aihara *et al.* seem to imply.

Atomic nuclei are made of protons and neutrons which are in turn clusters of quarks. Quarks possess an unusual type of charge called colour which operates in some ways like electrical charge. The relativistic quantum field theory of the colour-induced forces is called quantum chromodynamics (QCD) by analogy with the mathematically similar theory of quantum electrodynamics (QED). The photons of QED transmit electromagnetic forces; similarly gluons transmit the chromodynamic forces in QCD.

These similarities induce theorists to seek to build a unified theory of these forces. But first, is QCD correct? If it is, then in addition to ordinary matter there should exist glueballs — matter made of glue not of quarks. There are no balls of light in QED because photons are electrically neutral and do not mutually attract. However, the gluons of QCD carry colour charges and so mutually should attract by the same forces that cluster the quarks into conventional nuclear particles.

Following the discovery of the psi (ψ) particle, theorists in the late 1970s realized that QCD implied that radiative decays of the ψ should be a good source of glue matter. Prominent in the decay particles was a hitherto unknown state — the iota (ι), a prima facie candidate for resonating glue. It has a mass of 1.4 GeV (about 50 per cent more than a proton) in line with theorists' expectations for glueball masses.

Encouraging as this is, there are some features of its decays which do not fit well with the expectations for a glueball. There is also an unfortunate coincidence that an excited state of the eta (η) particle, a quark state, is expected to occur in this vicinity with the same quantum numbers of spin and parity (behaviour of the wavefunction under mirror reflection) as the ι. So the question is: is the ι a gluonic state or an excited η or a hybrid of quarks and glue?

To help answer this, difficult studies of the electromagnetic interactions of the ι have been made. Glue is electrically neutral and so glueballs should have rather feeble couplings to photons. In particular the ι should have a much-suppressed decay into two photons, a mode that is allowed by quantum mechanics.

In 1985 the TASSO collaboration referred to above showed that this mode is somewhat smaller than expected for a quark state at this mass. The experiment of Aihara *et al.* improved this by nearly a factor of two, which although suggestive is hardly conclusive given the various sources of error. There are two problems (Aihara and colleagues comment only on one) which call for more work before their claim is established.

During the past three years there have been reports that ι has a prominent decay into photon and rho ($\gamma-\varrho$). This is an electromagnetic coupling, and is so large that theorists began to suspect that there is significant quark content in ι: it is either an excited quark state or a hybrid. Independent of the interpretation there is a conundrum: the ϱ has the same quantum numbers as the photon and so can turn into a photon, this feeding the decay chain ι into two photons. The prominent rate into $\gamma-\varrho$ and this piece of quantum mechanics implies that the decay of two photons should be at least five times larger than the experimental upper limit! This discrepancy must be explained before conclusions are drawn.

One possibility is that there are two states in the 1.4 GeV region of mass: the ι and another. Supporting this is the fact that the mass and width of the signal in the $\gamma-\varrho$ channel seems not to be consistent with the properties of ι determined from other experiments. The true ι might have small couplings both to $\gamma-\varrho$ and two photons; a canonical glueball. The $\gamma-\varrho$ signal might herald the excited quark state expected in this mass region; if so then there should be interesting interference phenomena that will need analysis.

However, there is a a less exciting possibility that has already been discussed in a recent Toronto University preprint by T. Barnes. If the ι is an excited quark state (η^*) then in addition to its copious $\gamma-\varrho$ decay it will also have a powerful coupling to $\gamma-\varrho^*$ (an excited ϱ analogous to the excited η^*). This latter decay channel is closed by energy conservation but it can contribute destructively to the amplitude for ι decaying into two photons. The apparent anomaly between the small $\gamma-\gamma$ and large $\gamma-\varrho$ is then due to neglect of the (even larger) destructive $\gamma-\varrho^*$ coupling. If this is the explanation in decays of the ϱ^*: $\varrho^* \rightarrow \iota + \gamma$; or in electron–positron annihilation: $e^+e^- \rightarrow \gamma \rightarrow \varrho^* + \iota$.

Until the opening of the large electron–positron collider (LEP) in Geneva or the Stanford Linear Collider (SLC) and the hoped-for discovery of bound states of top quarks (whose decays should be a copious source of glueballs), it is most promising to continue studying ψ decays, or low-energy annihilation of protons and antiprotons (as at LEAR in Geneva) for sightings of glue. If there are several spinless particles with negative parity (pseudoscalars) in the 1 to 2 GeV mass range (as data suggest), then quarks will be unable to accommodate them all. Gluonic degrees of freedom will need to be invoked. Careful examination of pseudoscalars, and clarification of the electromagnetic coupling of ι, are therefore probably the best current strategies. □

Frank Close is at the Rutherford Appleton Laboratory and is visiting Professor of Physics at Queen Mary College, Mile End Road, London E1, UK.