CAMBRIDGE
Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

Introduction

This book examines the foundational consistency of quantum mechanics incorporated within relativistic frameworks. Quantum physics remains a perplexing formalism that, although very successful in explaining physical phenomena, poses many philosophical and interpretational questions. Several of the subtleties of quantum physics become more manifest when quantum processes are described using relativistic dynamics. For instance, the successful connection of spin to quantum statistics is a consequence of the consistent incorporation of special relativity into the quantum formalism. There should be similar profound explanations awaiting discovery as gravitating phenomena are successfully incorporated into quantum formulations.

The common theme of this manuscript is the examination of the incorporation of relativistic behaviors upon the foundations of quantum physics. The approach is to keep all formulations as close to observed phenomena as possible, rather than to present a set of speculative models whose primary motivations are internal aesthetics. In the search for the most elegant models of physical phenomena, one must recognize that at its core, physics is an experimental science. The dimensional analysis of fundamental units, taught at the very beginning of introductory physics classes, demonstrates that phenomenology lies at the foundations of physics. Fundamental ideas such as correspondence, the principle of relativity, and complementarity provide direct contact with the physics used to guide this exploration. This manuscript is an elaboration and expansion on previously published work, but also contains some new material.

The target audience of the manuscript includes theoretical physicists and natural philosophers with an interest in the foundational basis of physical models, the experimental consistency of mainstream physics, as well as those internal consistencies required of appropriate models. Readers should have interest in quantum mechanics, general relativity, statistical physics, and the foundations of physics. The content will include concise explanations that should be somewhat self-contained for those

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE

Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

with limited interest in a rigorous involvement with the equations. Supplements are provided as asides within the discourse for readers interested in the natural philosophy and foundations of the involved physics. Within the main text, rigorous, concise derivations are included when needed for the development of the subsequent arguments. Appendices have been added for readers interested in more technical details and background than that provided within the various chapters, or when the inclusion of technical rigor would disrupt the flow of the arguments presented in the text.

No attempt has been made to explain the fundamental kinematic/geometric constants $\hbar$, c, G_N, which provide foundational scales of length, time, and mass/energy. Neither has there been an attempt to explain or relate the fundamental thermodynamic constant k_B which relates the temperature convention to microdynamics, or the fundamental couplings, charges, particle masses, and mixing parameters that provide structure to particle interactions and dynamics. There are only a few discussions on the quantization aspects of dynamic couplings.

The approach of this manuscript is to examine the foundations of quantum physics and general relativity using non-perturbative, singularity-free descriptions of the analytic properties of physical measurables consistent with conservation properties (probability, energy-momentum, charge, etc.), cluster decomposability/classical disentanglement, and relativistic covariance. Such an approach has direct correspondence to well-understood physics, including non-relativistic and classical behaviors.

Part I of the manuscript examines those foundations of quantum physics in flat space-time that are relevant to gravitational physics. Most complicated physical models present dilemmas of which aspects are "real", and which are artifacts of the model. In addition, how one interprets a model or theory can affect how one utilizes its results to construct a more elegant model. For instance, the Copenhagen interpretation assigns elements of reality to a wavefunction that "collapses" into a measured state. Some therefore interpret the system as *being* a wavefunction. The approach presented here assigns a wavefunction only as a descriptive tool, describing those aspects of the theory subject to predictive parameterization. Wavefunctions and quantum fields are therefore considered to be merely tools of calculational convenience. To attribute a more substantial "reality" to these devices requires an assertion that the whole of nature is "contained" within models created by humanity up to this stage of our scientific progression. Such assertions have been made in the past but have yet to withstand the tides of increasing knowledge and scrutiny.

