

General Relativity: Exercises 2 -Solutions

May 25, 2011

Homework 1: Foucault Pendulum

Equations of parallel transport of vector V are

$$\dot{V}^\mu + \Gamma_{\alpha\beta}^\mu V^\alpha \dot{x}^\beta = 0, \quad (1)$$

where dot means differentiation according to t . Taking Christoffel symbols for 2-spheres and choosing parametrization $t = \phi$ we obtain system of coupled differential equations

$$\dot{V}^\theta - \sin \theta_0 \cos \theta_0 V^\phi = 0, \quad (2)$$

$$\dot{V}^\phi + \cot \theta_0 V^\theta = 0. \quad (3)$$

We can solve this system by differentiating first equation according to ϕ and inserting second equation into it. We obtain differential equation of second order

$$\ddot{V}^\theta + \cos^2 \theta_0 V^\theta = 0, \quad (4)$$

Solution to this differential equation is given by

$$V^\theta = A \cos(\phi \cos \theta_0) + B \sin(\phi \cos \theta_0), \quad (5)$$

where A and B are integration constants which we can determine from condition $V = (V^\theta, V^\phi) = (0, 1)$ at $\phi = 0$. We obtain $A = 1$ and $B = 0$. With knowledge of V^θ we can find (3) to be

$$\dot{V}^\phi = -\cot \theta_0 V^\theta = -\cot \theta_0 \cos[\phi \cos \theta_0], \quad (6)$$

which can be easily integrated and thus we obtain final solution

$$V^\theta = \cos[\phi \cos \theta_0], \quad (7)$$

$$V^\phi = -\frac{\sin[\phi \cos \theta_0]}{\sin \theta_0}. \quad (8)$$

To find angle by which is vector rotated we need

$$\cos \alpha = \frac{V \cdot V'}{|V| |V'|} \quad (9)$$

where V is $V = V(\phi = 0)$ and V' is after parallel transport, i.e. $V' = V(\phi = 2\pi)$ From there we can see that after parallel transport around full circle, i.e. from $\phi = 0$ to $\phi = 2\pi$, vector V will be rotated by angle

$$\alpha = 2\pi \cos \theta_0, \quad (10)$$

what is exactly angle by which Foucault pendulum will be rotated by one day. This is because motion of Foucault pendulum is inertial, i.e. is parallelly transported. In one day it is parallelly transported around full circle (because of rotation of Earth surface).

General Relativity Solutions To Exercises

Amol Sasane



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Solutions of Exercises of General Relativity Simplified & Assessed Taha Sochi, This book contains detailed solutions of all the 606 exercises of my book General Relativity Simplified Assessed These exercises represent an integral part of the original book as they fill many gaps and provide essential extensions and elaborations

Introduction To General Relativity And Cosmology Christian G Boehmer, 2016-10-06 Introduction to General Relativity and Cosmology gives undergraduate students an overview of the fundamental ideas behind the geometric theory of gravitation and spacetime Through pointers on how to modify and generalise Einstein's theory to enhance understanding it provides a link between standard textbook content and current research in the field Chapters present complicated material practically and concisely initially dealing with the mathematical foundations of the theory of relativity in particular differential geometry This is followed by a discussion of the Einstein field equations and their various properties Also given is analysis of the important Schwarzschild solutions followed by application of general relativity to cosmology Questions with fully worked answers are provided at the end of each chapter to aid comprehension and guide learning This pared down textbook is specifically designed for new students looking for a workable simple presentation of some of the key theories in modern physics and mathematics

A Student's Manual for A First Course in General Relativity Robert B. Scott, 2016-01-21 This comprehensive student manual has been designed to accompany the leading textbook by Bernard Schutz A First Course in General Relativity and uses detailed solutions cross referenced to several introductory and more advanced textbooks to enable self learners undergraduates and postgraduates to master general relativity through problem solving The perfect accompaniment to Schutz's textbook this manual guides the reader step by step through over 200 exercises with clear easy to follow derivations It provides detailed solutions to almost half of Schutz's exercises and includes 125 brand new supplementary problems that address the subtle points of each chapter It includes a comprehensive index and collects useful mathematical results such as transformation matrices and Christoffel symbols for commonly studied spacetimes in an appendix Supported by an online table categorising exercises a Maple worksheet and an instructors manual this text provides an invaluable resource for all students and instructors using Schutz's textbook

