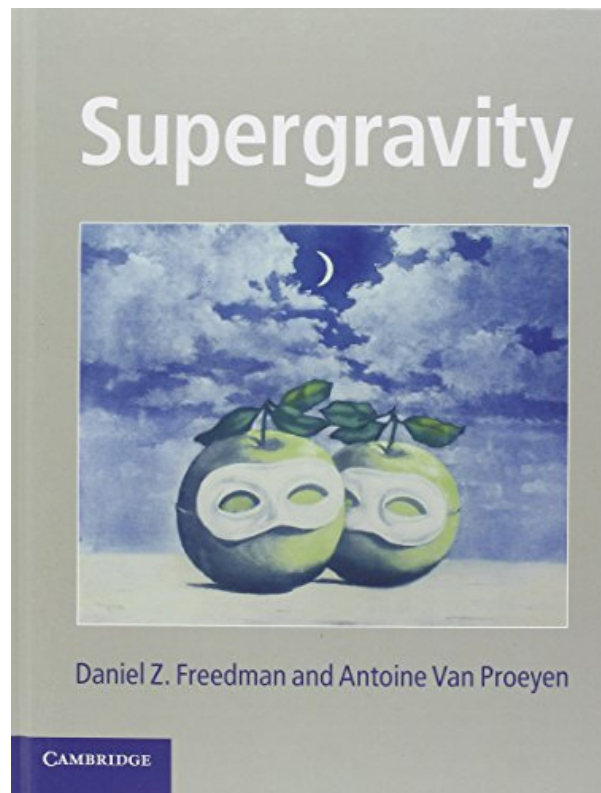


# **SUPERGRAVITY BY DANIEL Z. FREEDMAN, PROFESSOR ANTOINE VAN PROEYEN**



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# Supergravity



Daniel Z. Freedman and Antoine Van Proeyen

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## Review

### Endorsement:

"Over the last four decades, the theory of supergravity has emerged as a central ingredient in the search for the still-elusive unified theory of nature, and has led to many deep results in mathematical physics. This comprehensive, accessible text, written by the pioneers of the subject, fills a gap in the literature and will play an essential role in our future efforts to understand nature."

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Supergravity, together with string theory, is one of the most significant developments in theoretical physics. Written by two of the most respected workers in the field, this is the first-ever authoritative and systematic account of supergravity. The book starts by reviewing aspects of relativistic field theory in Minkowski spacetime. After introducing the relevant ingredients of differential geometry and gravity, some basic supergravity theories (D=4 and D=11) and the main gauge theory tools are explained. In the second half of the book, complex geometry and N=1 and N=2 supergravity theories are covered. Classical solutions and a chapter on AdS/CFT complete the book. Numerous exercises and examples make it ideal for Ph.D. students, and with applications to model building, cosmology and solutions of supergravity theories, it is also invaluable to researchers. A website hosted by the authors, featuring solutions to some exercises and additional reading material, can be found at [www.cambridge.org/supergravity](http://www.cambridge.org/supergravity).

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An excellent overview

By Dr. Lee D. Carlson

Those readers who have prior knowledge of supergravity probably gained it in graduate school when the subject was popular a couple of decades ago. Before superstring theory took off, supergravity theories were one attempt at unification that explicitly had to jointly deal with bosons and fermions when gravity is present. The subject was rife with painstaking calculations and "index gymnastics", and large artist sketchpads were used to keep track of these calculations. The physics behind supergravity theories it seems was taking a back seat, and it was difficult to see if there indeed were much physics at all in these theories. The subject has come a long way since then, even though it seemed to be overshadowed by superstring theories. One of the reasons for its current popularity is the discovery of the AdS/CFT correspondence (which is discussed in this book) and questions from cosmology.

The authors of this book give an excellent overview of the subject, and anyone could gain a lot from reading this book, with that gain also including relevant discussions of the physics. Even for those readers with prior exposure to supergravity theories, there may be a lot of questions that they still need answering. Some of these questions include:

