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The Lazy Universe: An Introduction to the Principle of Least Action

By Jennifer Coopersmith

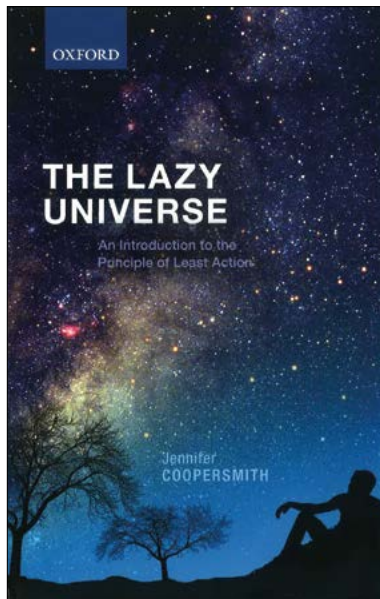
Oxford University Press

With contagious enthusiasm and a sense of humour unusual in this kind of literature, this book by Jennifer Coopersmith deals with the principle of least action or, to be more rigorous, of stationary action. As the author states, this principle defines the tendency of any physical system to seek out the “flattest” region of “space” – with appropriate definitions of the concepts of flatness and space. This is certainly not among the best-known laws of nature, despite its ubiquity in physics and having survived the advent of several scientific revolutions, including special and general relativity and quantum mechanics. The author makes a convincing case for D’Alembert’s principle (as it is often called) as a more insightful and conceptually fertile basis to understand classical mechanics than Newton’s laws. As she points out, Newton and D’Alembert asked very different questions, and in many cases variational mechanics, inspired by the latter, is more natural and insightful than working in Newton’s absolute space, but it can also feel like using a sledgehammer to crack a peanut.

The book starts with a general and very accessible introduction to the principle of least action. Then follows a long and interesting description of the developments that led to the principle as we know it today. The second half of the book delves into Lagrangian and Hamiltonian mechanics, while the final chapter illustrates the relevance of the principle for modern (non-classical) physics, although this theme is also touched upon several times in the preceding chapters.

An important caveat is that this is not a textbook: it should be seen as complementary to, rather than a replacement for, a standard introduction to the topic. For example, the Euler–Lagrange equation is presented but not derived and, in general, mathematical formulae are kept to a bare minimum in the main text. Coopersmith compensates for this with several thorough appendices, which range from classical textbook-like examples to original derivations. She makes a convincing critique of a famous argument by Landau and Lifshitz to demonstrate the dependence of kinetic energy on the square of the speed, and in one of the appendices she develops an interesting alternative explanation.

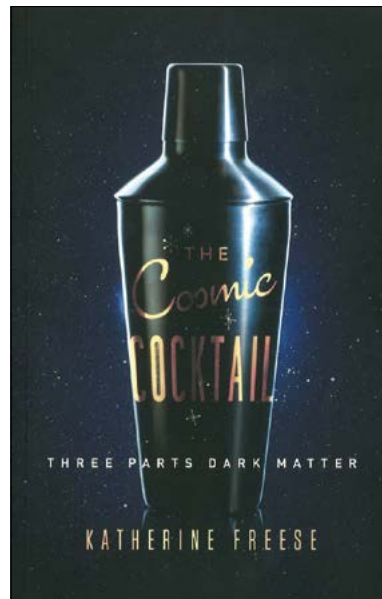
Although the author pays a lot of



credit to *The Variational Principles of Mechanics* by Cornelius Lanczos (written in 1949 and re-edited in 1970), hers is a very different kind of book aimed at a different public. Moreover, the author has developed several original and insightful analogies. For example, she remarks upon how smartphones know their orientation: instead of measuring positions and angles with respect to external (absolute) space, three accelerometers in the phone measure tiny motions in three directions of the local gravity field. This is reminiscent of the methods of variational mechanics.

Notations are coherent throughout the book and clearly explained, and footnotes are used wisely. With an unusual convention that is never made explicit, the author graphically warns the reader when a footnote is witty or humorous, or potentially perceived as far-fetched, by putting the text in parenthesis.

My main criticism concerns the frequent references to distant chapters, which entangle the logical flow. This is a book made for re-reading and, as a result, it might be difficult to follow for readers with little previous knowledge of the topic. Moreover, I was rather baffled by the author’s confession (repeated twice) that she was unable to find a quote by Feynman that she is sure to have read in his *Lectures*. Nevertheless, these minor flaws do not diminish my general appreciation for Coopersmith’s very useful



and well-written book.

The first part is excellent reading for anybody with an interest in the history and philosophy of science. I also recommend the book to students in physics and mathematics who are willing to dig deeper into this subject after taking classes in analytical mechanics, and I believe that it is accessible to any student in STEM disciplines. Practitioners in physics from any sub-discipline will enjoy a refresh and a different point of view that puts their tools of the trade in a broader context.

● Andrea Giammanco, UCLouvain, Louvain-la-Neuve, Belgium.

The Cosmic Cocktail: Three Parts Dark Matter

By Katherine Freese

Princeton University Press

Also available at the CERN bookshop

This book by Katherine Freese, now out in paperback, is aimed at non-professionals interested in dark matter. The hypothesis that the matter in galaxy clusters is dominated by a non-luminous component, and hence is dark, goes back to a paper published in 1933 by the Swiss astronomer Fritz Zwicky, who also coined the term “dark matter”. But it has only been during the last 20 years or so that we have realised that the matter in the universe is dominated by dark matter and that most of it is non-baryonic, i.e. not made of the stuff that makes up all the other matter we know. ➤

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The author explains the observational evidence for dark matter and its relevance for cosmology and particle physics, both in a formal scientific context and also based on her personal adventures as a researcher in this field. I especially enjoyed her detailed, well-informed discussion and evaluation of present dark-matter searches.

