

Nobel Prize for Physics 1980

Once more it is the elementary particle fraternity which is honoured with the Nobel Prize for Physics. This year the prestigious award goes to James W. Cronin of the University of Chicago and Val Fitch of Princeton for their epic experiment at Brookhaven in 1964 which showed that the so-called charge-parity (CP) symmetry was subtly violated in the decays of neutral kaons.

Although recent theoretical developments have provided some strong suggestions, this fundamental discovery has yet to fall neatly into place in our understanding of fundamental particles and their interactions.

After the Cronin-Fitch discovery, it was soon realized that if we could run physics backwards in time, we would not necessarily reencounter the past. CP violation means that at least as far as the neutral kaons are concerned, the symmetry of time between past and future is not perfect.

For many years, physicists had believed that everything obeys three basic symmetries – parity (P), charge conjugation (C) and time reversal (T). Rotations in space can be either right-handed or left-handed, and the principle of parity symmetry implies that Nature makes no underlying distinction between right and left, so that both options are equally possible. This means that the distinction between right and left is mere human convention, and that for any natural object or event, a 'mirror image' counterpart could exist. Charge conjugation symmetry says

that for any natural particle, there can exist a corresponding antiparticle which carries opposite (but equal) electric charge and other such quantum numbers. This symmetry implies that the phenomena seen in a world composed entirely of antimatter would be exactly the same as those seen with ordinary matter, so that the distinction between what is called matter and what is called antimatter is totally arbitrary. Time reversal symmetry says that if the motion of a physical system were to be subsequently reversed, the system would inevitably return to the situation from which it started.

Just twenty-five years ago, all these symmetry principles were believed to be universally valid, but since then it has been found that when the weak force is in action, in fact all of them are violated.

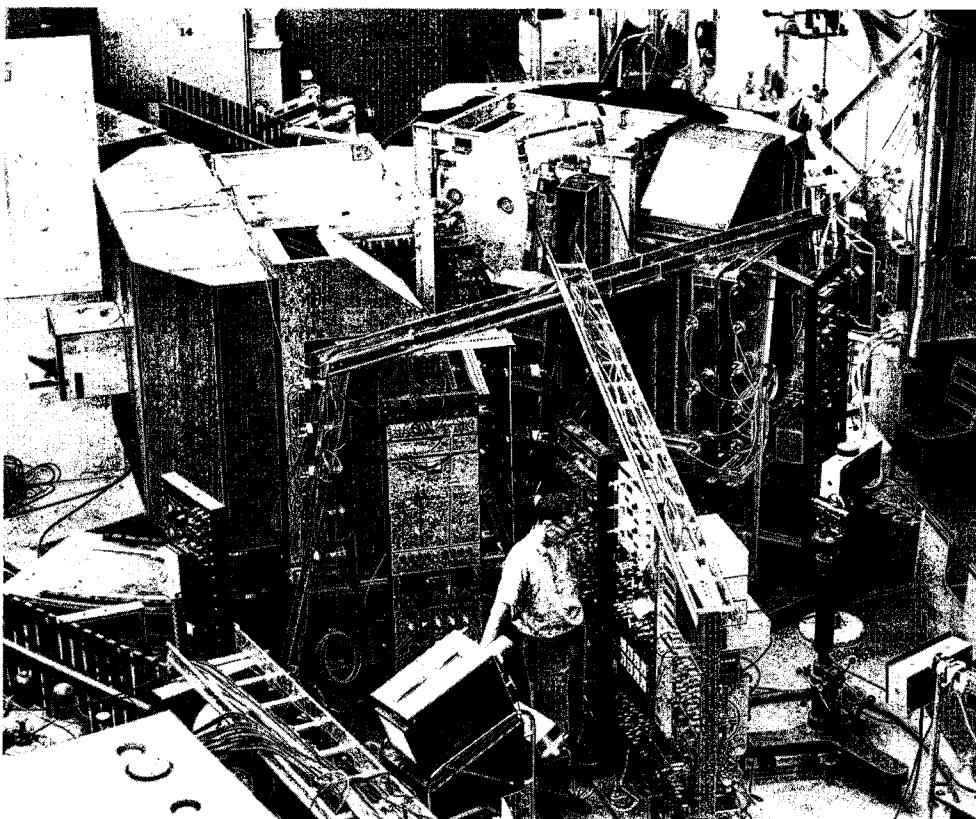
The first symmetry to fall was that of parity. In the early 1950s, physi-

cists were worried about the so-called 'theta-tau puzzle'. Two different weak decays were being seen, one giving two pions, the other giving three. These two pionic configurations have opposite parity, but apart from this, the properties of the decaying particle were highly similar. In 1956, T.D. Lee and C.N. Yang concluded that there was no evidence for the conservation of parity in weak interactions, and perhaps one particle, the neutral kaon, could be responsible for the two observed decay modes. New experiments were proposed to test conclusively whether parity symmetry was violated.