1. Why are there no "consistent" interactions for particles of spin greater than or equal to  $5/2$ ?
2. Is maximal  $N = 8$  supergravity ultraviolet fine to all orders in perturbation theory and where is there a consistent proof of this?
3. Why is the Bogomol'nyi-Prasad-Sommerfield (BPS) property useful in finding "tractable" first-order field equations?
4. Why even bother to incorporate conformal transformations into supergravity? The authors show how the understanding supergravity can be done using the superconformal algebra, and the discussion revolves around showing that conformal symmetry can be gauged. Also, it is shown that gauge fixing of a superconformal gauge multiplet coupled to a chiral multiplet lends
5. What really is the role of auxiliary fields in supergravity?
6. Can Fierz relations, Fierz rearrangements etc be given a more geometric foundation or are they merely bread-and-butter calculation tools in supergravity? In this book Fierz rearrangements are viewed as the key to doing calculations in supergravity, along with Majorana flip relations. The authors contrast the use of Fierz relations in showing supersymmetry in an interacting supersymmetric theory, and in restricting the fermion type in the theory, versus the use of superspace formulations, which they do not use in the book. The exception to this is when they rely on the superspace formulation in obtaining the auxiliary fields for the supersymmetric Yang-Mills vector multiplet.
7. Why are there no interacting field theories in Minkowski space for  $N$  greater than or equal to 9?
8. Does torsion result in any physical effects? The authors show how a 4-point contact term arises in the Feynman diagrams in fermion-fermion scattering amplitudes, and that a fermion theory with torsion is physically inequivalent from a fermion theory without torsion. Readers familiar with "tele-parallel" theories of gravity may find this discussion interesting.
9. Why does local supersymmetry imply that there is no Christoffel connection term in the spin- $3/2$  action?
10. Why is  $D = 11$  the largest space-time dimension allowed for supergravity? The authors give reasons that involve dimensional reduction. The authors refer to  $D = 11$  supergravity as "fixed and unalterable" in that it does not allow any more matter multiplets or cosmological modifications.

Many of these questions are answered in this book, but it also contains special insights that at least for the reviewer were very helpful in improving intuition and insight into supergravity theories. In this regard, some of the highlights of the book that should assist serious readers in their understanding of supergravity include:

1. "Linearly realized" symmetries form  $n$ -dimensional representations of a connected Lie group. Readers familiar with gauge theories and effective field theories will contrast this with "non-linear realized" symmetries.
2. In the classical realm, iterated Lie algebra variations must be compatible with the symmetry



transformations by Poisson brackets of conserved Noether charges, but in quantum physics they must be simply unitary transformations.

3. Lie algebras can be realized as differential operators on functions.
4. Symmetry transformations act directly on fields. Just what objects symmetry transformations act on can be a source of confusion for those beginning their study of supersymmetry, gauge theories, and supergravity.
5. Spinor representations are special representations of the Lorentz group, as distinguished from the defining representation.
6. Majorana representations are very special in supergravity, in that they have real representations in  $D = 2, 3, 4,$  and  $8$ . For generic  $D$  the gamma matrices are complex. One therefore speaks of Majorana spinors fields, and physically the anti-particles are not distinct from the particles. In the book Majorana spinor fields are viewed as being more fundamental than complex Dirac fields. Supergravity and superstring theories in dimension  $10$  are based on Majorana-Weyl spinors.
7. The statement that the Lorentz group is not compact has the implication that there are no finite-dimensional unitary representations and only spatial rotations are anti-hermitian.
8. Fermion spin is the main reason for supersymmetry and supergravity theories. This may seem like a banal statement, but readers can gain an appreciation of just how special fermionic fields are when attempting to calculate with them in high dimensions. A good example of this in the book is the viewpoint that highest rank tensor elements of the Clifford algebra are a link between even and odd dimensions and the "chirality" of fermions. As the authors show, there are methods for obtaining the Clifford algebra in odd dimensions from the Clifford algebra in even dimensions.
9. Supersymmetry requires bilinear expressions in spinors, and "barred" spinors are obtained using Majorana conjugates.
10. The role of 'symplectic' Majorana spinors.
11. To obtain non-trivial dynamics of theories based on Majorana spinors it is crucial that the Majorana fields are anti-commuting Grassmann variables; assuming commutativity will result in no dynamics at all.
12. Any field theory based on a Majorana spinor field can be rewritten in terms of a Weyl field and its complex conjugate.
13. Chiral transformations can be viewed as a kind of generalized  $U(1)$  symmetry that is compatible with the Majorana condition.
14. The difference between "on-shell" and "off-shell" degrees of freedom is explained as the number of helicity states (on-shell) and the number of field components - gauge transformations.
15. Duality acts as a symmetry in abelian gauge theory and in  $D = 4$ , duality transformations are members of the symplectic group.
16. The field tensor in non-abelian gauge theories is not gauge invariant like it is in the abelian case but instead transforms according to the adjoint representations. This fact can be a source of confusion to those who are learning gauge theories for the first time.
17. Supergravity is viewed as the gauge theory of global supersymmetry, and supergravity theories that are interacting need particular types of spinors. This forces the dimension to be less than or equal to  $11$ .
18. Supergravity theories are viewed as "atypical" gauge theories in that the gauge coupling to matter fields is to lowest order in the gravitational coupling only.
19. The connection of 'R-symmetry' with chiral symmetry, in that it is a phase transformation of the fields of the chiral and anti-chiral multiplets.
20. To be meaningful, supergravity must be incorporated into an interacting theory with spins  $1$  or  $3/2$ .
21. The need for using the frame (vierbein) field in theories where the fermions are coupled to gravity. Spinors play the key role here, since they are defined by their special transformation properties under Lorentz transformations.
22. The fact that Killing symmetries are nonlinearly dependent on the fields.
23. The view of general relativity as  $N = 0$  supergravity.
24. The origin of supergravity is viewed as a resulting from a requirement that supersymmetry holds locally,