Chapter 1 examines classical concepts of space and time. Galilean relativity and special relativity (with accelerations) are discussed from the foundation upwards. Although quantum concepts are later examined in Chapter 2, coherence properties

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

seem most directly examined using the proper dynamics of an interacting subsystem. This motivated the development of the canonical proper time formulation of relativistic dynamics. Such a formulation is particularly useful for gravitational physics, where the coordinates of fiducial observers or metric parameters are generally not those of inertial quantum systems. Since the space-like surfaces defining fixed proper times of gravitating systems are generally different from those defining fixed coordinate times, there are both subtle and non-trivial differences in dynamic descriptions whose interactions are characterized using the disparate temporal parameterizations. Examples of classical proper-time systems are examined in this chapter.

Chapter 2 examines the fundamentals of quantum mechanics in flat space-time. There remain questions about the extent to which "empty" space-time might have quantum properties that affect gravitational curvature. This chapter examines subtle quantum behaviors, like the zero-point motions of sources and fields, the Casimir effect in electromagnetic interactions, and the phenomenon of entanglement. Lifshitz successfully described the Casimir zero-point energies using the van der Waals attractions between sources, in the absence of the singularities associated with the vacuum of quantized field approaches. Therefore, the general approach of this manuscript is to include sources in any analysis of interacting systems, including gravitating systems. Such an approach avoids some of the conceptual complications associated with assigning zero-point energies to fields in the absence of sources.

Statistical physics as relevant to gravity will be developed in this chapter. In addition, one can examine the quantum mechanics of a self-gravitating mass, using canonical proper-time dynamics. Quantum non-locality can indeed prevent the formation of a singularity (regardless of the size of the mass), for much the same reason that the electron in a hydrogen atom does not have a singular wave function. To end the chapter, the thermal properties observed by a system undergoing proper acceleration will be developed. Several of the effects associated with horizons in gravitational physics are shown to be due primarily to the accelerations needed for an observer to remain fixed with respect to the chosen coordinates.

Chapter 3 develops non-perturbative scattering theory and Lagrangian dynamics. Any formulation of physical phenomena that has its insights derived from perturbative considerations must have renormalizability as a crucial tenet of its applicability. Since there are physical systems that have ill-defined low coupling limits (like superconductors), it is somewhat dubious to consider renormalizability as a universal fundamental property of all laws of nature, despite the obvious usefulness and widespread applicability of the tools of renormalization. For this reason, the chapter will develop non-perturbative descriptions of physical principles. Since all kinematic and dynamic analytical behaviors must be contained within any expression describing a physical process, one expects the formulations

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

to be somewhat complicated. Any non-perturbative formulation should have both non-relativistic and classical correspondence limits. In particular, a viable formulation should incorporate the cluster decomposability necessary for disentanglement within a viable unitary relativistic scattering theory.

The successful incorporation of disentangled clusters in relativistic quantum systems involves separating the off-shell (quantum) dynamics from the Lorentz-frame kinematics. Basically, this means that any formulation should allow each coherent cluster of an interacting system to independently maintain or break its coherence within its proper rest frame as the overall system goes off-shell. That proper rest-frame can be most directly parameterized in terms of the *velocities* (rather than *momenta*) characterizing those frames. Such separation of geometric kinematics from off-shell dynamics will prove quite useful in examining quantum behaviors in gravitating systems. A specific example calculating Compton scattering demonstrating the ambiguity expressed by Wheeler and Feynman's approach to electromagnetic interactions between distant sources and sinks provides valuable insights into the fundamental physics of the quanta of interactions. The chapter ends with a development of Lagrangian dynamics and the calculus of unique extrema. This formulation provides an elegant manner for introducing interactions between fundamental constituents.

Chapter 4 examines the formal incorporation of group theory into quantum mechanics. The transformation properties of fundamental particles or constituents under an extended set of operations (like space-time translations, rotations, Lorentz boosts, etc.) are discussed. Both continuous (proper) transformations, as well as discrete (improper) transformations are examined. The concept of a quantum field satisfying a well-defined equation of motion (in configuration space) is developed. There will be special constraints placed upon quantum fields that satisfy microscopic causality, i.e., that cannot develop communication outside of the light cone (for spacelike separations). This condition associates the spin of a particle with the quantum statistics satisfied by that particle.

