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An Introduction to Atmospheric Physics
Second Edition

The new edition of David Andrews' excellent textbook has been significantly revised and expanded. This textbook provides a quantitative introduction to the Earth's atmosphere for intermediate-advanced undergraduate and graduate students. It now includes a new chapter on the physics of climate change which builds upon material introduced in earlier chapters, giving the student a broad understanding of some of the physical concepts underlying this most important and topical subject. In contrast to many other books on atmospheric science, the emphasis is on the underlying physics. Atmospheric applications are developed mainly in the problems given at the end of each chapter. The book is an essential resource for all students of atmospheric physics as part of an atmospheric science, meteorology, physics, Earth science, planetary science, or applied mathematics course.

David Andrews has been a lecturer in physics at Oxford University and a physics tutor at Lady Margaret Hall, Oxford, for 20 years. During this time he has had extensive experience of teaching a wide range of physics courses, including atmospheric physics. This experience has included giving lectures to large student audiences and also giving tutorials to small groups. Tutorials, in particular, have given him insights into the problems that physics students encounter when learning atmospheric physics, and the kinds of topic that excite them. His broad teaching experience has also helped him to introduce students to connections between topics in atmospheric physics and related topics in other areas of physics. He feels that it is particularly important to expose today's physics students to the stimulation and challenges presented by the atmosphere and climate. He has also published a graduate textbook, *Middle Atmosphere Dynamics*, with J. R. Holton and C. B. Leovy (1987, Academic Press). He is a fellow of the Royal Meteorological Society and a member of the Institute of Physics.

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Second Edition

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Preface to the Second Edition

Atmospheric physics has a long history as a serious scientific discipline, extending back at least as far as the late seventeenth century. Today it is a rich and fascinating subject, sustained by detailed global observations and underpinned by solid theoretical foundations. It provides an essential tool for tackling a wide range of environmental questions, on local, regional and global scales. Although the solutions to vital and challenging problems concerning weather forecasting and climate prediction rely heavily on the use of supercomputers, they rely even more on the imaginative application of soundly based physical insights.

This book is intended as an introductory working text for third- or fourth-year undergraduates studying atmospheric physics as part of a physics, meteorology, or earth and planetary sciences degree course. It should also be useful for graduate students who are studying atmospheric physics for the first time and for students of applied mathematics, physical chemistry and engineering who have an interest in the atmosphere. Physics undergraduates, in particular, will discover that a sound understanding of atmospheric physics can be built up in the same quantitative and logical manner as the other areas of physics that they encounter in their courses.

Modern scientific study of the atmosphere draws on many branches of physics. I believe that a balanced introductory course in atmospheric physics should include at least some atmospheric thermodynamics, radiative transfer, atmospheric fluid dynamics and elementary atmospheric chemistry. Armed with a basic understanding of these topics, the interested student will be able to grasp the essential physics behind important issues of current concern – such as how the climate changes in response to increases in greenhouse gases, and why depletion of stratospheric ozone has occurred – as well as more familiar processes such as the formation of raindrops and the development of weather systems.

This book therefore aims to show how basic physical principles can be applied to help us to understand the workings of the Earth's atmosphere. It includes treatments of the topics mentioned in the previous paragraph, plus a few others. Attention is restricted to the troposphere, stratosphere and mesosphere, that is, the region between the ground and about 90 km altitude. Although other planets are seldom mentioned explicitly, many of the topics covered also apply to the atmospheres of Venus and Mars.

In contrast to many other books on atmospheric science, the emphasis in the text is on the *underlying physics*; atmospheric applications are developed mainly in the problems given at the end of each chapter. It is essential that the serious student should attempt some of these problems, to test his or her understanding of the material and to obtain a broader perspective on the subject than can be provided by the text alone. (In some cases important meteorological applications have been omitted because they rely on semi-empirical rules rather than on basic physics; there are excellent meteorology books covering this type of material.) Solutions to the problems are provided on a password-protected website for the benefit of course instructors.

The book assumes a basic knowledge of thermodynamics, electromagnetic radiation and quantum physics, together with some elementary vector calculus, at about the level reached in core physics courses at universities. It does not assume prior knowledge of fluid dynamics – which is frequently (and I believe mistakenly) omitted from core physics courses. Most of the material included here is based on over twenty years' experience teaching atmospheric physics to undergraduate physicists at Oxford University.

This Second Edition includes a new chapter on the physics of climate change, which builds upon material introduced in earlier chapters and aims at giving the student a broad understanding of some of the physical concepts underlying this most important and topical subject. I have also corrected and updated several other chapters, figures and problems.

Course instructors can use the book in its entirety, or can select topics of particular interest to them. However, I would strongly recommend covering most sections of Chapters 2 (thermodynamics), 3 (radiation) and 4 (basic fluid dynamics) as a minimum. Later chapters depend on these three in various ways: for example, Chapter 5 depends heavily on Chapter 4, Chapter 6 requires a little knowledge of Chapter 2, and Chapters 7 and 8 require a good understanding of parts of Chapter 3.

Several colleagues have provided invaluable assistance with this new edition, especially with the new Chapter 8. In particular, Myles Allen has shared many stimulating ideas with me on how the physics of climate change should be taught, though I take full responsibility for any shortcomings in my treatment of the subject. I would also like to acknowledge help and advice from Stephen Blundell, Anu Dudhia, Jonathan Gregory, William Ingram, Guy Peskett, Keith Shine and Philip Stier, and I thank all those colleagues and students who drew my attention to errors in the First Edition. Once again my wife, Kathleen Daly, gave much support and encouragement during the writing process.

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