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JUST SIX NUMBERS

The Deep Forces That Shape the Universe

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CHAPTER 1

THE COSMOS AND THE MICROWORLD

> Man is . . . related inextricably to all reality, known and unknowable . . . plankton, a shimmering phosphorescence on the sea and the spinning planets and an expanding universe, all bound together by the elastic string of time. It is advisable to look from the tide pool to the stars and then back to the tide pool again.
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> John Steinbeck, *The Log from the Sea of Cortez*

SIX NUMBERS

Mathematical laws underpin the fabric of our universe – not just atoms, but galaxies, stars and people. The properties of atoms – their sizes and masses, how many different kinds there are, and the forces linking them together – determine the chemistry of our everyday world. The very existence of atoms depends on forces and particles deep inside them. The objects that astronomers study – planets, stars and galaxies – are controlled by the force of gravity. And everything takes place in the arena of an expanding universe, whose properties were imprinted into it at the time of the initial Big Bang.

Science advances by discerning patterns and regularities in nature, so that more and more phenomena can be subsumed into general categories and laws. Theorists aim to encapsulate the essence of the physical laws in a unified set of equations,

and a few numbers. There is still some way to go, but progress is remarkable.

This book describes six numbers that now seem especially significant. Two of them relate to the basic forces; two fix the size and overall 'texture' of our universe and determine whether it will continue for ever; and two more fix the properties of space itself:

- The cosmos is so vast because there is one crucially important huge number N in nature, equal to 1,000,000,000,000,000,000,000,000,000,000,000,000,000. This number measures the strength of the electrical forces that hold atoms together, divided by the force of gravity between them. If N had a few less zeros, only a short-lived miniature universe could exist: no creatures could grow larger than insects, and there would be no time for biological evolution.

- Another number, ε, whose value is 0.007, defines how firmly atomic nuclei bind together and how all the atoms on Earth were made. Its value controls the power from the Sun and, more sensitively, how stars transmute hydrogen into all the atoms of the periodic table. Carbon and oxygen are common, whereas gold and uranium are rare, because of what happens in the stars. If ε were 0.006 or 0.008, we could not exist.

- The cosmic number Ω (omega) measures the amount of material in our universe – galaxies, diffuse gas, and 'dark matter'. Ω tells us the relative importance of gravity and expansion energy in the universe. If this ratio were too high relative to a particular 'critical' value, the universe would have collapsed long ago; had it been too low, no galaxies or stars would have formed. The initial expansion speed seems to have been finely tuned.

- Measuring the fourth number, λ (lambda), was the biggest scientific news of 1998. An unsuspected new force – a cosmic 'antigravity' – controls the expansion of our universe,

even though it has no discernible effect on scales less than a billion light-years. It is destined to become ever more dominant over gravity and other forces as our universe becomes ever darker and emptier. Fortunately for us (and very surprisingly to theorists), λ is very small. Otherwise its effect would have stopped galaxies and stars from forming, and cosmic evolution would have been stifled before it could even begin.

- The seeds for all cosmic structures – stars, galaxies and clusters of galaxies – were all imprinted in the Big Bang. The fabric of our universe depends on one number, Q, which represents the ratio of two fundamental energies and is about 1/100,000 in value. If Q were even smaller, the universe would be inert and structureless; if Q were much larger, it would be a violent place, in which no stars or solar systems could survive, dominated by vast black holes.

- The sixth crucial number has been known for centuries, although it's now viewed in a new perspective. It is the number of spatial dimensions in our world, D, and equals three. Life couldn't exist if D were two or four. Time is a fourth dimension, but distinctively different from the others in that it has a built-in arrow: we 'move' only towards the future. Near black holes, space is so warped that light moves in circles, and time can stand still. Furthermore, close to the time of the Big Bang, and also on microscopic scales, space may reveal its deepest underlying structure of all: the vibrations and harmonies of objects called 'superstrings', in a ten-dimensional arena.

Perhaps there are some connections between these numbers. At the moment, however, we cannot predict any one of them from the values of the others. Nor do we know whether some 'theory of everything' will eventually yield a formula that interrelates them, or that specifies them uniquely. I have highlighted these six because each plays a crucial and distinctive role in our universe, and together they determine how

the universe evolves and what its internal potentialities are; moreover, three of them (those that pertain to the large-scale universe) are only now being measured with any precision.

These six numbers constitute a 'recipe' for a universe. Moreover, the outcome is sensitive to their values: if any one of them were to be 'untuned', there would be no stars and no life. Is this tuning just a brute fact, a coincidence? Or is it the providence of a benign Creator? I take the view that it is neither. An infinity of other universes may well exist where the numbers are different. Most would be stillborn or sterile. We could only have emerged (and therefore we naturally now find ourselves) in a universe with the 'right' combination. This realization offers a radically new perspective on our universe, on our place in it, and on the nature of physical laws.