General Relativity Without Calculus Jose Natario, 2011-07-30 General Relativity Without Calculus offers a compact but mathematically correct introduction to the general theory of relativity assuming only a basic knowledge of high school mathematics and physics Targeted at first year undergraduates and advanced high school students who wish to learn Einstein's theory beyond popular science accounts it covers the basics of special relativity Minkowski space time non Euclidean geometry Newtonian gravity the Schwarzschild solution black holes and cosmology The quick paced style is balanced by over 75 exercises including full solutions allowing readers to test and consolidate their understanding

Student Solutions Manual for Mathematical Methods for Physics and Engineering Kenneth Franklin Riley, Michael Paul Hobson, 2006 The authors present a wide ranging and comprehensive textbook for physical scientists who

need to use the tools of mathematics for practical purposes

Mathematical Introduction To General Relativity, A (Second Edition) Amol Sasane, 2024-12-20 The book aims to give a mathematical presentation of the theory of general relativity that is spacetime geometry based gravitation theory to advanced undergraduate mathematics students Mathematicians will find spacetime physics presented in the definition theorem proof format familiar to them The given precise mathematical definitions of physical notions help avoiding pitfalls especially in the context of spacetime physics describing phenomena that are counter intuitive to everyday experiences In the first part the differential geometry of smooth manifolds which is needed to present the spacetime based gravitation theory is developed from scratch Here many of the illustrating examples are the Lorentzian manifolds which later serve as spacetime models This has the twofold purpose of making the physics forthcoming in the second part relatable and the mathematics learnt in the first part less dry The book uses the modern coordinate free language of semi Riemannian geometry Nevertheless to familiarise the reader with the useful tool of coordinates for computations and to bridge the gap with the physics literature the link to coordinates is made through exercises and via frequent remarks on how the two languages are related In the second part the focus is on physics covering essential material of the 20th century spacetime based view of gravity energy momentum tensor field of matter field equation spacetime examples Newtonian approximation geodesics tests of the theory black holes and cosmological models of the universe Prior knowledge of differential geometry or physics is not assumed The book is intended for self study and the solutions to all the 283 exercises are included The second edition corrects errors from the first edition and includes 60 new exercises 10 new remarks 29 new figures some of which cover auxiliary topics that were omitted in the first edition

Pseudo-Complex General Relativity Peter O. Hess, Mirko Schäfer, Walter Greiner, 2015-10-31 This book explores the role of singularities in general relativity GR The theory predicts that when a sufficient large mass collapses no known force is able to stop it until all mass is concentrated at a point The question arises whether an acceptable physical theory should have a singularity not even a coordinate singularity The appearance of a singularity shows the limitations of the theory In GR this limitation is the strong gravitational force acting near and at a super massive concentration of a central mass First a historical overview is given on former attempts to extend GR which includes Einstein himself all with distinct motivations It will be shown that the only possible algebraic extension is to introduce pseudo complex pc coordinates otherwise for weak gravitational fields non physical ghost solutions appear Thus the need to use pc variables We will see that the theory contains a minimal length with important consequences After that the pc GR is formulated and compared to the former attempts A new variational principle is introduced which requires in the Einstein equations an additional contribution Alternatively the standard variational principle can be applied but one has to introduce a constraint with the same former results The additional contribution will be associated to vacuum fluctuation whose dependence on the radial distance can be approximately obtained using semi classical Quantum Mechanics The main point is that pc GR predicts that mass not only

curves the space but also changes the vacuum structure of the space itself In the following chapters the minimal length will be set to zero due to its smallness Nevertheless the pc GR will keep a remnant of the pc description namely that the appearance of a term which we may call dark energy is inevitable The first application will be discussed in chapter 3 namely solutions of central mass distributions For a non rotating massive object it is the pc Schwarzschild solution for a rotating massive object the pc Kerr solution and for a charged massive object it will be the Reissner Nordström solution This chapter serves to become familiar on how to resolve problems in pc GR and on how to interpret the results One of the main consequences is that we can eliminate the event horizon and thus there will be no black holes The huge massive objects in the center of nearly any galaxy and the so called galactic black holes are within pc GR still there but with the absence of an event horizon Chapter 4 gives another application of the theory namely the Robertson Walker solution which we use to model different outcomes of the evolution of the universe Finally the capability of this theory to predict new phenomena is illustrated

