

3 Actions, Knowledge, and Information

3.1 The Anti-Newtonian Revolution

From the time of Isaac Newton until about 1925 science relegated consciousness to the role of passive viewer: our thoughts, ideas, and feelings were treated as impotent bystanders to a march of events wholly controlled by microscopically describable interactions between mechanically behaving microscopic basic elements. The founders of quantum mechanics made the revolutionary move of bringing conscious human experiences into basic physical theory in a fundamental way. After two hundred years of neglect, our thoughts were suddenly thrust into the limelight. This was an astonishing reversal of precedent because the enormous successes of the prior physics were due in large measure to the policy of excluding all mention of idea-like qualities from the formulation of the physical laws.

What sort of crisis could have forced the creators of quantum theory to contemplate, and eventually embrace, this radical idea of injecting our thoughts explicitly into the basic laws of physics?

The answer to this question begins with a discovery that occurred at the end of the nineteenth century. In December of 1900 Max Planck announced the discovery and measurement of the ‘quantum of action’. Its measured value is called Planck’s constant. This constant specifies one of three basic quantities that are built into the fundamental fabric of the physical universe. The other two are the gravitational constant, which fixes the strength of the force that pulls every bit of matter in the solar system toward every other bit, and the speed of light, which controls the response of every particle to this force, and to every other force. The integration into physics of each of these three basic quantities generated a monumental shift in our conception of nature.

Isaac Newton discovered the gravitational constant, which linked our understandings of celestial and terrestrial dynamics. It connected the motions of the planets and their moons to the trajectories of cannon balls here on earth, and to the rising and falling of the tides. In-

sofar as his laws are complete the entire physical universe is governed by mathematical equations that link every bit of matter to every other bit, and moreover fix the complete course of history for all times from physical conditions prevailing in the primordial past.

Einstein recognized that the 'speed of light' is not just the rate of propagation of some special kind of wave-like disturbance, namely 'light'. It is rather a fundamental number that enters into the equations of motion of every kind of material substance, and, among other things, prevents any piece of matter from traveling faster than this universal maximum value. Like Newton's gravitational constant it is a number that enters ubiquitously into the basic structure of Nature.

But important as the effects of these two quantities are, they are, in terms of profundity, like child's play compared to the consequences of Planck's discovery.

Planck's 'quantum of action' revealed itself first in the study of light, or, more generally, of electromagnetic radiation. The radiant energy emerging from a tiny hole in a heated hollow container can be decomposed into its various frequency components. Classical nineteenth century physics gave a prediction about how that energy should be distributed among the frequencies, but the empirical facts did not fit that theory. Eventually, Planck discovered that the empirically correct formula could be obtained by assuming essentially that the energy was concentrated in finite packets, with the amount of energy in each such unit being directly proportional to the frequency of the radiation that was carrying it. The ratio of energy to frequency is called Planck's constant. Its value is extremely small on the scale of normal human activity, but becomes significant when we come to the behavior of the atomic particles and fields out of which our bodies, brains, and the large physical objects around us are made.

Planck's discovery shattered the classical laws that had been for two centuries the foundation of the scientific world view. During the years that followed many experiments were performed on systems whose behaviors depend sensitively upon the properties of their atomic constituents. It was repeatedly found that the classical principles did not work: they gave well defined predictions that turned out to be flat-out wrong, when confronted with the experimental evidence. The fundamental laws of physics, which every physics student had been taught, and upon which much of the industrial and technological world of that era was based, were failing. More importantly, and surprisingly, they were failing in ways that no mere tinkering could ever fix. Something was fundamentally amiss. No one could say how these laws, which were