

Physics monitor

STANFORD SPEARhead

The electron-positron storage ring SPEAR continues to be the centre of intense scientific activity for both high energy physics and synchrotron radiation experiments. During the first half of this year there was the longest running period in SLAC's history (14 January to 13 July) when the storage ring operated almost continuously. The only interruption was seven days during which SPEAR could not run because of incompatibilities with the high-priority parity violation experiment performed in end station A. The asymmetries being studied in that experiment were so small that they could be overshadowed by small electrical transients caused, for example, by switching from positron to electron injection for SPEAR!

During that period SPEAR ran for 344 colliding-beam eight hour experimental shifts for the Mark II detector and for the DELCO experiment. Synchrotron radiation experiments were also under way on a parasitic basis. In addition, SPEAR operated as a single-beam dedicated synchrotron radiation source for one week (21 shifts) and during that week the stored beam energy was 3.0 to 3.7 GeV with currents as high as 100 mA in four bunches. Most of the colliding beam operation used stored beam energies of 1.8 to 2.2 GeV with 10 to 25 mA stored in one bunch.

A 14 week shutdown ending in mid-October saw the DELCO experiment removed from the east interaction region and the Crystal Ball experiment installed in its place. The Mark II continues in residence in the west interaction region until the summer of 1979 when it is scheduled to move to PEP. It has recently been decided that DELCO will also be installed on PEP as one of the first round experiments.

During this same shutdown period the Stanford Synchrotron Radiation Laboratory (SSRL) began installation of its major new experimental hall and several beam channels on the South arc of SPEAR as reported last month. A six-pole, 18 kG wiggler magnet was also installed in a SPEAR straight section. This is the beginning of the three year expansion programme for SSRL to provide 12 to 14 additional experimental stations beyond the ten now in operation. The first of these new stations will begin operation early in 1979 and the rest will be completed by the end of 1980.

There is an agreement between SSRL and SLAC that when PEP is well under way with its experimental programme, SPEAR will be available as a dedicated synchrotron radiation source for half of its operation time. With first stored beam trials of PEP now scheduled for October 1979 the transition to the new mode of operation for SPEAR should begin by early 1980.

Colour chemistry

Although our present picture of strong interactions is still in a formative stage, there are already signs that the range of hadronic states discovered so far might just be the tip of an iceberg. Once the experimental techniques have been developed, the mechanisms of strong interactions could rival those of chemistry in their ability to create new and interesting compounds.

It hinges on the idea of 'colour', alleged to play a role in strong interactions analogous to that of electric charge in electromagnetism. Additional particles called gluons carry colour between the quarks in much the same way that photons mediate electromagnetic interactions.

Although not many manifestations of colour have been seen, it enables us to account for the wave function of the decuplet of baryons being symmetric in flavour (electric charge and strangeness) and spin, while the Pauli exclusion principle would like the wave function to be antisymmetric. This dilemma can be solved by the addition of colour to bring in the required degree of asymmetry.

In the colour picture, quarks are attributed with another quantum number in addition to charge, flavour and spin. However little trace of this colour attribute is seen — it is as if the extra colour degree of freedom has been frozen out. The colour affinity between quarks seems to be so strong that they want to bind together to form 'colourless' (zero net colour) states.

Normally, when an extra degree of freedom exists in physics, it eventually shows up in spectroscopy, in the way that spin degrees of freedom add fine and hyperfine structure to the normal atomic spectrum. With hadronic spectroscopy, the question is where to look to see any additional effects due to colour.

For baryons made up of three quarks

Colour chemistry in action. A colour 'molecule' could consist of a pair of quarks and a pair of antiquarks held together by a 'tube' of colour force. Should this tube snap, a quark and an antiquark are formed either side of the break, in the much same way that sawing a bar magnet in half produces an additional pair of magnetic poles. The decay of the colour molecule produces a baryon and an antibaryon, and provides one explanation of 'baryonium' — states which although existing in mesonic channels, prefer to decay into baryon-antibaryon pairs.

and mesons composed of a quark-antiquark pair, the colour degree of freedom is completely frozen and in each case there is only one way of making a state with zero net colour.

However when hadron states become 'hot', so much energy can be brought in that at least one extra quark-antiquark pair is created inside the hadron and the colour configuration could change.

