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P. 93–95 (from meson factories), main thoughts

Meson factories provide the answer. The broken CP-symmetry may also be the reason to exist for the heavier generations of fundamental particles. Kobayashi and Maskava had predicted that B-mesons violate CP-symmetry, so their decays have been studied in detail. They indeed revealed the violation.

Symmetry lies hidden under spontaneous violations. The Standard Model describes three of the four fundamental forces of nature, but we haven't yet explained why they are so different. The reason is another broken symmetry. In physics, the vacuum is the lowest energy state of the system, and it doesn't have to be the most symmetric. The asymmetry between forces comes from our vacuum.

Higgs provides mass. It is commonly considered that a separate field called the Higgs field gives particles masses. In the early Universe, its state was symmetric, and all particles were massless. But as the Universe cooled down, the Higgs field decayed into its vacuum and started to differentiate particles. The Higgs boson, which represents the field, is now being sought at the largest accelerator in history — LHC.

Ex. 1, p. 96

Broken symmetry — нарушенная симметрия. *Mirror symmetry* — зеркальная симметрия. *Charge symmetry* — зарядовая симметрия. *Time symmetry* — симметрия обращения времени. *Conservation laws* — законы сохранения. *The double CP-symmetry* — двойная CP-симметрия. *Quarks* — кварки. *B-mesons* — B-мезоны. *Spontaneous symmetry violation* — спонтанное нарушение симметрии. *The Higgs particle* — частица Хиггса. *The Standard Model* — Стандартная модель.

Ex. 2, p. 96

Because of classical physics and our everyday experience, we are used to *nature's laws of symmetry*. But if it was translated to particle physics, there wouldn't be any *excess of matter* over antimatter. At least *a tiny deviation from perfect symmetry* is required at the early stages of the Universe. In classical physics, conservation laws help us *simplify awkward calculations* and *play a decisive role* in *the mathematical description of the microworld*. To detect the small asymmetry, it is necessary to *produce a constant stream of particles*. The Standard Model describes the *indivisible parts of matter*. The excess of matter *poses a challenge* to the theory behind the Standard Model. Modern accelerators can provide *insights into the innermost parts of matter*. The quark mixing CP violation mechanism *stands firmly on a theoretical base.* The Standard Model *stood up to countless tests*, and now we almost don't know how to extend it. A Chinese experimental physicist Chien-Shiung Wu conducted an experiment to *challenge mirror symmetry.* It appeared that we have to *reevaluate old principles* in particle physics. After the P-symmetry was broken, physicists hoped that it's not possible to *break the double CP-symmetry.* We should *point out the importance of broken symmetry* — it could *set up conditions for* our cosmos to survive the first seconds after the Big Bang. The broken CP-symmetry lets us *distinguish between matter and antimatter.* The amount of matter we have now had to *originate in the heat of the Big Bang*, but the current theoretical deviation from CP-symmetry is not enough. The only source of CP violation in the Standard Model is *the transformation of the quarks* also called quark mixing. To verify the suggestion of Kobayashi and Maskawa, we have to *confirm the symmetry violation of the B-mesons.* As collider experiments went on, the Universe was found to *be in accordance with the boldest predictions* of the Standard Model. Nambu realized that the same mechanism that makes superconductivity disappear could *introduce spontaneous symmetry violation into elementary particle physics.* Physicists are now searching for evidence of new physics to *extend the Standard Model* correctly and solve its major issues.

Ex. 3, p. 96

a) A tiny deviation from the perfect symmetry caused the excess of matter over antimatter that we observe now.
b) The three principles of symmetry are mirror symmetry, charge symmetry, and time symmetry. They let us consider the behavior of similar systems and test our understanding of the world.
c) Deeper investigations into the world of elementary particles made it possible to discover the structure of the proton and later the neutron. This discovery was a large sign of the quark model.
d) The strong force with its gluon, the electromagnetic force with its photon, and the weak force with its W and Z bosons are incorporated in the Standard Model. Gravity is not and is hence challenging.
e) Tsung Dao Lee and Chen Ning Yang challenged mirror symmetry by suggesting an experiment with the weakly decaying cobalt-60. The result was the discovery of P-symmetry violation.
f) James Cronin and Val Fitch are famous for their experiment with kaons that showed another symmetry breaking.
g) Andrei Sakharov set up three conditions for creating a world like ours. The laws of physics have to distinguish matter from antimatter. The cosmos had to originate

from the Big Bang. The proton has to decay.

h) A theoretical explanation for symmetry breaking was given by Kobayashi and Maskava, with their idea of quark mixing 3x3 matrix.

i) Two experiments, BaBar and Belle, also called b-factories, confirmed B-meson mixing and hence CP violation.

j) Yoichiro Nambu realized that the same mechanism that makes superconductivity disappear could introduce spontaneous symmetry violation. He suggested a theoretical source of such violation.

k) The Standard Model has not yet been extended with anything. Searches for new physics are still being conducted at the largest and most expensive accelerator facilities in the history of particle physics. Neither of the numerous possible extensions has been confirmed.