and conversely that any supersymmetric theory that includes gravity must have supersymmetry holding locally. Thus the local translation parameters must be viewed as diffeomorphisms and this is taken to be a sign that gravity is present.

25. The gauge symmetries in supergravity are given by "soft" algebras, and not Lie algebras. The authors give an interesting discussion of "zilch" symmetries, which are transformation rules that vanish on solutions of the equations of motion, but are not uniquely defined.

26. Curvature constraints imply that spin connections are composite gauge fields, in that they can be written in terms of the frame field and torsion tensor.

27. The discussion on Kahler geometry, which is viewed as arising from the occurrence of multiplets.

28. The fact that potentials in global supersymmetric theories are always positive definite, but in supergravity the gravitinos are gauge fields, and thus contribute negatively to the scalar potential.

29. The need for a positive graviton kinetic energy is viewed as the need for non-compact symmetry groups.

30. The use of Kahler manifolds is readily apparent in the construction of the general action of  $N = 1$  supergravity coupled to chiral and vector multiplets via conformal and superconformal methods. One of these is the embedding Kahler manifold with conformal symmetry, which takes into account the Weyl multiplet and chiral multiplets. The other is the projective Kahler manifold for physical fields that results after gauge fixing and the making use of the field equations. The projective manifold is obtained from the embedding manifold by identifying points that lie on the orbits of vector fields that generate symmetries of the embedding manifold. The scalar fields of  $N = 1$  supergravity are modeled by the mathematical theory of projective Kahler manifolds. The embedding manifold has a Kahler potential and superconformal symmetry requires it to satisfy homogeneity conditions. The vanishing of the cosmological constant is viewed as a geometric condition placed on the Kahler metric. These results come under the topic of Kahler-Hodge manifolds, which are extremely important objects in mathematics also.

31. A toy model is discussed that shows that gravitational effects appear at energy scales much lower than the Planck scale. This is due to the Kahler structure of the supergravity matter action.

32. The role of 'special geometry' in constructing  $N = 2$  supergravity. It has the property that the kinetic terms of scalars, gauge fields, and gauginos are determined from the imaginary parts of a holomorphic function, called a "pre potential". In  $D = 4$ ,  $N = 2$  supergravity there are hypermultiplets which play the role of chiral multiplets, and one obtains a 'hyper-Kahler' manifold and an "Obata" connection. Interestingly, the hypermultiplets are dependent on a metric that is compatible with 3 complex structures. Readers can also see the appearance of symplectic transformations in this context, which are needed to understand the structure of special geometry.

33. The AdS/CFT correspondence is discussed, but this discussion is rather hurried and disjointed, and the authors it might be fair to say are showing a little fatigue in this discussion. There is enough though to get one started in the understanding of this correspondence, but readers will have to have a solid understanding of conformal field theories and string theory to appreciate it. Some of the helpful insights gained from their discussion includes the view of the central charge as measure of the degrees of freedom of a theory, the discussion on holographic renormalization group flows, and why the superconformal  $SU(2,2|4)$  symmetry appears at the quantum level. The latter topic involves the use of "short" representations, which is explained as when the scale dimension of the primary operator is locked at a value determined by its R-symmetry properties. These are to be contrasted with "long" representations, wherein the primary scale dimension is restricted only by a lower bound due to unitarity. The authors view observables in AdS/CFT as being correlation functions of gauge invariant operators which are composites of elementary fields. These operators are classified via irreducible representations of  $SU(2,2|4)$  with the consequence that AdS/CFT is primarily interested in short representations.

Note: This book was read and studied between the dates of November 2012 and April 2013.

0 of 0 people found the following review helpful.

The best pedagogic introduction to off-shell supergravity ideas.

By John Joseph M. Carrasco

Casually referred to in certain circles as 'La Biblia', this is by far the best way of learning off-shell supergravity. Sufficiently clear for self-study. On my quick-reference shelf.

0 of 1 people found the following review helpful.

Good book but not for beginners!

By Vahid Nikoofard

I found this book well-written specially in the first chapters that has a good review of classical field theory. In my opinion the reader must have a good knowledge of Lie groups and Lie algebras before reading this book.

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