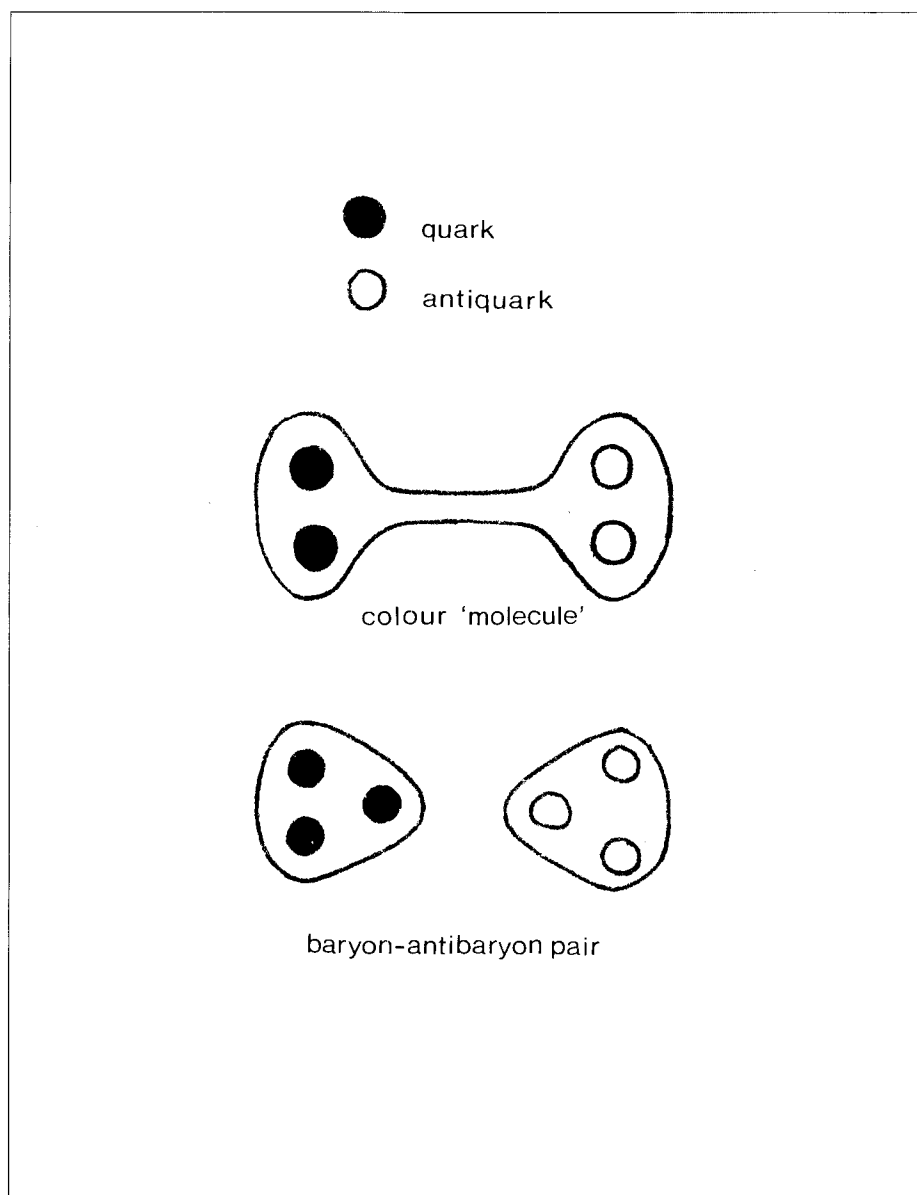
Then it would be possible to have colour isomers — states with the same quark content but with different physical properties as a result of the different distributions of colour. Such colour isomers could already have been seen in experiments, although this is not yet certain.

One of the proponents of the quark isomer idea, Chan Hong-Mo, prefers to talk in language borrowed from chemistry. Blobs of quark matter — 'chromions' — can bind together with tubes of colour field lines to form composite colour 'molecules' in much the same way that ordinary ionic molecules are formed.

If the constituent chromions are kept apart, for example by a high angular momentum barrier, they will keep their individual identities, so that the properties of the colour molecule could be deduced from the properties of its component chromions.

Normally when such a colour molecule breaks up, it will be as a result of the tube of colour field lines being broken, rather than the chromions themselves decaying. When the tube snaps, quarks and antiquarks appear on the two sides of the break, in much the same way as cutting a bar magnet in half produces an additional pair of magnetic poles.

Systems made up of two quarks (as opposed to a quark plus antiquark) do not have zero net colour and have unusual properties such as fractional electric charge. As a result they are not seen as free hadrons. However a diquark could be a simple form of chromion,



and a simple colour molecule would be 'diquonium' — a diquark and an antiquark, connected by a colour tube, rotating around each other.

