the first type of quasar, it is of doubtful theoretical value to have a second type for which these problems can be sidestepped. Also, the overall similarity of spectral properties of quasars suggests a single kind of object. It is therefore tempting to apply Occam's razor and propose that there are only cosmological-redshift quasars, and that ballistic quasars do not exist. How could Arp and Hazard's alignments then be explained?

The answer could be that such associations are not as unlikely by chance as it might seem at first sight — perhaps the right statistics have not yet been done — it is anyway very difficult to apply *a posteriori* statistics once a peculiar pattern has been found. At least this point can, and should, be investigated more carefully by proponents of both quasar models.

It is perhaps surprising that the distances of quasars remain uncertain almost twenty years since their high redshifts were recognized, but a glance at the history of the debate over the nature of spiral nebulae should be enough to convince anyone that important questions sometimes take a long time to settle. Whatever their explanation, Arp and Hazard's fascinating triplets surely deserve a constellation name — Cosmology's Damocles or Hoyle's Banderillas perhaps? □

Antimatter back to front

from C.H. Llewellyn Smith

BEFORE 1956 it was taken for granted that parity is conserved — in other words, that the laws of nature do not distinguish between left and right. The shock produced by the discovery of parity violation was alleviated by Landau's observation that symmetry under the combined operation of 'charge conjugation' (C), which turns particles into antiparticles, and parity (P) could remain exact, that is, that there could be symmetry between left-handed matter and right-handed antimatter. If this CP invariance holds, then according to Landau "space remains completely symmetrical" and an asymmetry which "in view of the isotropy of space (conservation of momentum) would be more than strange" could be avoided. This view was generally accepted and CP invariance came to seem almost self evident. The discovery of CP violation by Christenson, Cronin, Fitch and Turley in 1964, for which they received the Nobel prize in 1980, was therefore almost as great a shock as the discovery of parity violation.

The existence of P and CP violation makes it possible to tell from watching a film of submicroscopic processes whether they involve matter or antimatter and whether the film is being projected correctly or has been loaded back to front. In contrast, if CP were conserved it would be impossible to distinguish a correctly shown film of matter from a back-to-front film of antimatter. If both C and P were conserved we could distinguish neither a film of matter from one of antimatter nor whether it had been loaded back to front.

Up to now CP violation has only been observed in the decays of neutral K mesons. The particles have fascinating properties which directly demonstrate fundamental aspects of quantum mechanics. In energetic collisions of strongly interacting particles, such as protons, either a K°, which contains an antistrange quark, or its antiparticle $\bar{K}^\circ$, which contains a strange quark, can be produced. However, strange quarks are unstable and decay into non-strange quarks. This allows K° and $\bar{K}^\circ$ to decay into identical products (either two or three pi mesons). It also allows a K° to turn into a $\bar{K}^\circ$ and vice versa. Consequently it is possible to make coherent quantum mechanical superimpositions or mixtures of K° and $\bar{K}^\circ$. Two particular mixtures behave as particles with definite masses and lifetimes. One, called K_S, is relatively short lived and decays predominantly into two pi mesons. The other, K_L, is longer lived and decays mainly into three pi mesons. A K° or $\bar{K}^\circ$ produced in a proton collision can be regarded as a mixture of K_S and K_L; the K_S component decays relatively quickly leaving pure K_L.

If CP symmetry were exact, the decay of K_L to two pi mesons would be completely forbidden, because K_S and the two-pion state into which Ks can decay would be symmetric under CP symmetry whereas K_L would be antisymmetric. The Cronin and Fitch experiment was designed to look for the CP violating decay $K_L \rightarrow \pi^+\pi^-$ and convincingly showed that it accounts for about two K_L decays in every thousand. A more direct manifestation of CP violation was provided by the later observation that the rates for the decays $K_L \rightarrow \pi^+ e^- \upsilon_e$ and $K_L \rightarrow \pi^- e^+ \bar{\upsilon}_e$ differ by about half a per cent; exact CP symmetry would turn K_L into itself, π^+ into π^-, e^- into e^+ and υ_e into $\bar{\upsilon}_e$ and require the rates to be equal.