Linear spinor fields are very convenient for describing cluster decomposable relativistic quantum systems, since these fields satisfy equations of motion that are linear in the space-time derivatives, and therefore in the energy momentum. The linear dispersion relations are ideal for separating dynamic off-shell behaviors from the kinematics. Therefore, the quantum field theory for (non-interacting) general linear spinor fields is developed. The linear spinor field equation has a form that is natural for generalization into gravitational dynamics.

Part II of the manuscript develops fundamental concepts in the geometrodynamics of gravitation. This part of the manuscript utilizes the insights gained from the flat space-time examples in Part I to construct curvilinear geometries that are consistent with quantum sources, or upon which quantum systems can gravitate.

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

Experiments have demonstrated that the development of spatial-temporal relationships for a gravitating quantum system does not break its coherence, or alternatively, that accelerated motions of an observer do not affect the phase relationships of an inertial system. Such experiments provide verification of the principle of equivalence. One interpretation of experiments that demonstrate the maintenance of quantum coherence of gravitating systems with space-time dependent phases is that space-time coordinates are constructs, i.e., convenient parameters developed by the observer for describing relational aspects of events. A coherence breaking process cannot be involved in localizing the field of a gravitating quantum system. This means that space-time coordinates cannot "bubble up" during such a process in a manner that would break the coherence of a freely falling system being examined in order to establish the phase relationships at differing locations in a gravitational field. Rather, the coordinates of space-time are viewed to be an emergent property of the relational aspects of physical interactions and detections. The very act of creating and measuring temporal and spatial coordinates fixes them, generating a fixed past, but uncertain future.

There is therefore a focus on examining dynamic geometries as expectation-valued constructs of convenience to those choosing a particular coordinate parameterization. In particular, Einstein's equation is taken to describe geometric parameterizations in terms of classical relationships constructed from the expectation values (i.e., averaged behaviors) of quantum constituents $G_{\mu\nu} = \kappa \langle T_{\mu\nu} \rangle$. Those constructs must satisfy geometric consistency and quantum measurement constraints, which can be readily examined on conformal space-time diagrams. Such diagrams were shown to be particularly useful for examining regions of space-time within which space-like coherence can be established, as well as delineating regions of space-time that can have causal influence. One might expect that the construction of conformal space-time diagrams would be more complicated for general curvilinear geometries. A curvilinear geometry is usually described by a metric that describes space-time relationships between events, whether quantum or classical detections. A technique that constructs conformal space-time diagrams using the null trajectories obtained directly from the metric, without needing to solve directly for conformal coordinates, is demonstrated. The construction of such Penrose diagrams is valuable for examining the global causal structures of various geometries. Wherever practical these diagrams have been exhibited for example geometries.

Chapter 5 examines the fundamentals of general relativity, especially as derived from the principle of equivalence. Brief discussions of tensors and curvature are presented, and Einstein's equations are justified and demonstrated to have classical correspondence with Newtonian gravitation. Radially stationary geometries, such as stellar systems and Schwarzschild's geometry, are examined in the classical

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

context, and a notion of gravitational energy is developed. To end the chapter, an axially stationary rotating geometry is briefly examined.

Chapter 6 examines quantum mechanics in curved space-time backgrounds and spatially coherent dynamic geometries. The chapter begins by exploring the quantum dynamics of systems on a background unaffected by those systems. The quantum dynamics of a scalar Klein–Gordon field as a system of considerable familiarity are examined on radially stationary backgrounds. However, by dimensional analysis one can demonstrate that Klein–Gordon fields are not convenient for constructing co-gravitating systems that co-generate the gravitational field. There is a focus upon developing collective disentangled co-gravitating quantum systems consistent with experimental evidence, whose disentangled clusters can generate geometries that correspond to standard general relativity. In particular, substantive gravitating flows can be dimensionally consistent with self-gravitated fields, and can provide well-defined contributory energies to co-gravitating systems. Linear spinor fields are demonstrated to provide a description of micro-physical systems consistent with Dirac spinors that undergo such substantive gravitating flows. To end the chapter, canonical proper-time dynamics are used to develop a self-gravitating system for single and co-gravitating quanta as a tool for demonstrating conformal diagrams for quantum systems.