Soon afterwards, C.S. Wu and her collaborators looked at the radioactive (weak) decays of polarized nuclei and found that the emitted electrons preferred to emerge on one side relative to the direction of spin of the parent nucleus. Other

Apparatus used by Cronin and Fitch at Brookhaven in 1964 to detect the two pion decay mode of the long-lived neutral kaon and so overthrow charge conjugation/parity (CP) symmetry. The two spectrometer arms, symmetrically placed about the incoming neutral beam, picked up the charged products of the neutral kaon decays.

(Photo Brookhaven)



James W. Cronin at a news conference after the announcement of the award of the 1980 Nobel Prize for Physics.

(Photopress)

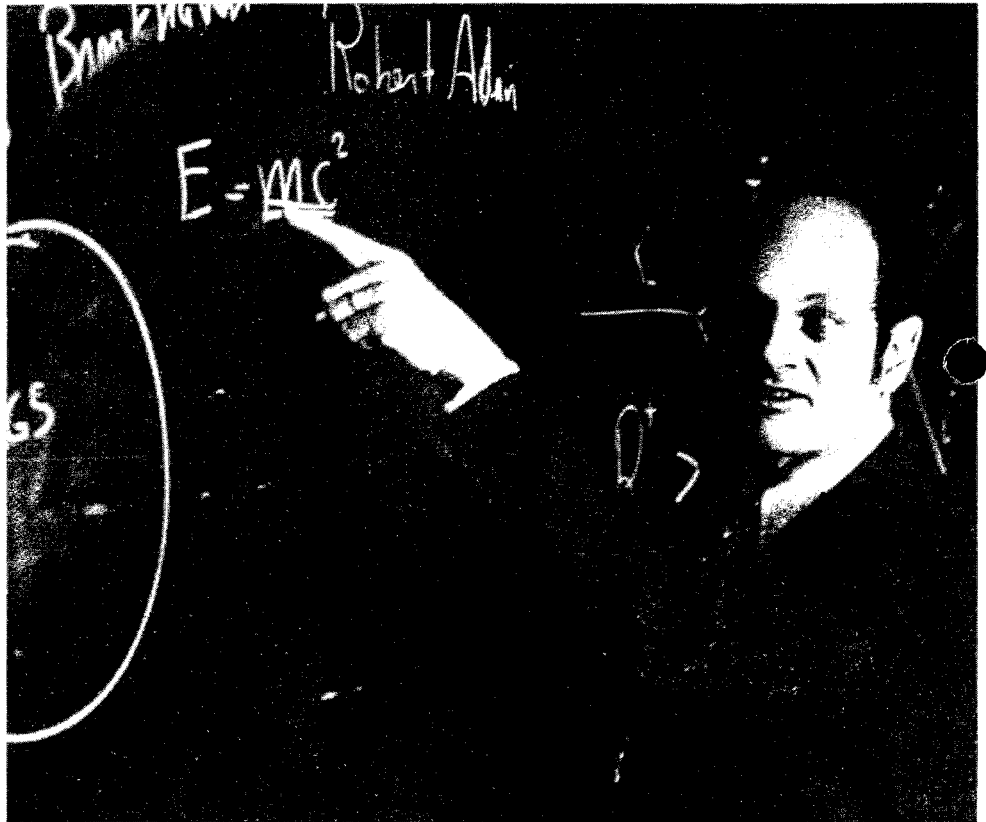
experiments soon saw similar behaviour, which confirmed that when the weak force is in action, Nature definitely cares about the direction in which things can happen. In 1957, the Nobel Prize for Physics was awarded to Lee and Yang.

In weak decays, antimatter moreover behaves in the opposite way to ordinary matter, for example a decaying neutron prefers to emit electrons spinning left-handedly while a decaying antineutron gives mainly right-handed positrons. This means that charge symmetry too has to go by the board. However if the double CP operation – particle to antiparticle and left to right transformations – were carried out, this CP symmetry would be good and order would seem to be restored.

The strange world of the neutral kaon

In the study of the basic symmetries of the weak interactions, the neutral kaons, which carry strangeness but no electric charge, play an especially important role. In strong interactions, strangeness is a 'good' quantum number, so that the neutral kaon and its antiparticle can be distinguished. However weak interactions do not conserve strangeness, so that in these interactions the neutral kaon and its antiparticle have to be considered together.

In high energy collisions both the 'true' neutral kaon and its antiparticle are formed. For the subsequent weak interactions, one can have either a symmetric or an antisymmetric superposition of the two kaons. According to CP symmetry, the symmetric mixture can decay into two pions, but the antisymmetric cannot. The latter therefore has to find some other way of decaying, for example into three pions. Such a decay is more difficult, so that the



antisymmetric combination lives longer than the symmetric one.

Up to 1964, this was in agreement with all experiments. The symmetric mixture, called the short-lived kaon, was known to live for about 10^{-10} seconds and subsequently decay into two pions, while the antisymmetric one, called the long-lived kaon, was about a hundred times more durable, decaying eventually into three pions. It had never been seen to decay into two pions, or put more precisely, experiments had shown that any decay into two pions did not exceed one three-hundredth of all decays.