Immediately after Christenson *et al.* announced their result in 1964, various ingenious ways to reconcile it with CP symmetry were proposed. Perhaps the most interesting was the idea of a long-range force which couples to K° and $\bar{K}^\circ$ and to other forms of matter and antimatter with opposite signs. Such a force would generate apparent CP violation due to the predominance of matter over antimatter in the Universe. However, it would also give rise to an apparent violation of lorentzian invariance causing the fraction of decays of K_L to $\pi^+\pi^-$ to depend on velocity. This was quickly ruled out.

It soon became apparent that not only CP but also time reversal invariance (T) is violated or, in other words, that the laws of nature depend on the arrow of time. This makes it possible to tell whether a film of certain submicroscopic processes is being run forwards or backwards. The possibility of T violation was immediately obvious because it was known that any theory which respects lorentzian invariance and the general principles of quantum mechanics is necessarily symmetric under the combined operation CPT. This CPT symmetry makes it impossible to distinguish a correctly projected film of matter run forwards from a back-to-front film of antimatter run backwards. If CPT is unbroken, then CP violation necessarily requires T violation. However T violation can be demonstrated directly without invoking CPT symmetry. Further study of the neutral K system showed that the quantum mechanical probability amplitude for K° to turn into $\bar{K}^\circ$ differs from the amplitude for $\bar{K}^\circ$ to turn into K° by about one per cent — a direct manifestation of T noninvariance. However, the amplitudes for K° and $\bar{K}^\circ$ to remain themselves, which must be the same if CPT symmetry holds, are equal to better than one part in 10^{17}.

It is hardly surprising that the origin of CP violation was mysterious in the 1960s since the nature of the weak interactions was not understood then. The advent of unified electroweak theories did not help at first since the simplest model which fitted the known facts did not allow CP violation. However, in 1973 Kobayashi and Maskawa pointed out that if there were more than four quarks CP violation would be almost unavoidable. Since the discovery of the fifth quark in 1977, CP violation has therefore seemed very natural. In fact, available unified models give rise to CP violation of the observed order of magnitude, although the precise strength of the effect can not be predicted at present. According to these models the only other likely observations of CP violation in the near future will be in the decays of mesons which contain the fifth quark and possibly also in neutrino oscillations, if they really occur, which are similar to K°- $\bar{K}^\circ$ oscillations.

This relatively happy situation has been jolted by the discovery that quantum chromodynamics (QCD), an extremely elegant and plausible candidate theory of the strong force, can give rise to CP violating effects, which are potentially much too large. Ironically one of the arguments for taking QCD seriously in the first place was that it could never generate strong CP violation. However, although this argument is true to all orders if the theory is treated perturbatively, it turns out that non-perturbative effects (called

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'instantons') generate T and P violating effects which involve a new parameter called θ. Although θ could have any value, it would seem natural for it to be of order one. However, the experimental upper limit on the T and P violating electric dipole moment of the neutron requires $\theta < 10^{-8}$. No good reason why θ should be so small is known.

Thus there are still some mysteries surrounding CP violation. Indeed, it is still not clear whether C, P and T are intrinsically broken. It is possible to construct electroweak theories in which the underlying equations are completely symmetrical but the solutions are asymmetrical. Recently interest in the nature of CP violation has been greatly increased by the discovery that it may be a key element in explaining the large excess of matter over antimatter in the Universe. Attempts to unify the strong with the electroweak interactions suggest that baryon number is not conserved. Indeed, they predict that the proton decays with a lifetime of about 10^{30} years, and experiments designed to search for proton decay are now under construction. In this case, as originally discussed by Sakharov, a universe containing mostly matter can develop from a state of equilibrium between matter and antimatter because of the asymmetry due to CP violation. Furthermore, this picture is capable of explaining the observed ratio of about 10^8 between the number of photons and baryons in the Universe. If baryon number is conserved, it is necessary to invoke an initial asymmetry of one part in 10^8 to explain this ratio. If these cosmological speculations hold up they will put severe constraints on the fundamental mechanism responsible for CP violation.