Chapter 7 examines the physics of horizons and trapping surfaces, especially with regards to dynamic spherically symmetric black holes and black objects. During gravitational collapse, the fundamentals of quantum non-locality are not constrained by the statistical arguments that result in limits upon the quantum degeneracy pressures that can prevent the fall of stellar structures towards a classical singularity. One expects that the quantum measurement constraints associated with microscopic physics should prevent gravitational collapse towards a point singularity much as they prevent the (spatial) collapse of the ground state of electrons in atomic systems, regardless of the strength of attraction. Indeed, using proper-time gravitation with stationary expectation values, one can give credence to such ideas. The energy distribution and global causal structure of a Planck mass–sized stationary non-singular black hole is demonstrated to provide the reader with an intuitive feel for such systems. Ideas involving the temperature and thermodynamics of general stationary systems with finite Planck's constant $\hbar$ are developed, emphasizing expected radiations that would be generally inconsistent with a static geometry. Such considerations suggest that the reader consider utilizing radially dynamic geometries when examining quantum gravitating systems. In particular, the behaviors of quantum fields and co-gravitating quantum clusters on a spatially coherent evaporating black hole are examined in some detail as a means of developing intuitions into the subtleties of co-gravitating quantum systems.

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

The reader is motivated to examine non-singular black objects with temporally transient trapped surfaces (within which any future-seeking causal trajectory must necessarily have decreasing radial coordinate) that never develop a horizon or a space-like center. Such slowly evolving dynamic black objects should appear to have properties quite similar to those of dynamic black holes in the exterior. However, a non-singular geometry provides an unambiguous background for quantum explorations. A black object free of singularities or space-like boundaries is constructed, and a method of constructing non-singular dynamic black holes is likewise demonstrated. The dynamics of information on non-singular transient black geometries is of particular interest. The formation of a horizon for a transient black hole implies that there must be an interior space-like future boundary (the center) near or upon which any interior information must undergo transmutation (or perhaps enter a causally disjoint region of a parallel space-time, a viewpoint that is not here advocated), whether that boundary is singular or not. However, a temporally transient black object will manifest a *temporary* trapping region in the space-time, within which interior information can eventually escape in its original form (at least in principle). The radiations that leak away the interior energy of a black object carry quanta and information that change the local geometry. This geometry-changing information from an evaporating black object has likely been transmuted by the interior microscopic physics (generating the radiation) that reflects the loss of entanglement information in the exterior (using complementarity). Thus, any information retention associated with the collapsed geometry of a temporally transient black object should mimic that of a transient black hole. However, not all information that has traversed the interior need be transmuted, since the center is time-like. An entangled pair of massless particles produced at the evaporating surface of a black object are propagated until later detection by exterior observers, as an example of the maintenance of coherence information by dynamic geometries.

Chapter 8 examines cosmology and the Big Bang. The equations of standard cosmology are motivated, and in particular, the subtleties of the existence of a persistent dark energy are briefly discussed in regards to the de Sitter cosmology of a positive cosmological constant. One outstanding concern of the standard cosmological model is how the geometry transitions into and away from the thermal descriptions of the Friedmann–Robertson–Walker geometries that model the known behaviors of the Big Bang so well. For this reason, a dynamic de Sitter cosmology is developed that allows a smooth transition from an early inflation or system with coherence of cosmological scale, through a thermal expansion, towards a remnant dark energy consistent with standard cosmology. The description of the dynamics of the cosmology is expressed completely in terms of the physical densities and pressures, irrespective of the behaviors of the geometric scales. The resultant global

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE

Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

conformal diagram has one time-like surface (the center) and two space-like surfaces (one past and one future) as its boundaries, consistent with the cosmological principle, and the geometry manifests horizons consistent with a persistent dark energy.

