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CP Violation and the Matter Anti-Matter Asymmetry of the Universe[1]

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There is no scientific question more fundamental than "Why are we here?" or as we physicists might phrase it "Why is there more matter than anti-matter?" Because, as Andrei Sakharov first showed, CP violation is necessary to any explanation of the matter anti-matter asymmetry, CP violation is the focus of much of the international experimental program in particle physics. CP conservation was what could be salvaged after parity was overthrown in 1956, but it survived only until 1964 when K mesons were found not to respect it. While parity violation was a large effect in weak interactions, CP violation seemed small and confined to the kaons. When the Standard Model of particle physics emerged in early 1970's, Kobayashi and Maskawa observed that if there were three families of quarks, CP violation would arise quite naturally. The Standard Model suggested that CP violation could be large in decays of B mesons. Nonetheless, no matter what parameters are used in the Standard Model, CP violation among quarks cannot be large enough to explain the matter anti-matter asymmetry. Major experiments in the U.S. and Japan were undertaken to explore CP violation in B mesons to search for signs of CP violation outside the Standard Model, which might explain the dominance of matter over anti-matter. Neither experiment found such a discrepancy, but new programs will continue this search with much higher statistics. While the three families of leptons are in many ways analogous to the three families of quarks, the neutrinos have a unique character. As neutral particles, it is possible that they are their own antiparticles. If this is so, there may be additional, very heavy, neutrinos beyond those we know already. If they violate CP they may be the source of the matter anti-matter asymmetry. But do neutrinos experience CP violation? Experiments around the world are just now setting out to answer this question.

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