The accidental universe

The accidental universe

P. C. W. DAVIES

Professor of Mathematical Physics, University of Adelaide

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521286923

First published 1982
Reprinted 1983, 1984, 1985, 1986, 1987, 1988, 1990, 1993
Re-issued in this digitally printed version 2009

A catalogue record for this publication is available from the British Library

Library of Congress Catalogue Card Number: 81-21592

ISBN 978-0-521-24212-7 hardback
ISBN 978-0-521-28692-3 paperback

CONTENTS

PREFACE

In spite of the spectacular progress made by physicists in recent years in understanding the basic forces of nature, many fundamental features of the physical world seem to be arbitrary and meaningless. Why are there three space dimensions? Why is gravity so weak? Why is the proton 1836 times heavier than the electron? And so on.

The numerical values that nature has assigned to the fundamental constants, such as the charge on the electron, the mass of the proton, and the Newtonian gravitational constant, may be mysterious, but they are crucially relevant to the structure of the universe that we perceive. As more and more physical systems, from nuclei to galaxies, have become better understood, scientists have begun to realize that many characteristics of these systems are remarkably sensitive to the precise values of the fundamental constants. Had nature opted for a slightly different set of numbers, the world would be a very different place. Probably we would not be here to see it.

More intriguing still, certain crucial structures, such as solar-type stars, depend for their characteristic features on wildly improbable numerical accidents that combine together fundamental constants from distinct branches of physics. And when one goes on to study cosmology – the overall structure and evolution of the universe – incredulity mounts. Recent discoveries about the primeval cosmos oblige us to accept that the expanding universe has been set up in its motion with a cooperation of astonishing precision.

Many of these ‘accidents of nature’ have been known for decades. In the 1930s, Eddington and Dirac were struck by the curious and unexpected concurrence of certain very large numbers computed from atomic physics and cosmology –

apparently unrelated topics. These, and other examples, give the impression of a universe that is delicately balanced in a variety of ways.

The only systematic attempt (outside religion) to explain the extraordinarily contrived appearance of the physical world has developed out of a radical departure from traditional scientific thinking. Called the *anthropic principle*, the idea is to relate basic world features to our own existence as observers. The principle has its origins with great physicists such as Boltzmann, and in recent years has been restated by a number of eminent scientists, including Brandon Carter, Robert Dicke, Freeman Dyson, Stephen Hawking, Martin Rees and John Wheeler. Some of these scientists go so far as to claim that our existence can be used as a biological selection effect, allowing one to actually explain the otherwise mysterious numerical values of the fundamental physical constants.

Although some writers have found the philosophical basis of the anthropic principle objectionable, it is difficult not to be struck by some of the surprisingly fortuitous accidents without which our existence would be impossible. This book surveys some of these accidents and numerical coincidences, and only in the final chapter is the issue of the anthropic principle raised.

Intended for the general reader, the treatment is non-specialist, and will appeal to both scientists and scientifically-inclined laymen alike. Students of philosophy and science will find the text easy to follow in most parts, and will require only a general familiarity with basic physics. Chapter 1 summarizes much of the physics needed for the subsequent chapters. The level corresponds roughly to that of *Scientific American* or *New Scientist*. Where mathematics is used, it almost always involves only elementary algebra.

Much of the treatment presented here follows the pattern of some excellent technical surveys already published. Rather than interrupt the text with references, I have instead given each chapter a bibliography.

I am especially indebted to Dr Bernard Carr and Professor Martin Rees, on whose review article much of this book is based. I have received many helpful comments and suggestions from these authors, as well as from Dr John Barrow, Dr Frank Tipler and Dr John Leslie. I have also benefited from several useful discussions with members of the Physics and Philosophy departments of the University of Canterbury, New Zealand.

P.C.W. Davies

Cambridge University Press
978-0-521-28692-3 - The Accidental Universe
P. C. W. Davies
Frontmatter
More information

NOTE ON UNITS AND NOMENCLATURE

The mathematical relations of most interest in this book are not exact equations, but inequalities or approximate equalities. The symbol $\sim$ is most frequently employed, and means that two quantities are equal to within an order of magnitude or so. For example, $7 \times 10^8 \sim 5 \times 10^9$. Where used in front of a single symbol, $\sim$ means 'of this order': for example $\sim 10^3$ means a number, such as 630 or 2018, that is of the same order of magnitude as 10^3. The symbols $>$ and $<$ mean 'greater than' and 'less than', as usual, while $\gtrsim$ means 'greater than about' a certain number, with a corresponding meaning for $\lesssim$.

Sometimes the symbol $\simeq$ is used. This is the approximate equality sign and is applied when two quantities are equal to within a factor of two or so. Thus $\pi^2 \simeq 10$. Finally $\equiv$ is used to mean 'defined by': for example $\alpha \equiv e^2/4\pi\varepsilon_0\hbar c$ means that α is the shorthand symbol for the quantity $e^2/4\pi\varepsilon_0\hbar c$. Readers who wish to rework the expressions to greater accuracy will find a table of numerical values for the fundamental constants on page 39, and further useful data on page 79.

Throughout the text SI units are used. The reader should be warned that almost all the references cited in the bibliography use either c.g.s. units (especially astronomical works) or special units where all, or some, of the constants $\hbar$, c, G and k are put equal to 1. Because the SI convention for electric charge in free space requires that e^2 is accompanied by $(4\pi\varepsilon_0)^{-1}$, where ε_0 is the permittivity (dielectric constant) of free space, the 4π factors associated with this will be carried through the expressions explicitly, even when other numerical factors and powers of π have been removed as part of the $\sim$

approximation. Moreover, although the style ε_0 is conventional, we shall never have occasion to consider dielectric media, so for compactness the zero subscript on ε will be suppressed.