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This Week's Citation Classic

Glashow S L, Iliopoulos J & Maiani J. Weak interactions with lepton-hadron symmetry. *Phys. Rev. D* **2**:1285-92, 1970. [Lyman Lab. Physics, Harvard Univ., Cambridge, MA]

It is shown that the theory of weak interactions gives conflicts with experiment unless a fourth 'charmed' quark is introduced. Its electromagnetic and weak interactions are prescribed. The existence of a large class of new particles containing charmed quarks is predicted. [The *SCI*® indicates that this paper has been cited over 1085 times since 1970.]

Sheldon Lee Glashow
Theoretical Physics Group
Lyman Laboratory
Harvard University
Cambridge, MA 02138

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"Soon after quarks were invented, it was suggested that there could and perhaps should exist more than three quark species. With four quarks corresponding to the four then known leptons, the weak interactions of quarks and leptons could be made more symmetrical. The conjectured fourth quark was dubbed the charmed quark.[1] However, it was the work of myself, John Iliopoulos, and Luciano Maiani that made the case for charm truly compelling. Without charm, theories of weak interactions led to strangeness-changing neutral currents (SCNC) which would induce phenomena that are absent in nature. The existence of a charmed quark provides a mechanism (called the GIM mechanism) for the cancellation of these unwanted effects. Agreement between theory and experiment is restored. We predicted the existence of a new kind of matter (charmed particles) weighing no more than 'several GeV.'

"When this work was done, Iliopoulos and Maiani were both postdoctoral fellows at Harvard. Since then, they have become leading theoretical physicists in France and Italy, respectively. I stayed at Harvard and won a share of the 1979 Nobel Prize in Physics. The common citation for Abdus Salam, Steven Weinberg, and me was for our 'contributions to the unification of weak and electromagnetic interactions.' The work on charm was relevant, but not central, to my award.

"Charmed particles have been discovered, and have just the properties they were predicted to have. The first particle containing charmed quarks to be observed was the J/Ø. Its discovery earned the Nobel prize for Burton Richter[2] and Samuel C.C. Ting.[3] Many different charmed particles have been subsequently identified.

"The popularity of a paper correctly predicting the existence and properties of a new kind of matter is easy to understand. What is amazing to me is that the work had not been done several years earlier than it was. I first encountered the problem of SCNC in 1960. I realized that the unification of weak and electromagnetic interactions demanded the existence of weak neutral currents.[4] In itself, this was quite acceptable, but the neutral currents were necessarily strangeness-changing. They would lead to processes that do not happen. In discussing such gauge theories in 1961, Murray Gell-Mann and I wrestled with the problem and concluded that 'some important ingredient in the theory was missing/5 What was missing was charm, and its introduction could have been seen to solve the problem. Yet, by 1964 I had apparently lost interest in gauge theories, and I failed to make the connection. The statement of the problem, and the *ansatz* which solved it were both in the published literature. There was even a common author. Yet no one, least of all me, put things together until the work of 1970."

1. **Bjorken B J & Glashow S L.** Elementary particles and SU(4). *Phys. Lett* **11**:255-7, 1964.
2. **Richter B.** From the psi to charm—the experiments of 1975 and 1976. *Les prix Nobel en 1976.* Stockholm: Imprimerie Royale P.A. Norstedt & Söner, 1977. p. 45-74.
3. **Ting SCC.** The discovery of the J particle: a personal recollection. *Les prix Nobel en 1976.* Stockholm: Imprimerie Royale P.A. Norstedt & Soner, 1977. p. 79-106.
4. **Glashow S L.** Partial symmetries of weak interactions. *Nucl. Phys* **22:**579-91, 1961.
5. **Glashow S L & Gell-Mann M.** Gauge theories of vector particles. *Ann. Phys. NY* 15.437-60. 1961.