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Vesselin Petkov

Seven Fundamental Concepts in Spacetime Physics

Second Edition

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To my wife Svetla and our son Vesselin (Jr)
for their unconditional love and support

Preface to the Second Edition

There are two main reasons for the second edition of the book. First, despite positive reviews of the first edition and constructive discussions with colleagues, especially at the sixth spacetime conference (September 2022) and at the third Minkowski Meeting (September 2023), it became clear that elaborations on a number of complex and counter-intuitive explanations are necessary mostly in five chapters (Chaps. 2 and 3 needed only some small changes). Second, to reflect in the corresponding chapters relevant papers and books that appeared after the publication of the first edition, particularly the books *Physics of Gravitational Waves: Sources and Detection Methods*[1] and *Regular Black Holes: Towards a New Paradigm of Gravitational Collapse*.[2]

The first three chapters (mostly Chap. 1) contain additional explanations and clarifications, prompted by reviews of and reactions to the first edition, which will prove helpful, I hope, for the proper understanding of the discussed concepts. To emphasize even further (i) the essence of Minkowski's explanation of length contraction and (ii) its importance for the adequate understanding of the nature of spacetime, Fig. 1.9 and the corresponding explanation were added in Chap. 1. As Chap. 1 contains a quote from Hermann Weyl, where he suggests that it is the consciousness which creates our feeling that time flows, a second Appendix "Ancient Logical Arguments Against the Everyday View of Time" was added, where it is shown that the same idea had been discussed in ancient philosophy and later.

The fourth chapter (on relativistic mass) now includes an authoritative statement of what the accepted definition of mass is. Such a statement turned out to be an essential part of any discussion of mass, because physicists, who reject the concept of relativistic mass, have been employing, almost explicitly, an inadequate everyday notion of mass—as quantity of matter—including in discussions after the publication of the first edition. The use of this inadequate notion of mass has been causing

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[1] A. Kenath, C. Sivaram, *Physics of Gravitational Waves: Sources and Detection Methods* (Springer 2023).

[2] C. Bambi (ed.), *Regular Black Holes: Towards a New Paradigm of Gravitational Collapse* (Springer 2023).

most objections to the concept of relativistic mass. That is why Max Born's explicit warning about the danger of improper understanding of mass in relativity has been added to the chapter[3]:

> In ordinary language the word *mass* denotes something like amount of substance or quantity of matter, these concepts themselves being defined no further... In physics, however, as we must very strongly emphasize, the word *mass* has no meaning other than... the measure of the resistance of a body to changes of velocity.

Also added to the chapter is Feynman's brilliant concise explanation[4] of both the role of relativistic mass in physics and its experimental confirmation. Reading this explanation makes one wonder whether the controversy over relativistic mass would have occurred if Feynman had been alive.

The fifth chapter (on gravitation) contains a further emphasis on the full explanation of all gravitational phenomena (following Minkowski's program of geometrizing physics) as nothing more than manifestations of the non-Euclidean geometry of spacetime without the need to assume that gravitation is a physical interaction, confirming Eddington's 1921 observation that "gravitation as a separate agency becomes unnecessary."[5] Also added is an explanation of why only loop quantum gravity (LQG) makes a relevant effort to unify general relativity and quantum physics—LQG is rigorously based on the mathematical formalism of general relativity (gravitation = spacetime geometry) without trying to modify it in order to make it amenable to quantization. This is precisely what distinguishes LQG from the other approaches to create a theory of quantum gravity—LQG quantizes the (curved) spacetime itself, not the regarded as self-evident gravitational interaction.

The sixth chapter (on gravitational waves) contains a more detailed elaboration (also prompted by comments on the first edition and latest publications on the subject) of the explanation of why no gravitational waves are emitted by inspiraling stars in binary systems *before* they collide and merge. It is specifically stressed that in general relativity it is impossible to have the following two statements both correct—(i) stars (modeled as point masses) in binary system are *geodesic* worldlines and (ii) inspiraling stars in binary systems emit gravitational waves *before* they collide. The reason is that in general relativity, a body, represented by a geodesic worldline, does not emit gravitational waves. Gravitational waves are emitted only when the stars' worldlines are not geodesic (i.e., when the stars are subjected to *absolute acceleration* as Einstein demonstrated), that is, when they collide. When the stars are realistically regarded as extended bodies, weak gravitational waves are emitted before the collision, but they originate from strong tidal effects, not from the *relative motion* of the stars as often and misleadingly stated.

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[3] Max Born, *Einstein's Theory of Relativity* (Dover Publications, New York 1965), p. 33.

[4] *The Feynman Lectures on Physics*. The New Millennium Edition. Vol. 1 (Basic Books, New York 2010), p. 15-9. See also Sect. 16-4 Relativistic mass.

[5] A. S. Eddington, The Relativity of Time, *Nature* **106**, 802–804 (17 February 1921), reprinted in: A. S. Eddington, *The Theory of Relativity and its Influence on Scientific Thought: Selected Works on the Implications of Relativity* (Minkowski Institute Press, Montreal 2015) pp. 27–30, p. 30.

