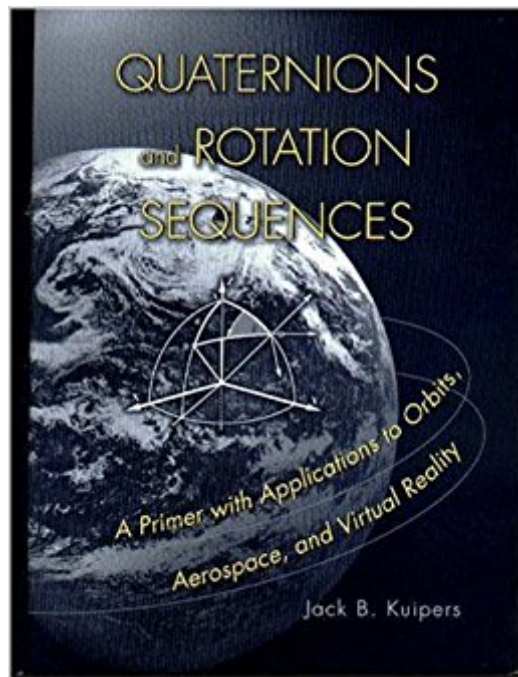




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# Quaternions And Rotation Sequences



## Synopsis

Ever since the Irish mathematician William Rowan Hamilton introduced quaternions in the nineteenth century--a feat he celebrated by carving the founding equations into a stone bridge--mathematicians and engineers have been fascinated by these mathematical objects. Today, they are used in applications as various as describing the geometry of spacetime, guiding the Space Shuttle, and developing computer applications in virtual reality. In this book, J. B. Kuipers introduces quaternions for scientists and engineers who have not encountered them before and shows how they can be used in a variety of practical situations. The book is primarily an exposition of the quaternion, a 4-tuple, and its primary application in a rotation operator. But Kuipers also presents the more conventional and familiar  $3 \times 3$  (9-element) matrix rotation operator. These parallel presentations allow the reader to judge which approaches are preferable for specific applications. The volume is divided into three main parts. The opening chapters present introductory material and establish the book's terminology and notation. The next part presents the mathematical properties of quaternions, including quaternion algebra and geometry. It includes more advanced special topics in spherical trigonometry, along with an introduction to quaternion calculus and perturbation theory, required in many situations involving dynamics and kinematics. In the final section, Kuipers discusses state-of-the-art applications. He presents a six degree-of-freedom electromagnetic position and orientation transducer and concludes by discussing the computer graphics necessary for the development of applications in virtual reality.

## Book Information

Hardcover: 371 pages

Publisher: Princeton University Press (December 14, 1998)

Language: English

ISBN-10: 0691058725

ISBN-13: 978-0691058726

Product Dimensions: 10.3 x 7.8 x 1.4 inches

Shipping Weight: 2.2 pounds

Average Customer Review: 4.3 out of 5 stars 21 customer reviews

Best Sellers Rank: #641,483 in Books (See Top 100 in Books) #37 in [Books > Science & Math > Mathematics > Matrices](#) #972 in [Books > Textbooks > Science & Mathematics > Mathematics > Calculus](#) #1614 in [Books > Science & Math > Mathematics > Pure Mathematics > Calculus](#)

## Customer Reviews

"This book will appeal to anyone with an interest in three-dimensional geometry. It is a competent and comprehensive survey. . . . This book is unique in that it is probably the only modern book to treat quaternions seriously. . . . A valuable asset."--Aeronautical Journal "[A] splendid book . . . everything one could wish for in a primer. It is also beautifully set out with an attractive layout, clear diagrams, and wide margins with explanatory notes where appropriate. It must be strongly recommended to all students of physics, engineering or computer science."--Peter Rowlands, Contemporary Physics

"The text is written in a clear and readable style well suited for students wishing to master fundamental quaternion concepts."--Mark C. Allman, Senior Engineer, The Boeing Company "This is the most complete discussion of quaternions and their applications that I have seen."--Alan C. Tribble, author of A Tribble's Guide to Space

This book is one of the most understandable and down-to-earth mathematics texts I've ever read. For instance, after presenting a new concept, he'll summarize it again in the sideline of the book every time he refers to it for the next twenty pages or so. At first, I was finding myself getting annoyed, and thinking, "What, does he think I'm stupid?" Then I considered the alternative, the terse style of so many mathematical texts that has me regularly flipping between eight different pages trying to put everything together. I stopped complaining and started appreciating Kuipers' approach. Kuipers does assume a certain amount of familiarity with mathematics, but not any knowledge in particular, as he reviews basic matrix multiplication and the like at the beginning of the book. For a topic that can seem daunting (our artist always makes fun of me using seemingly gratuitous big phrases like "spherically interpolated quaternion splines") this book makes it very understandable. If you need to work with computational rotation, for a flight sim, robotics visualization, or (most importantly) for a computer game, I can't recommend this book highly enough!

