between the two and the decay mode vanishes. However, if there is a mass difference then the amplitude is finally proportional to $m_H - m_L$ scaled by m_W, the mass of the W boson.

The W boson is believed to have a mass of around 60 GeV. The mass difference of the two neutrinos is at most some 650 keV (it could even be zero) and so the predicted rate can at most be

$$(\mu \rightarrow e\gamma)/(\mu \rightarrow \text{all}) \lesssim 10^{-25}$$

which is far below the present limits.

New heavy leptons

In the light of the above, what price must we pay if the decay were found at a level of 1 in 10^9 or so? This could have been accommodated in the above arguments if the heavy neutrino has a mass of several GeV, far in excess of the known limit. Could there be further heavy leptons in nature which could help in this respect? There is now good evidence for a heavy charged lepton τ around 2 GeV in mass, probably accompanied by a neutral ν_τ. The latter has a mass less than 700 MeV (Perl *Phys. Lett.* **63B,** 466) and so cannot be of use in the present context. However, this discovery does release one's inhibitions and shows that a whole new spectroscopy of heavy leptons is not necessarily absurd.

If such further heavy leptons indeed exist then the $\mu \rightarrow e\gamma$ decay can arise and several mechanisms have been suggested. One way is to have right handed doublets involving new neutrals and the electron or muon. With the massive neutrals introduced this way the previous game can be played and a sizeable $\mu \rightarrow e\gamma$ decay accommodated. This idea has been proposed by T. Cheng and L. Li in the USA. An interesting by-product could arise in connection with the failure to see parity violation in atoms. Parity violation occurs if the electron (muon) only takes part in left handed weak interactions. If the electron (muon) now also couple to heavy neutral leptons in the right handed mode, parity can be conserved. (Of course, parity will still be violated in neutron β decay as the neutron–proton mass difference is so small that only the electron and its massless left-handed neutrino can be produced). In a similar vein, F. Wilczek and A. Zee of Princeton University have proposed doubly charged heavy leptons to generate the μ decay.

Before we conclude that the observation of $\mu \rightarrow e\gamma$ would force us to deduce that heavy leptons exist we should notice a proposal of J. Bjorken and S. Weinberg of Stanford, California. In the gauge theories, particles gain masses by coupling to scalar fields known as Higgs particles. The coupling of the Higgs particles to fermions can generate contributions to weak interaction decay rates. However this is usually ignored since the coupling is proportional in strength to the masses of the fermions concerned, and the electron and muon are very light. In rare and ultrarare decay processes these couplings could turn out to have important phenomenological consequences. Furthermore, Bjorken and Weinberg noted that in the standard Weinberg–Salam gauge theory one can have a naturally occurring coupling of a Higgs particle, a muon and an electron all at one point and hence generating the transition $\mu \rightarrow e\gamma$ without extending the number of leptons in nature beyond the famous four.

Before the advent of gauge theories an observation of $\mu \rightarrow e\gamma$ would have left us puzzling as to how to proceed. With the great advances of the past few years not only do we know how to tackle the problem but even have several solutions in advance of any signal! Perhaps none of the models is very suasivious. However, if a signal is seen in the current experiments then one must take these ideas seriously and more impressive support for the gauge theories will have been unearthed. That this will happen in the next month or two is many theorists' midsummer night's dream—but it could turn out to be much ado about nothing.

Spin waves in superfluid ^{3}He

from P. V. E. McClintock

One of the most intriguing features of the recently discovered superfluid phases of liquid ^{3}He is that in sharp contrast to ^{4}He, the only other superfluid known in nature, they have magnetic properties. It is hardly surprising, therefore, that efforts to understand superfluid ^{3}He have been influenced by making comparisons with more conventional types of magnetic material, attempting to explore both the similarities and the fundamental differences in their properties. One characteristic feature of ordered magnetic solids is that they may support so-called spin waves, a form of collective excitation among the magnetic elements. The possible existence of spin waves in ^{3}He has consequently been a subject of much discussion during the four years which have elapsed since the superfluid phases were discovered by D. D. Osheroff, then working at Cornell University. It is of particular interest, therefore, that Osheroff and his coworkers at Bell Laboratories have now reported (*Phys. Rev. Lett.* **38,** 134; 1977) the first experimental observation of spin waves in the B phase of superfluid ^{3}He.

