10. The Physics of the Universe

10.1 The Unity of Nature

Cosmology is unique among sciences because it deals with the whole physical Universe, while other sciences deal with only part of it, or with certain aspects of physical reality.

This uniqueness of cosmology makes it particularly interesting and also particularly difficult. All fundamental and unsolved problems of the other sciences usually lead us to cosmological problems. For example, chemistry studies the properties of the chemical elements; but why do these chemical elements exist on the Earth? The problem of the formation of the elements leads us to the initial creation of the Universe or to the formation and evolution of stars, that is, directly to cosmology or to branches of astrophysics intimately related to cosmology.

Similarly, the existence of a solid crust on the Earth, the existence of oceans and even more, the existence of life on the Earth are directly related to the conditions under which the Earth and the whole solar system were formed. As we shall see later, small differences in the initial conditions and properties of the Universe could lead to a completely different Universe, without stars, without planets and without life.

Another fundamental question also closely relates cosmology to physics and the other sciences. This refers to the unification of the physical laws, and their reduction to other more fundamental laws. The unification of the forces of nature, about which we talked in Sect. 8.5, is directly related to cosmology.

This unification is present in various branches of science. For example, the complex movements of the celestial bodies led Newton to the universal law of gravity which can explain all relevant phenomena, apart from some corrections brought about by the general theory of relativity. Einstein's theory achieved an even deeper unification by treating gravity as a geometrical property of spacetime. A similar revolution came about in chemistry and biochemistry, when all forces relevant to the chemical phenomena were shown to be of electromagnetic nature. Today, physicists go even further in the same direction, in trying to unify all the forces of nature, from the nuclear to the electromagnetic and gravitational forces.

At this point, however, a basic and fundamental question arises. Is it possible to show why the laws of nature are what we observe and not
different? For example, can we deduce that the law of gravity must be the way it is (namely an attractive force between two bodies proportional to their masses and inversely proportional to the square of their separation)? At this point people disagree. Some scientists, like Einstein and Eddington think that the basic laws of physics can be deduced by syllogisms a priori. Most scientists, however, accept experience as the only starting point for the expression of physical laws and their applications.

Of course, everybody accepts that observation and experiment provide the essential checks for the various theories. A simple theory, however, is much more attractive than any observation. That is why, when in 1919 the deflection of light due to the gravitational field of the Sun was measured and Einstein was asked what he would have said if the result were different from his prediction, he answered: “I would have said pity to God, because the theory is correct”.

This incident shows Einstein’s confidence in his theory. It is true that Einstein was proved right not only on this occasion, but on many other occasions as well, when his theory was put to the test. However, very few people have the amazing intuition that Einstein had, and even Einstein himself failed when he tried to advance beyond general relativity by developing his Unified Theory. Therefore, not everything that looks simple is necessarily true. In some strange way, however, whatever is true, is simple, provided one looks at it from the right angle. For example the motions of the planets appear very complicated. Ptolemy’s attempts to explain them with his epicyclic theory failed. Even Copernicus, in spite of his basic simple idea that the Sun was at the centre of the solar system, needed even more epicycles than Ptolemy to explain the planetary motions. The problem was made simpler by the introduction of Kepler’s elliptical orbits, but its final solution was due to Newton. Newton found that the gravity law, expressed so simply, can account for all the complications in the motions of the planets.

Later on, when the general theory of relativity was introduced, it was thought that the simplicity of Newton’s laws was lost. This impression, however, lasted only as long as it took scientists to understand the new theory. The general theory of relativity not only explains all phenomena which Newton’s theory could explain and the deviations which Newton’s theory could not explain, but it also sheds light on the fundamental properties of gravity in a simple and elegant way. That is, Einstein’s theory explains why Newton’s laws hold (approximately). Thus, we find again the simplicity of the physical laws, at a level deeper than the level at which Newton’s laws apply.

The modern unified theories of the four basic forces of nature try to explain not only gravity, but also electromagnetism and the weak and strong nuclear forces. That is, they try to formulate some very general principles from which one can deduce all the complicated properties of