The developed description is particularly useful for parameterizing the early microscopic physics that results in thermalization of the primordial cosmology and "reheating". The spatial coordinates are convenient for describing the scales of microscopic physics, rather than those of the expanding co-moving (geometrically stationary) centers of gravitational clusters. The propagation of cosmological fluctuations are concisely described, and a brief introduction to the acoustic waves of the cosmological energy density is given. Arguments that associate the microphysics of the dark energy with the scale of the fluctuations in the cosmic microwave background radiation are presented. The chapter ends with some discussions on the nature of time in cosmology, especially with regards to the likely recurrences that are associated with any system of finite entropy. Such a finite entropy is a characteristic of the horizon of finite area associated with a remnant dark energy. The consequences of cosmological recurrences are perplexing and intriguing.

The final chapter examines gravitating systems with microscopic interactions. Electromagnetism, which is probably the most understood of interactions, serves as an exemplar of how a micro-physical coupling modifies a geometry. For this reason, Maxwell's equations on a general curvilinear geometry, and in particularly on one with orthogonal coordinates, are explicitly demonstrated. Subsequently, the geometry of a radially stationary charge is developed for radially stationary geometries. The features of a classical charged stationary black hole are briefly discussed. In order to examine the properties of a non-singular stationary charged geometry, the equations for a canonical proper self-gravitating charged system are developed. The modification of the energy density for this system is shown to be as expected due to the electromagnetic self-interaction.

Of particular relevance to this text is the development of gravitating interacting linear spinor fields. The group structure of these fields is particularly well-suited for providing a micro-physical motivation for the behaviors of spinors in gravitational environments described using curvilinear coordinates. This occurs because the algebra of the non-commuting operators of the extended Lorentz group generate the space-time metric. The group algebra of the complete extended Poincaré transformation expands the algebra of a standard Lie transformation group precisely in a manner that incorporates curvilinear coordinate transformations. Special coordinates consistent with the principle of equivalence are derived directly from the group parameters. This is suggestive of some fundamental significance of how the algebra of these fields includes coordinate transformations consistent with the principles of general relativity.

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

Part I

Galilean and special relativity

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-107-00840-3 — Foundations of Quantum Gravity
James Lindesay
Excerpt
More Information

1

Classical special relativity

1.1 Foundations of special relativity

The special theory of relativity has had a profound impact upon notions of time and space within the scientific and philosophic communities. This well-established model of local coordinate transformations in the universe is built upon two fundamental postulates:

- *The principle of relativity*: the laws of physics apply in all inertial reference systems;
- *The universality of the speed of light*: the speed of light in a vacuum is the same for all inertial observers, regardless of the motion of the source or observer.

The principle of relativity is not unique to the special theory of relativity; indeed it is assumed within Galilean relativity. However, if the equations of electrodynamics described by Maxwell's equations describe laws of nature, then the second postulate immediately follows from the first, since Maxwell's equations predict a universal speed of propagation of electromagnetic waves in a vacuum. The consequences of these postulates will be developed briefly.

1.1.1 Lorentz transformations

One of the most direct routes towards developing the transformations satisfying the postulates of special relativity involves examining the distance traveled by a propagating light pulse: $(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2 = (\Delta ct)^2$. One can conveniently define a *space-time interval*, Δs which takes on the invariant value zero for *any* propagating light pulse:

$$\Delta s^2 = (\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2 - (\Delta ct)^2. \tag{1.1}$$

The set of transformations that leave this interval invariant are the *Lorentz transformations*. These transformations are an extension of the subset of transformations

© in this web service Cambridge University Press & Assessment www.cambridge.org