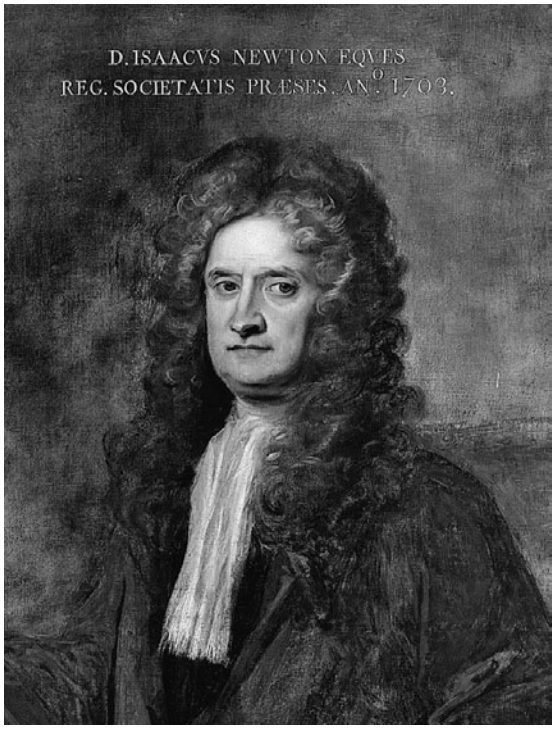
Tides: A scientific history

Throughout history, the prediction of earth's tidal cycles has been extremely important. This book provides a history of the study of the tides over two millennia, from the primitive ideas of the Ancient Greeks to the present sophisticated geophysical techniques which require advanced computer and space technology.

Tidal physics has puzzled some of the world's greatest philosophers, scientists and mathematicians: amongst many others, Galileo, Descartes, Bacon, Kepler, Newton, Bernoulli, Euler, Laplace, Young, Whewell, Airy, Kelvin, G. Darwin, H. Lamb, have all contributed to our understanding of tides. The problem of predicting the astronomical tides of the oceans has now been, in essence, almost completely solved, and so it is a perfect time to reflect on how it was all done from the first vague ideas to the final results. The volume traces the development of the theory, observation and prediction of the tides, and is amply illustrated with diagrams from historical scientific papers, photographs of artefacts, and portraits of some of the subject's leading protagonists.

The history of the tides is in part the history of a broad area of science, and the subject provides insight into the progress of science as a whole: this book will therefore appeal to all those interested in how scientific ideas develop. It will particularly interest those specialists in oceanography, hydrography, geophysics, geodesy, astronomy and navigation whose subjects involve tides.

David Cartwright's long and distinguished research career has taken him from the UK National Institute of Oceanography and Scripps Institute of Oceanography, on to become Assistant Director of the UK Institute of Oceanographic Sciences. On retirement from IOS in 1987, he accepted a Senior Research Associateship at the NASA–Goddard Space Flight Center. He is currently Visiting Research Fellow at Southampton Oceanography Centre, and a consultant on tidal matters to the NASA–Goddard Space Flight Center.



The pathfinders: Sir Isaac Newton (1642–1727) and Marquis Pierre Simon de Laplace (1749–1827). (Both by permission of the President and Council of the Royal Society, London.)

Tides

A SCIENTIFIC HISTORY

David Edgar Cartwright FRS

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Contents

Preface

This book describes the growth of scientific understanding of a phenomenon which is superficially familiar but subtly complex, starting with primitive ideas in the remote past and leading up to sophisticated geophysical relationships which require modern computers and space technology for their evaluation. It is not an encyclopedic review of modern tidal knowledge, but it is the story of how such knowledge came about. It is not a catalogue of every book and paper that has been written about tides, but it includes at least a brief account of every major discovery and most branches of related research, whether they involve physical observations, theory, analysis of data or prediction technique.

Those readers who are themselves historians of science should realise that, unlike the history of physics or astronomy, the history of tidal research during the last two centuries has been very largely neglected. The present work not only summarises the early history which has been treated, at least piecemeal, by others, but it attempts to provide for the first time a basic framework and perspective for the vast area of all post-Newtonian tidal science, whose history is practically unwritten. This framework is mostly based on the published record of scientific papers and reviews, interpreted with specialist understanding of the subject from many years' personal experience of all aspects of tide research. I must, however, leave the *minutiae* of biographies, private correspondence and notebooks to the specialist historian who wishes to focus on a particular period, subject or personality.