The seventh chapter (on black holes) is expanded with a more detailed discussion (again prompted by comments on the first edition) of the term "asymptotically," which is sometimes used in the explanation of the formation of black holes for us (as distant observers). It is explained that the term leads to confusion, because it hides the real problem and, by the same argument (that black holes somehow form "asymptotically"), it implies that, if light asymptotically approaches the event horizon, it will reach it and eventually escape (which is not the accepted understanding). In any case, if black holes do form asymptotically, then, by absolutely the same logic, the event horizon will be as bright as a star.

I would like to acknowledge many helpful discussions (mostly on issues covered in Chaps. 1, 4, 5 and 7) with colleagues who attended the sixth spacetime conference (12–15 September 2022, Albena, Bulgaria) and the third Minkowski meeting (11–14 September 2023, Albena, Bulgaria).

I owe special thanks to Robert Geroch for his constructive criticism and for many insightful discussions on most of the concepts examined in the first edition of this small book.

Finally, I would like to thank the Springer Executive Editor Dr. Angela Lahee for her exemplary professionalism.

Montreal, Canada
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Vesselin Petkov

Preface to the First Edition[6]

The main reason for writing about the seven selected fundamental concepts in spacetime physics—spacetime, inertial and accelerated motion in spacetime physics, origin and nature of inertia in spacetime physics, relativistic mass, gravitation, gravitational waves, and black holes—is that their present understanding does not appear to reflect adequately and fully the deep ideas and even the mathematical formalism of spacetime physics initially introduced by Hermann Minkowski for flat spacetime and developed by Albert Einstein for curved spacetime. The second reason for writing about these fundamental concepts by discussing the problems with them is to express not only my worry (I know I am not alone) that fundamental physics might not have been heading in the right direction especially in the 21st century.

Whether or not it is explicitly admitted, it is a fact that in the last several decades there have been no major breakthroughs in fundamental physics as revolutionary as the theory of relativity (the discovery of the spacetime structure of the world) and quantum mechanics.[7] This is particularly difficult to explain given the efforts of many brilliant physicists and the unprecedented advancements in applied physics and technology which made it possible to increase enormously the precision of experiments that can test new hypotheses in the search for even more fundamental physics.

I think the most probable reason for the lack of major advancements in fundamental physics is that the art of doing physics, inherited from such giants of scientific thought as Galileo, Newton, Maxwell, Einstein, Minkowski and the founding fathers of quantum mechanics, does not appear to have been fully and creatively followed. It seems to me that three meta-theoretical issues might have been behind the inability even of some of the most talented physicists to make revolutionary contributions to

[6] This Preface was updated in the second edition.

[7] From time to time, including at the last month's (11–14 September 2023) third Minkowski meeting (held in the famous Black Sea resort Albena, near Varna in Bulgaria), some colleagues have been trying to question this (unquestionable, not only in my view) statement by giving different examples of theoretical advancements, which in all cases turn out to be nothing deeper than merely further developments of the quantum and the spacetime ideas.

the never ending efforts to achieve a more profound understanding of the physical world.

1. Failure to recognize the need to extract from the accepted physical theories, and particularly from the existing unambiguous experimental evidence, some foundational (*true*) knowledge that can serve as the basis on which future theories should be built. Such knowledge, comprising seeds of *true* information about features of the physical world, rigorously confirmed by experiment, can indeed form un unshakable foundation of fundamental physics because it cannot be challenged by future experiments since experiments do not contradict one another.

The lack of such, explicitly accepted, foundational knowledge hampers the advancement of fundamental physics in different ways; for instance, sometimes it results in virtually wasting a lot of intellectual potential by developing theoretical models and even theories that contradict the already existing and accepted physical knowledge. For example, mostly prompted by the attempts the create a theory of quantum gravity, there have been proposals for alternative theories of gravitation containing the concept of gravitational force, whereas *it is an experimental fact that such a force does not exist in Nature* (see Chapter 5); another example is even the Hamiltonian formulation of general relativity which *involves a preferred time, whereas there is no such thing in Nature.*

An integral and important role of established foundational knowledge is to identify research directions (like the two examples above) that should be *excluded*. Excluding research directions is nothing new in science (e.g., *perpetuum-mobile*-related research) but should be employed more rigorously in order intellectual efforts, time and funds be focused on promising novel ideas, which do not contradict the accumulated foundational knowledge.

2. Inadequate scientific philosophy or perhaps even lack of scientific philosophy,[8] i.e., lack of true understanding of the *nature of physical theories*, which is a necessary condition not only for making a scientific discovery but also for productive research in fundamental physics. For example, part of the art of doing physics is to identify what in the mathematical formalism of fundamental physics is, as some physicists say, "just a description" (like the Newtonian, Lagrangian and Hamiltonian formulations of classical mechanics) and what represents entities in the physical

[8] The present situation is sometimes even worse—some physicists appear to think they do not need in their research any scientific philosophy (i.e., a system of guiding meta-theoretical principles such as the understanding of physical theories *not* as "just descriptions," but as *adequately* representing features of the physical world). This is an unfortunate misconception—as explained in Chapter 1 an inadequate (not just lack of) scientific philosophy can prevent even great scientists such as Poincaré from making a discovery (Thibault Damour, ref. 8 in Chapter 1):

> The sterility of Poincaré's scientific philosophy: complete and utter "conventionality" … stopped him from taking seriously, and developing as a physicist, the space-time structure which he was the first to discover.