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Epilogue

Six quarks, six leptons, together with the gluons of QCD and the photon and weak bosons, are enough to describe the tangible world and more, with remarkable economy. Only the Higgs boson is missing among the ingredients of the canonical Standard Model. And yet we know we are missing much more than this. The last ten years of cosmological observations have established that the ordinary matter of quarks and leptons accounts for just 5% of the energy density of the Universe, that another 23% is "dark matter," outside the Standard Model, and 72% of the energy density isn't due to matter at all. Moreover, we can't answer the most basic question of all: why is there something rather than nothing? Why didn't all the matter created in the Big Bang ultimately annihilate, particle against antiparticle? Andrei Sakharov explained that CP violation must be part of the answer, but we know it isn't just the CP violation of the CKM matrix, for that wouldn't account for the amount of matter that remains. On the other hand, the strong interactions might have been CP violating but aren't. Why not?

These questions are pressed upon us by facts and demand answers. Other questions arise more from aesthetics: Are the strong and electroweak forces themselves unified? What about gravity? Are there more forces still to be discovered? Why are there three generations of quarks and leptons? Even more audaciously, why are there three spatial dimensions, or perhaps, are there more than three spatial dimensions?

These are questions of physics, not metaphysics, because there are experiments to address them. At CERN, the LEP tunnel is filled with 8-T magnets to constrain counter-rotating beams of 7-TeV protons. The gargantuan ATLAS and CMS detectors, the descendants of UA-1, UA-2, CDF, and D0, are there to pick out the 100 or so most interesting events of the 10^9 that will be produced each second. At this energy, either the Higgs boson or some surrogate must make its appearance. Supersymmetry would provide a replica of each known particle, with its spin offset by half a unit. Among these could be the particle that makes up dark matter.

Particle physics, which has its origins in studies of cosmic rays and nuclear decays, is returning to these phenomena to answer basic questions. Dark matter must be a form of cosmic rays and might be detected through collisions with ordinary matter if only all the extraneous backgrounds could be excluded by going deep underground with supersensitive detectors. The absence of CP violation in the strong interactions can be explained at the

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cost of introducing an axion, a feebly interacting particle a bit like a completely stable neutral pion. The axion might itself be the dark matter and could be detected by converting it to a photon in a resonant cavity.

The CP violation that accounts for the baryon–antibaryon asymmetry might reside in very heavy neutrinos, which are beyond our reach. Still, we can seek circumstantial evidence by looking for CP violation in the light neutrinos, whose mixing is only partially understood. We don't know yet how much of the electron-neutrino resides in the third neutrino mass eigenstate, the one whose mass is far from that of the other two. All CP violating effects in neutrinos are proportional to this amplitude, $\sin\theta_{13}$. Experiments both with accelerators and nuclear reactors are underway to measure this small quantity.

Perhaps words borrowed from Winston Churchill best describe Dark Energy "a riddle wrapped in a mystery inside an enigma." It dominates the energy budget of the Universe but it isn't matter at all. About its properties we only know one thing: its pressure is nearly the negative of its energy. Einstein's abandoned Cosmological Constant, Λ, fits the bill, for it gives $p/\rho = -1$ exactly, but the value of Λ required is some 120 orders of magnitude larger than one would expect on dimensional grounds, showing that we really don't understand this at all. Alternatively, the Dark Energy might be something dynamical, not static. The expansion history of the Universe, gleaned from precision measurements of distant type Ia supernovae, from weak gravitational lensing of distant galaxies, and from correlations between the locations of galaxies extracted from hundreds of millions of redshifts, provide the best means of learning more about Dark Energy. The same measurements can check that the acceleration of the expansion of the Universe is not due to a failure of General Relativity, but really due to Dark Energy.

Some of the questions before particle physics have puzzled people for millennia. What is the world, the Universe, made of? How did it start? How will it end? Others – like why is there any matter at all – require both understanding and imagination even to pose. What is remarkable and thrilling is that we can expect to learn something about these formerly metaphysical questions by doing real experiments.

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