Inevitably the subject requires the use of at least some of the terminology of elementary mathematical physics, but I have kept such terminology to the minimum necessary to make work in a wide range of disciplines intelligible to the general scientific reader who understands mathematical language, without trivialising the thought behind it. The essence of what I wish to convey is the historical growth of ideas over the centuries. In general, I have used equations only to express relationships between physical quantities which would be hard

to express succinctly in words. I trust that readers who find a particular section 'difficult' will practise the art of skipping to a more accessible page or chapter in the interest of following the march of scientific history, perhaps to return later when the context has become clearer. I have added appendices and diagrams to some chapters in order to explain unavoidable jargon or to enlarge on some point of theory for those who would appreciate it, without interrupting the main text.

I feel that a few direct quotations and photographic excerpts from the original writings of classic sages convey valuable insight of the 'period flavour' of ideas and the way they were originally expressed. I have used standard English translations where the original writings were in Latin. The one exception is Figure 5.2, photographed directly from Newton's *Principia*, where the illustrated passages formed the first major turning point in our understanding of the tides. Sufficient explanation in English is given in the Figure caption and in the main text. The second major turning point was Laplace's enunciation of his equations of tidal dynamics, and I have displayed in Figure 7.1 an even longer excerpt from Laplace's seminal paper of 1776, in the hope that more readers are able to appreciate the classic French style than understand Latin. French scientists supplied important initiatives at several points in the history of tidal science, especially in the 18th and 19th centuries, and I have seen fit to include photographs of other classic pages of French (Figures 5.4, 6.1–6.3, 10.1, 13.1), which are rarely if ever referred to in modern scientific literature, English or French. At the suggestion of a referee, I have added my own English translation to all French quotations in the text. In return, I hope that English readers will accept the legitimate spelling 'tide-gage' to rhyme with 'green-gage', instead of the more conventional spelling which suggests the sound of 'gauze' or 'gaunt'.

Chapters 1–5 follow progress more or less chronologically, but in Chapters 6–10 I have found it more appropriate to allocate a specific subject to each Chapter, with looser chronological sequence. Chapters 11–15 are firmly in the 20th century (with occasional retrospect) and the increasing pace of research forces narrower time limits with consideration of several subjects making contemporary progress. However, the time intervals stated in some Chapter headings are interpreted with a good deal of elasticity; they are intended merely as a rough guide to the central epoch of the Chapter. The subject matter reaches to about the end of 1995, but I have endeavored to avoid imitating the style of the modern scientific *Review*, with its comprehensive survey of every item of published literature.

Following the usual historical convention, dates of birth and death of scientists are quoted once, where known, at first or nearly their first mention. I am disinclined to quote the names of scientists still living and active at the time of writing (including of course my own name) in an essentially historical context. Chapters 12–15 therefore progressively ascribe the origins of research to institutions rather than to individuals, with a few practically unavoidable exceptions.

The names of the individual authors involved are retrievable from the numbered references.

I have for long felt the historical background to tidal studies to be unjustifiably neglected. I hope that the present work will fill a gap in the literature available to the modern science historian, and that it will also be interesting to those specialists in oceanography, hydrography, geophysics, geodesy, astronomy and navigation whose subjects involve tides, and of course to more general amateurs of earth science.

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Research for this book has been aided by a one-year Research Grant from the Royal Society of London, with the Proudman Oceanographic Laboratory at Bidston Observatory, Birkenhead (a distant successor to the Liverpool Tidal Institute of 1919–1968) named as 'Host Institution'. The Library and Archives at POL provided valuable material for Chapters 11 and 12 in particular, and various staff members gave advice and technical assistance for line-drawings. I have also made extensive use of the National Oceanographic Library at Southampton and of its predecessor at Wormley, Surrey (originally part of the National Institute of Oceanography of 1949–1973 under Sir George Deacon).

Outside oceanography, I have found much useful material in the British Library, Bloomsbury, and in the libraries of the Royal Astronomical Society, London and of the National Maritime Museum, Greenwich. However, my most important source of historic scientific literature before about 1850 has been the Library and Archives of the Royal Society of London, whose staff have always been so helpful. More papers on tides have appeared in the *Philosophical Transactions* and the *Proceedings* of the Royal Society from Volume 1 (1665) onwards than in any other scientific journal in the world.

On the personal level, Dr. Philip Woodworth of POL gave helpful opinions on Chapters 7, 10 and 14; likewise, Professor George Platzman of Chicago on Chapter 15. Professor Willard J. Pierson jr. of CUNY made useful suggestions regarding the early days of satellite altimetry as an oceanographic tool, with which he was closely associated, and general encouragement for the book as a whole. But I am especially grateful to my ex-colleague Richard D. Ray at NASA/Goddard Space Flight Center, who volunteered to read through and criticise the entire text from the point of view of science history. The comments from all these people and from Professor Carl Wunsch of MIT as referee resulted in improvements and additions to the text. Finally, I must thank my wife, Anne-Marie, for cheerfully supporting some 40 Moons of asocial behavior from her spouse.

David E. Cartwright,
Petersfield, Hampshire