Depending on the colour configuration of the diquarks, one or two quarks are formed on each side of the break if the connecting colour tube snaps and causes diquonium decay. If just one new quark is created on each side, the decay produces a baryon-antibaryon pair (see diagram).

These diquoniums could be identified with the 'baryonium' states now seen in a range of different experiments. A number of these states have been reported, all having the property of appearing reluctant to decay into mesons. Even though they appear in meson-like (integer spin) channels, they prefer instead to couple to baryon-antibaryon pairs.

Such states had been expected on a number of theoretical grounds. The

meson exchange forces which make it difficult to form any bound state of two baryons other than the deuteron are expected to produce, on the other hand, a relative wealth of states which couple to the baryon-antibaryon system. Baryoniums also smooth out difficulties with the simple quark model in baryon-antibaryon reactions, where basic ideas of 'duality' seemed to break down (see June 1977 issue, page 197).

Experiments seem to show that there are two kinds of baryonium. Some states are broad, having typical hadronic decay widths of a hundred MeV or more, and are seen at 2190 and 2350 MeV in painstaking analysis of nucleon-antinucleon scattering data.

Other baryoniums have a much narrower width, usually of the order of tens of MeV, and are seen in selected channels of production experiments, such as the proton-antiproton pair in $\pi^- p \rightarrow p\bar{p}\pi^0$.

In the diquonium picture, these two kinds of baryonium are explained as being colour isomers with the same quark content but different interior colour configurations. Depending on this configuration either one or two quark pairs are formed when the colour tube connecting the diquarks snaps.

It is more difficult to produce two quark pairs than one, so the diquoniums producing two quark pairs will have a narrower decay width than those which produce just one pair. They will tend to emit mesons and change into other diquoniums.

However the diquark is only one simple example of a chromion, and whole ranges of new hadronic states could be formed from other chromions. Some narrow resonant states which have been reported could be explained as colour molecules built from two chromions, one containing three quarks and the other a quark-antiquark pair.

According to the ideas of colour

chemistry, these hadronic states are the forerunners of an infinite number of possible colour molecules. If so, this will provide fuel for many more years of experimental effort.

The solar neutrino problem

The puzzle of solar neutrinos has now been with us for some 20 years, but new technical developments afoot in the US and the USSR giving greatly improved capabilities for neutrino detection might soon resolve the problem.

It was W. Fowler and A. Cameron who first pointed out that the range of thermonuclear reactions in the sun's interior should produce an appreciable flux of neutrinos. These intense reactions provide the temperature which resists the immense gravitational forces trying to crush the sun, and the level of these reactions, as measured by neutrino fluxes, is a good thermometer for the sun's interior.

These neutrinos fly out through the sun and into space, some of them arriving on the earth. However observations so far show that the detected level of solar neutrinos is only a fraction of what is expected from theoretical estimates. If this is correct, it means that we do not understand well enough what is going on in the sun.

Solar neutrinos can be detected through a variety of neutrino-induced nuclear reactions, such as the conversion of chlorine-37 to argon-37. One of the pioneers of solar neutrino work, Ray Davis of Brookhaven, has built a neutrino detector consisting of a 100 000 gallon tank of dry-cleaning fluid (perchloroethylene) buried 5000 feet below the ground in a disused gold mine in South Dakota.

Results from this huge installation give results that are consistently less

than the predictions of various theoretical models, and moreover the results seem to be independent of the sun's position, showing that the recorded level might be due to some other source instead.

Theorists have tried to find ways out of the problem by tinkering with the parameters of the sun's interior, but these attempts appear to produce more difficulties than they remove.

One reason for the present impasse could be that the currently-used methods for neutrino detection have threshold energies which do not match well the spectra of the solar neutrinos. As a result, only the high energy tail of the neutrino spectrum is intercepted and the lower energy component of the flux remains undetected. To catch these more elusive but much more abundant neutrinos, other detection methods must be sought.

An example of such a method uses gallium-71, which is converted by neutrinos into germanium-71, but until recently it appeared difficult to extract the tiny amounts of produced germanium from the mass of gallium in the detector. However recent developments in the US now show how this can be done. All that remains is to find the money to purchase the gallium — some 15 million dollars would be required for a typical detector containing 50 tons of gallium.

In the USSR, a huge neutrino observatory in the Caucasus is now nearing completion. Among other things, this uses gallium detectors and should be able to identify solar neutrinos with much lower energies.

Asthenodynamics

In our July / August issue (page 246), we intimated that someone might come up with a name to describe the new unification of our description of the weak and electromagnetic interactions.