The Cronin-Fitch experiment set out to improve this limit using spark chambers to detect kaon decay products in a narrow beam of secondary neutral particles at the Brookhaven Alternating Gradient Synchrotron. Their detector consisted of two identical spectrometer arms, one either

side of the neutral beam axis, which looked for events in which one charged decay product passed through each arm. The distance from the production target to the decay region in front of the spectrometers was long enough to ensure that the short-lived kaons had decayed away, and that only the decay products of long-lived kaons were detected.

The pairs of charged particles picked up in the detector arms could come from several different decay modes of the long-lived neutral kaons – pion plus electron plus neutrino (the neutrino being undetected), or pion plus muon plus neutrino, or three pions (with the third pion eluding the spectrometer arms), as well as the possible two-pion mode.

To eliminate the first two possibilities, an effective mass of the parent particle in each decay event was

calculated, assuming each particle recorded in the spark chambers was a pion. By selecting only those events giving an effective mass which corresponded to the neutral kaon, decays giving electrons and muons could be eliminated.

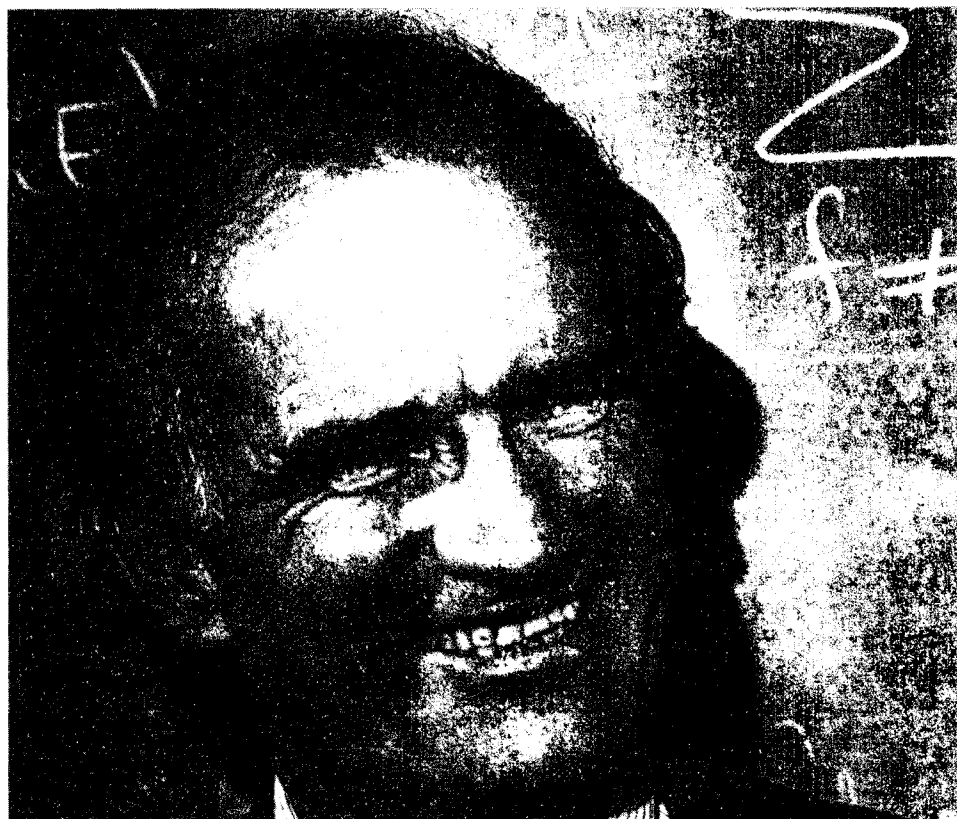
The next step was to calculate the combined momentum of the pair of pions picked up in the two spectrometer arms, and to compare the direction of this momentum with that of the neutral beam. For decays into three pions, the angle between the momentum of the detected muon pair and the beam would be the result of the 'missing' third pion. However this angular distribution revealed an excess of two-pion events whose combined momentum coincided with the direction of the neutral kaon beam and which could not be explained by any other effect. From a sample of 22 700 long-lived kaon decays, some 45 events were

found which corresponded to the production of just two pions.

Although only a tiny effect (0.2 per cent), this evidence was enough to overthrow CP symmetry. This discovery immediately had serious implications because the belief in an overall CPT symmetry, combining charge conjugation, parity and time reversal, is a vital part of the theoretical description of particle behaviour. If CPT were to have been found invalid, then theoretical physics would have been in serious trouble. Subsequent experiments on neutral kaon decays showed that time reversal, as well as CP symmetry, is violated, but in such a way that the overall CPT symmetry is still good.

The origin of this CP and T symmetry violation is attributed to a 'superweak' force, whose strength is only 10^{-9} that of the already feeble weak interaction. Recently, theorists have proposed that the existence of

at least two heavier quarks beyond charm could naturally explain this force. Whatever its explanation, CP violation is an integral part of physics and has to be an integral part of physical theory. Until it is, only optimists can say that particle physics is understood.



Val Fitch, chairman of Princeton's Physics Department.

(Photopress)