My graduate school work was in theoretical quantum mechanics, and was especially concentrated in the group properties of rotations. I can honestly say that I would have been twice as effective if I had this reference available then. Kuiper does an outstanding job of pulling together the traditional matrix-based approach to describing rotations with the less-frequently encountered quaternion approach. In doing so, he clearly shows the benefits of the quaternion algebra, especially for

computer systems modeling rigid body rotations and virtual worlds. The exposition is clear, concise, and aimed at the practitioner rather than the theoretician. The examples are taken from classical engineering problems -- a refreshing change from the quantum-mechanical problems I was used to from previous works on the subject. Despite the practical focus, though, there is plenty of material here for those more interested in understanding the minutia of the  $SO(3)$  symmetry group. And unlike most work in this field, he doesn't stop with algebra, but includes the calculus of rotation matrices and quaternions using material on kinematics and dynamics of rigid bodies, celestial mechanics, and rotating reference frames. I give the book my highest recommendation. It should be considered an essential reference work for anyone who encounters rotational problems with any frequency.--Tony Valle

This book is an excellent source for learning about Quaternion. I found it very useful and have used the provided algorithms in codes and they work. The book has a lot of material. However, I would like it even more if it had included more details and derivations for many of the equations.

There are no great books on quaternions; but if you need an introduction, this is the book to have.

Excellent book. Well written. Clear. Thoughtful. Plenty of examples. I would highly recommend it!

This book was a delightful read! If you ever have been curious or puzzled or even terrified by Euler angles then read this text. Many questions will be answered and much knowledge revealed. For a gentle introduction to quaternions this is also a good place to start. The book starts out with a review of complex numbers (in order to emphasize the similarity to quaternions later on), then reviews rotations and matrix methods (sorry but vectors don't do rotations) and then gets into the nitty-gritty of rotations in 2-space and on into 3-space. Three problems involving rotations are discussed in detail. All of this at first with matrix methods and then a nice easy introduction to quaternions is given and these three problems are then handled with quaternions. There is a strong comparison made between complex number arithmetic and quaternion arithmetic, such as norms, conjugates and computation of multiplicative inverses. Ever wonder how far it is between say Dallas and London? And what direction to take to go from one to the other? Well, airplanes do it every day but if I were asked that question on an exam I would have flunked it. Not anymore! The explanation of the answer to such questions is presented in a simple/y delightful manner in this text. There is also stuff here on spherical trigonometry and a description of an orientation and distance sensing system, using the

near field pattern of magnetic dipole antennas. Finally there is discussion of ordinary differential equations and an overview of what is needed for displaying moving objects with computer graphics. Well, that is quite a lot, but the pace is easy going and the text takes this into account by reproducing say the equation or the figure under discussion in the margins as it goes along. A very well executed text, no constant back-paging to figure out what we were talking about! The text has the flavor being written from lecture notes, not the usual cryptic ones, but well expanded and well thought out ones. This leads to some repetition but that's O.K. by me. It makes easy reading for a varied audience. Who is this text aimed at? Well I did find it enlightening even with a background in physics and a rudimentary introduction to Euler angles in an advanced classical mechanics course, but I never had the occasion to use them in my career, so this was a good refresher for me. What do you need to know to get something out of this text? A good grip on the meaning of sines and cosines and the various addition and multiplication formulas or at least know where to look them up. A little knowledge of vectors, the dot and cross product will also be handy even though it is explained in the text. For one chapter a smattering of differential calculus is useful and for another a whole lot of knowledge about differential equations, more than I have is needed. But if you don't have this background you can safely skip these parts and not lose any of the further stuff in the text. You should know how to solve sets of simultaneous equations, inhomogeneous and homogeneous. Matrix operations are all discussed in detail and you can learn them here. You will probably get one of the best introductions to the concept of eigenvectors that you can find anywhere, something that will stick with you for the rest of your career. Well who is it aimed at? Anyone interested in spherical metrology, astronomy, robotics, orbital mechanics, graphical stuff, classical mechanics and so on. A smart high school student could learn a lot here and anyone with a few years of college math/science under his belt will find it profitable as will some, like me, with an advanced degree but no detailed experience in this field. What did I miss in this text? You know how you visualize two component complex numbers as points in the plane and you might think that a 3 component entity might do the same thing with points in 3 dimensional space. Not so if you want it to be an algebra says Frobenius, as mentioned in the book. But there is a short (half page) demonstration that a 3 component hyper-complex number with real coefficients leads immediately to a logical contradiction (e.g. Simmons, Calculus Gems.) This demo would reinforce the need for 4 component quaternions. Why do quaternions describe a rotation in terms of the half angle? Well maybe because you need a quaternion and its conjugate both to describe the rotation. But to me there is an even better source for this oddity, namely the description of a rotation as two successive reflections. Then the origin of half angles shines right out of the geometry (e.g. Snugg, Clifford Algebra, a 2-3 page description in

Chapter 1. Also find here a solution to the spinning top problem using quaternion calculus.) Quaternions do simplify the derivation of many formulas but do they speed up the numerical computations? There is no real discussion of this topic. It might take a couple of chapters and you need to quit somewhere I guess. Criticisms? No, merely matters of taste. The final chapter treats the more general motion of a body: rotations, translations, scaling, perspective and sensitivity factors. Here we run into the puzzle that all this can be easily handled with matrix methods but apparently not with quaternions. The question then arises why bother with quaternions at all, at least for numerical work. I found the text here a little weak. A criticism that I do have is the definition by the author of the reversal of the vector part of the quaternion as its complex conjugate. One property of this conjugate is that the conjugate of the product of two quaternions is the product of the conjugates in reverse order. But this is not true of the usual complex conjugate, the complex conjugate of the product of two matrices, say, is the product of the complex conjugates of each matrix but in the same order. Does this lead to problems in this text? No, complex numbers and matrices or quaternions are never mixed here. But the idea can lead a novice astray in future work. At any rate this is a great text with no typos in the many formulas that I could detect. As I said a Great Read.

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