The discovery of CP violation completed the conceptual revolution begun by the discovery of parity violation. This revolution has led to a healthy scepticism about other old shibboleths such as baryon conservation. Current theory can naturally accommodate CP violation. It is true that its magnitude cannot be predicted at present but this problem is on the same footing as other unanswered questions, such as how to predict the masses of quarks, if we leave aside the θ problem. The asymmetry between matter and antimatter which previously seemed "more than strange" now seems natural and perhaps even inevitable. But without it the Universe might be quite different. □

Genetic engineering and foot and mouth disease vaccines

from J. B. Brooksby

WHEN genetic engineering was first discussed in relation to foot and mouth disease vaccines, conventional virologists were sceptical of a practical outcome in less than perhaps ten or fifteen years. Enough was known of the viral genome to suggest that appropriate information might be incorporated into plasmids but a pessimistic view was taken of the possibility of expression of this information to provide the antigenic moiety of the virus in active form. The paper by Kupper and his co-authors on p.555 of this issue shows that the obstacle of expression has been surmounted and a milestone has been passed on the road to production of antigens for vaccine.

Although this is not the first report of the production of a viral antigen in this way, it is a happy circumstance that a foot and mouth disease product is early in the field, not perhaps because the agent was the first animal pathogen discovered to be a virus, but because of the importance of foot and mouth disease vaccine in controlling what is still one of the most serious diseases of animals throughout the world. More foot and mouth disease vaccine is produced than any other vaccine, but more is yet needed to begin campaigns in countries where the disease continues to spread. Compulsory regular vaccination in Western European countries over the past 25 years covering more than 60 million cattle has reduced the incidence of the disease to vanishing point — indeed, most recent outbreaks have been linked, at least circumstantially, to vaccine containing residual live virus. In South America, which has a long-standing problem, at least 500 million doses of polyvalent vaccine are produced annually. These figures indicate the importance of the disease to the animal industry, through its debilitating effects, lowering of milk production and interference, because of its remarkable spreading power, with trade in animals, meat and other products.

Present vaccines are produced from virus cultivated either in surviving tongue epithelial tissue collected from animals slaughtered for meat, or in cell lines grown in suspension in large (2,000 litres or more) vessels. Problems arise in the production of sufficient viral antigen, especially with some strains of virus, and the multiplicity of types (there are seven) and sub-types (over 60) necessitates either expensive polyvalent vaccines or vaccines appropriate to particular areas which may have to be changed rapidly to meet new strains arising in the field. Thus, although much has been achieved with available vaccines, as the experience of European countries shows, there is still a real need for alternative methods for producing viral antigen.

The application of genetic engineering may offer such a method and the work reported, together with other studies proceeding in the UK (at the Animal Virus Research Institute and Wellcome Foundation Ltd) and in the US (at the Plum Island Animal Disease Center and Genentech — see *Nature* **288**, 663; 1979), indeed give promise for the future.

The advantages of a vaccine based on an antigen consisting of the appropriate viral protein, prepared in a way that does not involve infective material at any subsequent stage after isolation of the viral RNA and which allows the production of greater quantities than from natural sources, are obvious. Kupper *et al.* have concentrated on the preparation of VP1, the coat protein responsible for the production of the antibody response to foot and mouth disease virus. Laporte and Bachrach and their colleagues in France and the US showed that purified VP1 from disrupted virus stimulates an antibody response, albeit weak, in guinea pigs and swine, and large doses will protect swine against subsequent infection.

In the present experiments, VP1 produced in the bacterial cell has been identified by its reaction with specific VP1 antibody and from the serological reaction it is estimated that at least 1,000 VP1 molecules are synthesized per cell. This is a signal achievement which is not diminished by the question — what remains to be done? Clearly, the new VP1 must be shown to immunize animals. The quantitative aspect is important, for the earlier work suggested that at least 1,000 times more antigen was required when the VP1 had been isolated than when it was carried on the intact, but inactivated virus particle. Yields from bacterial culture can probably be raised above those from mammalian cell culture and the factor by which this is possible will be critical for the success of the method. The quality of the antigen is also fundamental. It may be that, in order to preserve VP1 from degradation, it will be advantageous to synthesize the precursor which cleaves to form all four capsid proteins.

A new and exciting prospect is the possibility of overcoming some of the difficulties created by virus variation in the field. It may well be practicable to tailor strains to stimulate immunity to a wider antigenic spectrum than that given by naturally occurring viruses. There is no doubt that the progress reported will lead to a redoubled effort by the various groups and the prospects for new foot and mouth disease vaccines are indeed bright.

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