General Relativity Simplified & Assessed Taha Sochi, 2022-08-17 This book is about the general theory of relativity which is concisely labeled as general relativity The book is the result of a rather extensive view to the literature of this theory over most of its lifetime reflecting various stages of its development The book contains 129 solved problems as well as 606 exercises whose detailed solutions are published in another book that accompanies the present book The book also includes a detailed index and many cross references The book can be used as an introduction to general relativity at undergraduate and graduate levels Unlike most other books on general relativity which are mostly dedicated to the presentation justification application and validation of the formalism of the theory and hence rather minor attention is usually paid to the interpretation and epistemology of the theory this book is primarily interested in the interpretative and epistemological aspects of the theory

Lectures on General Relativity A. Papapetrou, 1974-11-30 This book is an elaboration of lecture notes for the graduate course on General Relativity given by the author at Boston University in the spring semester of 1972 It is an introduction to the subject only as the time available for the course was limited The author of an introduction to General Relativity is faced from the beginning with the difficult task of choosing which material to include A general criterion assisting in this choice is provided by the didactic character of the book Those chapters have to be included in priority which will be most useful to the reader in enabling him to understand the methods used in General Relativity the results obtained so far and possibly the problems still to be solved This criterion is not sufficient to ensure a unique choice General Relativity has developed to such a degree that it is impossible to include in an introductory textbook of a reasonable length even a very condensed treatment of all important problems which have been discussed until now and the author is obliged to decide in a more or less subjective manner which of the more recent developments to omit The following lines indicate by means of some examples the kind of choice made in this book

FUNDAMENTALS OF SPECIAL AND GENERAL RELATIVITY, REVISED EDITION KRORI, K. D., 2013-08-01 Relativity apart from quantum mechanics is the

greatest wonder in science unfolded single handedly in the 20th century by Albert Einstein The scientist developed general relativity as a logical sequel to special relativity This comprehensive book presents explication of the conceptual evolution and mathematical derivations of the theories of special and general relativity The book follows an Einsteinian approach while explaining the concepts and the theories of relativity Divided into 14 chapters the revised edition of the book covers elementary concepts of Special relativity as well as the advanced studies on General relativity The recent theories like Kerr geometry Sagnac effect Vaidya geometry Raychaudhuri equation and Gravitation physics vis vis Quantum physics are presented in easy to understand language and simple style In addition to it the book gives an in depth analysis on the applications of advanced theories like Vaidya Krori Barua solution from author s own research works Apart from that the book also discusses some of the isotropic and anisotropic cosmological models in detail The salient topics discussed in the revised edition of the book are extrinsic curvature detection of gravitational waves early universe evolution of a dead star into a white dwarf or a neutron star or a black hole dark matter and dark energy This book is intended for the undergraduate and postgraduate students of Physics and Mathematics **KEY FEATURES** Step by step derivation of equations Easy demagogic approach Review questions to widen the analytical understanding of the students

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Table of Contents General Relativity Solutions To Exercises

1. Understanding the eBook General Relativity Solutions To Exercises
 - The Rise of Digital Reading General Relativity Solutions To Exercises
 - Advantages of eBooks Over Traditional Books
2. Identifying General Relativity Solutions To Exercises
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an General Relativity Solutions To Exercises
 - User-Friendly Interface
4. Exploring eBook Recommendations from General Relativity Solutions To Exercises
 - Personalized Recommendations

- General Relativity Solutions To Exercises User Reviews and Ratings
- General Relativity Solutions To Exercises and Bestseller Lists
- 5. Accessing General Relativity Solutions To Exercises Free and Paid eBooks
 - General Relativity Solutions To Exercises Public Domain eBooks
 - General Relativity Solutions To Exercises eBook Subscription Services
 - General Relativity Solutions To Exercises Budget-Friendly Options
- 6. Navigating General Relativity Solutions To Exercises eBook Formats
 - ePub, PDF, MOBI, and More
 - General Relativity Solutions To Exercises Compatibility with Devices
 - General Relativity Solutions To Exercises Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of General Relativity Solutions To Exercises
 - Highlighting and Note-Taking General Relativity Solutions To Exercises
 - Interactive Elements General Relativity Solutions To Exercises
- 8. Staying Engaged with General Relativity Solutions To Exercises
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers General Relativity Solutions To Exercises
- 9. Balancing eBooks and Physical Books General Relativity Solutions To Exercises
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection General Relativity Solutions To Exercises
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine General Relativity Solutions To Exercises
 - Setting Reading Goals General Relativity Solutions To Exercises
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of General Relativity Solutions To Exercises
 - Fact-Checking eBook Content of General Relativity Solutions To Exercises

- Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
- 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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