

Proton Decay, Massive Neutrinos, Magnetic Monopoles, Quantum Gravity

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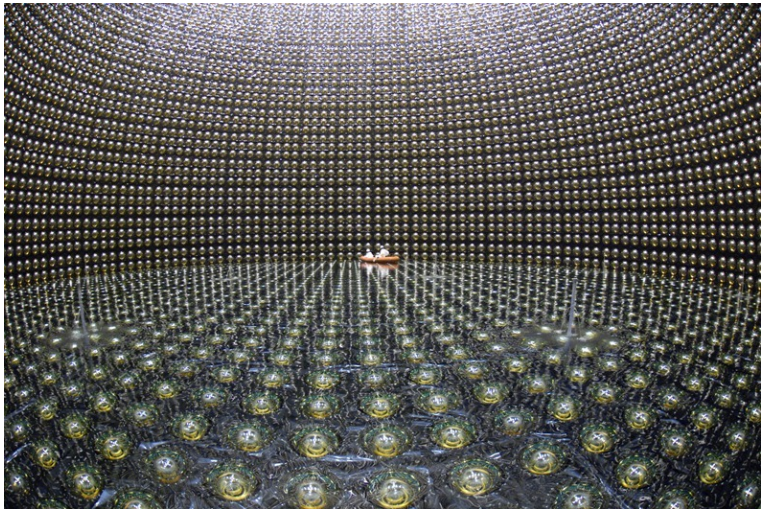
Proton Decay

- ▶ In GUTs quarks and leptons are states of one particle called *leptoquarks*
- ▶ Can each type of particle be changed to the other?: Quark, Lepton flavors
- ▶ From GUTs: 10^{30} to 10^{33} year lifetime of proton, a consequence of the large energy of interaction unification
- ▶ Examples of Possible Decay "signatures": $p \rightarrow \pi^0 e^+$ $p \rightarrow \pi^+ \bar{\nu}_e$
- ▶ No observations of proton decay yet, still searching
- ▶ Further, no nonconserving lepton-number event has been found

Note

Nonconservation of the baryon number in the early universe provides an explanation of a major cosmological problem: Why does the present universe have more baryons than antibaryons?

SuperK



Super-Kamiokande, World's largest Neutrino detector

Interesting points

SuperK website: 3D tour, +info.



April 2020, Nature Journal cover

Massive Neutrinos

- ▶ From Pauli until GUTs: Neutrinos have no mass
- ▶ GUTs require that neutrinos have mass, predicting:
Equation 12-33: Neutrino mass $m_\nu \approx M_{eW}^2/M_x$
- ▶ Massive neutrinos solve:
the solar neutrino problem(CH.11), Missing Energy in the universe (CH.13)
- ▶ Prediction: $m(\nu_e) \ll m(\nu_\mu) \ll m(\nu_\tau)$
- ▶ MSW effect: Wavefunctions of neutrinos consist of a superposition of mass states allowing oscillation of $\nu_e \rightarrow \nu_\mu$ or ν_τ

M_{eW}^2 is characteristic mass of electroweak interaction, $10^2 \text{ GeV}/c^2$

M_x is unification mass $E_x/c^2 \approx 10^{16} \text{ GeV}/c^2$, Nearly all GUTs have this order of magnitude

Magnetic Monopoles

- ▶ Magnetic Monopoles were first suggested by Dirac in 1929 and are also proposed in GUTs
- ▶ Predicted charge: $q_m = n\hbar c/2e$ for $n = 1, 2, 3...$
- ▶ Predicted mass $\approx 10^{16} \text{ GeV}/c^2$
This is a very large figure, far beyond the energy achievable in any accelerator.
- ▶ Cosmic ray searches have proved to be inconclusive as only one possible observation has ever been reported (B.Cabrera 1982). That observation is inconsistent with current limits.
- ▶ In 2009, two research groups created quasi particles that behaved as predicted monopoles would. These are considered a valuable tool to learn about how real monopoles would behave.

Quantum Gravity

- ▶ GUTs need quantum gravity
- ▶ Superstring theories treat particles as strings rather than points.
 - ▶ Properties of Super-string theories: compact dimensions (as many as 11 in M-Theory), Gauge theories (i.e Lagrangian is invariant under local transformations)
- ▶ Theorized to be $10^{-35}m$ too small to measure
- ▶ No experimental evidence to support representation of physical reality
- ▶ Many unanswered questions regarding internal structure of quarks, a "sea" of quark-antiquarks around hadrons, and more...
- ▶ Bigger better accelerators are needed to move forward experimentally

A little more...

- ▶ **Approaches to Quantum Gravity:**
 - ▶ String theory
 - ▶ Loop quantum gravity
 - ▶ Many more approaches:
 - ▶ Asymptotic safety in quantum gravity
 - ▶ Euclidean quantum gravity
 - ▶ Group Field Theory....