Further Topics in Philosophy of Quantum Field Theory (L8)

Non-Examinable (Part III Level)

J. Butterfield and B. Roberts

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 CPT theorem: roughly, that a Lorentz-invariant quantum field theory must be invariant under the combined operations of charge-conjugation, parity and time-reversal;
(b) 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);
(c) quantum field theory on curved spacetime, especially generalizations of the Unruh effect to curved spacetime, and thermal radiation from black holes (the Hawking effect).

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

Pre-requisites

There are no formal prerequisites. But of course, some familiarity with quantum field theory will be essential; and familiarity with the Michaelmas Term course, 'Philosophical Aspects of Quantum Fields', 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*: especially up to Chapter 9. Oxford University Press, 2011.

Literature

For the CPT theorem, item 1 will be our main source. For both the Unruh effect and radiation from black holes, item 2 is a good introduction. For details of the Unruh effect, we will mainly use: (i) for the physics, the books listed in item 3, which are approximately in order of increasing difficulty, and which also deal with black hole evaporation; (ii) for the philosophy, the articles listed in item 4. For philosophical discussion of radiation from black holes, our main source will be Wallace's papers in item 5.

1. Swanson, N. (2019), 'Deciphering the algebraic CPT theorem', *Studies in History and Philosophy of Modern Physics* **68** 106-125. Available at: http://philsci-archive.pitt.edu/16138/

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

3. (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

4. (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

5. (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.