The magnetism of liquid ^{3}He arises from the magnetic moments carried by the nuclei of the ^{3}He atoms. In ordinary normal liquid ^{3}He in the absence of a magnetic field the nuclei are so weakly coupled to each other that the liquid is completely devoid of any overall magnetic order. When the liquid is sufficiently cooled, however, things become very different: the onset of long range order at the superfluid transition temperature involves the orientation of nuclear spins in definite directions, producing just the sort of ordered magnetic structure which might be expected to support spin waves.

In the case of a magnetic metal, one of the most convenient ways of demonstrating the existence of spin waves is through use of a resonance technique to excite standing waves in a very thin layer of the material. The situation is somewhat analogous to the more familiar one of standing waves on a stretched string whose ends are fixed in position. Unlike the case of the string, however, it is not the position, but rather the direction of the spins which is fixed on the boundaries of the material and which varies coherently through its thickness. Absorption of energy takes place for radio waves of the right frequency to excite a standing spin wave, that is, one such that the thickness of the layer of metal is equal to an integral number of half-wavelengths. Thus, if the rate of absorption of electromagnetic radiation is measured while its frequency is gradually increased, a series of peaks will be seen corresponding respectively to the fundamental, and higher orders of standing spin waves being excited.

The Bell Laboratories group used what in many ways is a very similar technique in their search for spin waves in superfluid ^{3}He. The combination of a strong magnetic field and the presence of a solid surface was used to fix the spin anisotropy axis n, thus defining the directions of the spins at the surfaces of a series of thin laminae of liquid. These were formed between a set of 20 fused quartz plates each about 7×11 mm in area, spaced 210 μm apart. The magnetic field was applied in the plane of the plates. Under these conditions, although n tries to lie parallel to the magnetic field in the bulk liquid between the plates, it is compelled to take up a different fixed direction where the liquid touches the surfaces of the plates. The competition between these effects causes the direction of n to vary smoothly with position in a completely determined way between the plates. Spin waves consist, therefore, of coherent deviations from this equilibrium situation, and may be expected to reveal their existence, as in the case

of the thin metallic film, through the resonant absorption of electromagnetic radiation at particular frequencies depending, in this case, on the temperature and on the magnitude of the applied magnetic field. The cell was placed in a compressional cooling apparatus in which the temperature of the liquid was lowered by reducing its volume and thus solidifying some of it, which was able to reach the so-called superfluid B phase which is stable below its transition temperature at about 2 mK.

In the event, a series of striking absorption peaks was indeed found approximately at the frequencies predicted by theory. Although the peaks were broader than ordinary NMR resonances in ^{3}He, they were quite well defined, thus eliminating the lurking possibility that spin waves in ^{3}He might be modes which are overdamped and therefore unobservable. As the authors point out, it is quite possible that the observed width of the resonance maxima is merely an experimental effect arising from small variations in the spacing of the quartz plates. The change with temperature of the resonant frequencies turned out qualitatively to be very much in line with theoretical expectations.

The experimental results are not, however, in close quantitative agreement with theory. However, although the authors' tentative explanation of the discrepancies (typically about 20%) may or may not be correct, there seems little doubt that they were indeed observing spin waves. Further experimental and theoretical work is clearly required, but it seems that spin wave resonance has now been added to the rapidly growing battery of techniques available for elucidating the dauntingly complicated properties of superfluid ^{3}He. □

Complementary genetics

from M. J. Hobart

An EMBO Workshop on Complement Genetics was held in Cambridge, UK on 18–22 March, 1977. It was organised by Dr P. Lachmann, MRC Group on Mechanisms in Tumour Immunity, Cambridge.

THE genetics of the complement system were put on the map, both chromosomally and as a topic of general scientific interest, by the discoveries in 1974 by F. H. Allen, S. M. Fu and their colleagues that the genes coding for Factor B and C2 are linked to *HLA*. This had been foreshadowed in 1973 by the work of P. Demant and colleagues showing that the Ss protein, coded within the *H-2* region of mice, was a complement component, subsequently shown by several groups of workers to be C4.