The book is structured in nine chapters. The first is a personal introduction, followed by a historical account of the growing evidence for dark matter. Chapter 3 discusses our present understanding of the expanding universe, explaining how much of what we know is due to the very accurate observations of the cosmic microwave background. This is followed by a chapter on Big Bang nucleosynthesis, describing how the first elements beyond hydrogen (deuterium, helium-3, lithium and especially helium-4) were formed in the early universe. In the fifth chapter, the plethora of dark-matter candidates – ranging from axions to WIMPs and primordial black holes – are presented. Chapter 6 is devoted to the LHC at CERN: its four experiments are briefly described and the discovery of the Higgs is recounted. Chapters 6 and 7 are at the heart of the author's own research (the author is a dark-matter theorist and not heavily involved in any particular dark-matter experiments). They discuss the experiments that can be undertaken to detect dark matter, either directly or indirectly or via accelerator experiments. An insightful and impartial discussion of present experiments with tentative positive detections is presented in chapter 8. The final chapter is devoted to dark energy, responsible for the accelerated expansion of the universe. Is it a cosmological constant or vacuum energy with a value that is many orders of magnitude smaller than what we would expect from quantum field theory? Is it a dynamical field or does the beautiful theory of general relativity break down at very large distances?

Even though in some places inaccuracies have slipped in, most explanations are rigorous yet non-technical. In addition to the fascinating subject, the book contains a lot of interesting personal and historical remarks (many of them from the first- or second-hand experience of the author), which are presented in an enthusiastic and funny style. They are one of the characteristics that make this book not only an interesting source of information but also a very enjoyable read.

As a female scientist myself, I appreciated the way the author acknowledges the work of women in science. She presents a picture of a field of research that has been shaped

by many brilliant female scientists, starting from Vera Rubin's investigations of galaxy rotation curves and ending with Elena Aprile's and Laura Baudis' lead in the most advanced direct dark-matter searches. It seems to need a woman to do justice to our outstanding female colleagues.

The fact that less than three years after the first publication of the book some cosmological parameters have shifted and some information about recent experiments is already outdated only tells us that dark matter is a hot topic of very active research. I sincerely hope that the author's gut feeling is correct and the discovery of dark matter is just around the corner.

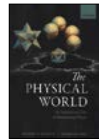
● Ruth Durrer, University of Geneva, Switzerland.

Books received

The Physical World: An Inspirational Tour of Fundamental Physics

By Nicholas Manton and Nicholas Mee

Oxford University Press



Ranging from classical to quantum mechanics, from nuclear to particle physics and cosmology, this book aims to provide an overview of various branches of physics in both a comprehensive and concise fashion. As the authors state, their objective is to offer an inspirational tour of fundamental physics that is accessible to readers with a high-school background in physics and mathematics, and to motivate them to delve deeper into the topics covered.

Key equations are presented and their solutions derived, ensuring that each step is clear. Emphasis is also placed on the use of variational principles in physics.

After introducing some basic ideas and tools in the first chapter, the book presents Newtonian dynamics and the application of Newton's law of gravitation to the motion of bodies in the solar system. Chapter 3 deals with the electromagnetic field and Maxwell's equations. From classical physics, the authors jump to Einstein's revolutionary theory of special relativity and the concept of space–time. Chapters 5 and 6 are devoted to curved space, general relativity and its consequences, including the existence of black holes. The other revolutionary idea of the 20th century, quantum mechanics, is discussed in chapters 7 and 8, while chapter 9 applies this theory to the structure and properties of materials, and explains the fundamental principles of chemistry and solid-state physics. Chapter 10 covers thermodynamics, built on the concepts of temperature and entropy, and gives

special attention to the analysis of black-body radiation. After an overview of nuclear physics (chapter 11), chapter 12 presents particle physics, including a short description of quantum field theory, the Standard Model with the Higgs mechanism and the recent discovery of its related boson. Chapters 13 and 14 are about astrophysics and cosmology, while the final chapter discusses some of the fundamental problems that remain open.

The Photomultiplier Handbook

By A G Wright

Oxford University Press



This volume is a comprehensive handbook aimed primarily at those who use, design or build vacuum photomultipliers.

Drawing on his 40 years of experience as a user and manufacturer, the author wrote it to fill perceived gaps in the existing literature.

Photomultiplier tubes (PMTs) are extremely sensitive light detectors, which multiply the current produced by incident photons by up to 100 million times. Since their invention in the 1930s they have seen huge developments that have increased their performance significantly. PMTs have been and still are extensively applied in physics experiments and their evolution has been shaped by the requirements of the scientific community.

The first group of chapters sets the scene, introducing light-detection techniques and discussing in detail photocathodes – important components of PMTs – and optical interfaces. Since light generation and detection are statistical processes, detectors providing electron multiplication are also considered statistical in their operation. As a consequence, a chapter is dedicated to some theory of statistical processes, which is important to choose, use or design PMTs. The second part of the book deals with all of the important parameters that determine the performance of a PMT, each analysed thoroughly: gain, noise, background, collection and counting efficiency, dynamic range and timing. The effects of environmental conditions on performance are also discussed. The last part is devoted to instrumentation, in particular voltage dividers and electronics for PMTs.

Each chapter concludes with a summary and a comprehensive set of references. Three appendices provide additional useful information.

The book could become a valuable reference for researchers and engineers, and for students working with light sensors and, in particular, photomultipliers.