Philosophical Aspects of Quantum Field Theory on Curved Spacetime (L8)

Non-Examinable (Part III level)

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This is a sequel to the Michaelmas Term course, 'Philosophical Aspects of Quantum Fields'. But that course is not a formal pre-requisite. The content of the course will be moulded by students' interests. But we expect to cover the following topics, often using ideas from algebraic quantum theory:
(a) the Unruh effect: roughly, that an observer accelerating through the vacuum state of a free quantum field on Minkowski spacetime sees—not *no* particles—but a thermal bath of particles (at a temperature that depends on the observer's acceleration); this will invoke ideas, both technical and interpretative, from the Michaelmas Term course;
(b) the formulation of quantum field theory on curved spacetimes, including generalizations of the Unruh effect to curved spacetime;
(c) thermal radiation from black holes (the Hawking effect), with an emphasis on interpretative aspects.

We may also discuss the recent philosophical literature about testing black hole radiation on analogue systems.

Prerequisites

There are no formal prerequisites. But of course, some familiarity with quantum field theory and general relativity will be essential. Familiarity with the Michaelmas Term course, 'Philosophical Aspects of Quantum Fields', and the Lent Term course on Black Holes, will be helpful.

Preliminary Reading

This is the same list as for the Michaelmas Term course, 'Philosophical Aspects of Quantum Fields'. It is approximately in order of increasing difficulty.

1. S. Weinberg (1997), 'What is Quantum Field Theory, and What Did We Think It Is?'. Available online at: http://arxiv.org/abs/hep-th/9702027 and in T. Cao, (ed.) *The Conceptual Foundations of Quantum Field Theory*. Cambridge University Press, 1999.

2. D. Wallace (2006), 'In defense of naiveté: The conceptual status of Lagrangian quantum field theory', *Synthese*, **151** (1):33-80, 2006. Available online at: http://arxiv.org/pdf/quant-ph/0112148v1

3. D. Wallace (2001), 'Emergence of particles from bosonic quantum field theory'. Available online at: http://arxiv.org/abs/quant-ph/0112149

4. L. Ruetsche, *Interpreting Quantum Theories*: Chapters 4 to 8 for algebraic methods and their interpretation; Chapters 9 to 11 for field and particle aspects. Oxford University Press, 2011.

Literature

For both the Unruh effect and radiation from black holes, item 1 is a good introduction. For the physics of both the Unruh effect and quantum field theory on curved spacetime (including radiation from black holes), we will mainly use the books listed in item 2, which are approximately in order of increasing difficulty. For philosophical aspects, we will discuss, for example: (i) for the Unruh effect, the articles listed in item 3; and (ii) for radiation from black holes, the articles listed in item 4.

1. Lambert, P. (2013), 'Introduction to black hole evaporation', *Proceedings of Science*, gr-qc: 1310.8312

2. (1): Carroll, S. (2019), *Spacetime and Geometry*, Cambridge University Press; Chapter 9.
   (2): N. Birrell and P. Davies *Quantum Fields in Curved Space*, Cambridge University Press 1984, Chapters 1 to 4.
   (3): Fulling, S. *Aspects of quantum field theory in curved spacetime*, LMS Student Texts 17, Cambridge University Press 1989, up to Chapter 6.
   (4): Parker, L. and Toms, D. (2009), *Quantum Field Theory in Curved Spacetime*, Cambridge University Press; Chapters 1-4.
   (5): Wald, R. (1994), *Quantum field theory in curved spacetime and black hole thermodynamics*, Chicago University Press

3. (1): Clifton, R. and H. Halvorson (2001), 'Are Rindler quanta real? Inequivalent particle concepts in quantum field theory', *British Journal for Philosophy of Science*, **52**, pp 417-470. especially Sections 1, 2.1, 2.2, 3.1, 3.2. Available online at: http://arxiv.org/abs/quant-ph/0008030 Reprinted as Chapter 9 in R. Clifton *Quantum Entanglements*, ed. J. Butterfield and H. Halvorson, Oxford University Press 2004.
   (2): Clifton, R. and H. Halvorson (2001a), 'Entanglement and opens systems in algebraic QFT', *Studies in History and Philosophy of Physics* **32**, 1-31.
   (3): Earman, J. (2011), 'The Unruh Effect for Philosophers', *Studies in History and Philosophy of Physics* **42** 81-97

4. (1): Wallace, D. (2018), 'The case for black hole thermodynamics Part I: Phenomenological thermodynamics', *Studies in History and Philosophy of Modern Physics* **64** 52-67.
   (2): Wallace, D. (2019), 'The case for black hole thermodynamics Part II: Statistical mechanics', *Studies in History and Philosophy of Modern Physics* **66** 103-117.
   (3): Wallace, D. (2017), 'Why Black Hole Information Loss is Paradoxical', available at https://arxiv.org/abs/1710.03783

Additional support

One or two Part III essays will be offered in conjunction with this course.