The complement system consists of at least 18 proteins, including proenzymes and inhibitors, whose activity is usually triggered by the binding of antibody to antigen. It is the major humoral effector system for the elimination of bacteria and viruses in vertebrates and is characterised by complex reaction pathways reminiscent of the clotting, fibrinolysis and kinin systems.

There is now good evidence that three complement components are coded by genes located within the *HLA* region: C2, Factor B and C4. The electrophoretic variants of C4 described by P. Teisberg (Ulleval Hospital, Oslo) show clear *HLA* linkage and both G. Mauff (Hygiene Institute, Cologne) and G. Hauptmann (Institut d'hematologie et de transfusion sanguine, Strasbourg) reported their methods which show the same phenomenon with rather improved resolution. These results confirm the earlier evidence for C4 linkage from studies of a deficient patient's family (C. Rittner, Institute of Forensic Medicine, Bonn). *HLA* linkage is now firmly established for C2 polymorphism (C. Alper, Center for Blood Research, Boston). The less common allele of *C2* (*2C*^{z} in the nomenclature proposed) was reported by T. Meo (Basel Institute for Immunology) to be in strong linkage disequilibrium with *HLA* BW15 and *HLA* CW3.

Alper also demonstrated polymorphism of C8 detected by isoelectric focusing and specific functional detection by haemolytic assay. There are at least three structural variants of C8, two of them common. The locus is not closely linked to *HLA*. Two new families with C8 deficient members were described by N. K. Day (Sloan Kettering Institute, New York) and F. Tedesco (Transplantation, Immunology and Blood Transfusion Service, Milan). In both families, there were totally C8 deficient individuals with different *HLA* types, showing that the deficiency genes also cannot be close to *HLA*. Furthermore it was apparent that there is difficulty in ascertaining the heterozygous deficiency states, since in both families, both parents of the propositi had C8 levels within the normal range. Furthermore Alper reported that members of a deficient family heterozygous for the structural variant could nevertheless have low C8 levels. This may explain the discrepancy between these reports and that of Merritt *et al.* (*Third International Workshop on Human Gene Mapping. Birth Defects* **XII** (7) 331, The National Foundation, New York, 1976) which claimed *HLA* linkage for C8 deficiency.

D. Glass (Robert B. Brigham Hospital, Boston) presented a large series of carefully measured cases of heterozygous C2 deficiency. There seems to be a significant association with juvenile rheumatoid arthritis and systemic lupus erythematosus in these patients. J. Soothill (Institute for Child Health, London) and J. Mowbray (St. Mary's Hospital, London) have evidence that there is an increased incidence of heterozygous C2 deficiency in infantile asthma and eczma. However, it was pointed out in discussion that apparently high recombination frequency between C2 and *HLA* observed by Glass is probably due to ascertainment errors inherent in measuring complement levels.

C3, C4, C5 and C8 are known to be composed of more than one polypeptide chain, but in no case is there any evidence that more than one locus is involved in coding for the observed polymorphisms. A possible explanation for this phenomenon is given by preliminary experiments of H. Colten (Children's Hospital Boston) and his colleagues (reported by Alper). They have shown that both C4 and C3 obtained from cell-free synthesis by immunoprecipitation occur as larger than expected chains. Their suggested interpretation of this result is that C3 and C4 (and, by analogy, perhaps C5 and C8) are synthesised as single polypeptide chains which are cleaved before secretion, rather like insulin. Only one cistron will then be involved in coding for the whole molecule and all markers will be alleles, irrespective of the chain on which they are found. Since there are now some 20 variants of C3, all of them apparently alleles, this view has its attractions. Some similar complement components seem to be the products of tandem duplicated genes. This is the case with C2 and Factor B. Both are linked to *HLA* in the same subregion and with no crossovers indentified between them. Both are single polypeptide chains, heat labile and form part of a complex C3 splitting enzyme. C6 and C7 are consecutively acting components and are both single polypeptide chains. They show close linkage to each other as demonstrated by allotyping (M. J. Hobart, MRC Group on Mechanisms in Tumour Immunity, Cambridge). Although C3, C4 and C5 are similar, C4 is linked to *HLA* but the other two components are not. If these molecules are the products of related genes, then they have been duplicated by processes other than (or additional to) tandem duplication.

A remarkable case of combined