LPS 241: Gauge Theories (Fall 2012)
Draft Syllabus of September 23, 2012

Instructor: Jim Weatherall
E-mail: weatherj@uci.edu
Office: SST 781
Seminar: Th 2:00-5:00 in SST 777
Office Hours: Tu 2:00-4:00 and by appointment

Description: Our most fundamental theories of matter and its interactions are members of a class of physical theories known as (quantum) gauge theories. This course will address the mathematical and philosophical foundations of these theories by focusing on the foundations of classical field theory, in which context many of the most important conceptual questions concerning gauge theories arise without the additional complications associated with quantum theories. The first four weeks of the course will cover mostly mathematical topics in differential geometry and mathematical physics (smooth manifolds, tensor fields, fiber bundles, Lie groups and principal bundles, Lagrangian field theory) needed to understand the foundations of classical field theories. The second half of the course will cover philosophical questions related to these theories, including questions concerning the nature and origin of gauge symmetry, interpretations of gauge quantities (including issues related to locality and separability), and symmetry breaking.

Audience: This course is a graduate seminar. Graduate students with appropriate backgrounds in physics, mathematics, and/or philosophy are welcome.

Course Website: http://eee.uci.edu/12f/66339

Principal Course Books:
Symmetries in Physics, edited by Katherine Brading and Elena Castellani (Cambridge University Press, 2003; ISBN: 0521821371)
Gauging What's Real, by Richard Healey (Oxford University Press, 2007; ISBN: 0199287961)
The Metaphysics Within Physics, by Tim Maudlin (Oxford University Press, 2007; ISBN: 0199218218)
Space, Time, and Stuff, by Frank Arntzenius (Oxford University Press, 2012; ISBN: 0199696608)

Recommended Supplemental Texts:
Topics in the Foundations of General Relativity and Newtonian Gravitation Theory, by David Malament (University of Chicago Press, 2012; ISBN: 0226502457)
Differential Geometry, by Robert Geroch (Unpublished lecture notes, 1972)[1]
Topology and Geometry for Physics, by Helmut Eschrig (Springer-Verlag, 2011; ISBN: 364214700)
Introduction to Smooth Manifolds, by John M. Lee (Springer-Verlag, 2003; ISBN: 0387954481)
Fiber Bundle Techniques in Gauge Theories, by Meinhard Mayer and Wolfgang Dreschler (Springer-Verlag, 1977; ISBN: 0387083502)
Preparation for Gauge Theory, by George Svetlichny (arXiv:math-ph/9902027 v3, 1999)

Notes on Readings: The first four weeks of the course will be taught from my lecture notes, which I will make available as we go. However, for various reasons it is useful to have alternative presentations to turn to. The supplemental texts listed above are all excellent books/lecture notes on the topics at hand that are readily available for free online, either through UCI's institutional access to SpringerLink or because the author has posted them. The course website has links to each of these. If you are looking for still more background, my lecture notes will have moderately extensive references. Regarding the more philosophical material in the

[1]There is a link on the website to a collection of unpublished notes by Geroch. The notes on differential geometry available there are referred to as Geroch (1972) throughout the syllabus. However, I also refer to some other notes on special topics—fiber bundles, Lie groups, calculus of variations—below in the course schedule; these can be found in the same place as the longer notes on differential geometry.

course: many of the readings are from Brading and Castellani (2003), which is an excellent collection. I recommend that you buy it. We will also be reading a substantial chunk (roughly 40%) of Healey (2007), and so I recommend you buy that too. Though Maudlin (2007) and Arntzenius (2012) should be in any philosophy of physics library, the readings from them will be much more limited, so I will find a way to make them available to you. We have access to all of the other readings through the UCI library system; links to these can be found on the course website.

Requirements: All that is required for an S is attendance and occasional participation. If you would like a grade, several options are available. You could write a full-length term paper (15-20 pages). Or, you could lead discussion during one of the more philosophical weeks and write a shorter paper (7-10 pages) on a more focused topic, perhaps related to your presentation. Or, you could do a problem set (essentially, a take-home midterm), lead a discussion, and write a very short paper (750-1250 words). Or, do the problem set and write a 7-10 page paper. Or make some other proposal. Whatever you choose, however, please aim to talk to me in the first few weeks of the quarter so I know what you plan to do.

Collaboration: You are encouraged to collaborate on the problem set, though everyone needs to produce his or her own write-up. If you do collaborate, you should indicate as much on top of the problem set before turning it in. Also, if you choose to do the problem set, please feel free to talk with me as much as you like.

Course Schedule: Below is the course schedule. Readings marked with a ♦ are on the course website.

Meeting 1: Overview; Manifolds; Vector and tensor fields on manifolds — 27 September 2012

Required reading:
Lecture notes §§1–3.
Supplemental reading:
Malament (2012) §§1.1–1.5.
Geroch (1972) §§1–6.
Eschrig (2011) §§2.1–2.5 (useful background on topology), §§3.1–3.5, and §§4.1–4.3.
Lee (2003) Chs. 1–4 & 11.

Meeting 2: Fiber bundles; Connections and covariant derivatives; Curvature — 4 October 2012

Required reading:
Lecture notes §§4–5.
Supplemental reading:
Malament (2012), §§1.7–1.9.
Geroch (1972), §§10, 12, 16–18, & 25–26.
Geroch, Note on Fiber Bundles.
Eschrig (2011), Ch. 7.
Lee (2003), Chs. 5–6.
Svetlichny (1999), §4.

Meeting 3: Lie groups; Principle bundles; Holonomies — 11 October 2012

Required reading:
Lecture notes §§6–8.
Supplemental reading:
Malament (2012), §1.6.
Geroch (1972), §§7 & 21–23.
Geroch, Note on Lie Groups and Lie Algebras.
Eschrig (2011), Chs. 6–7.
Lee (2003), Chs. 9, 18, & 20.
Svetlichny (1999), §3.
Drechsler and Mayer (1977), Chs. 3–4.

Meeting 4: Lagrangian field theory; Electromagnetism; Yang-Mills Theory — 18 October 2012

Required reading:

Lecture notes §§9–11.

Supplemental reading:

Healey (2007), Chs. 1 & 3.

Geroch, Note on Calculus of Variations.

Eschrig (2011), §§8.3–8.4.

Drechsler and Mayer (1977), Chs. 1–2 & §6.1.

Svetlichny (1999), §§6–7.

Wu, T. T. and Yang, C. N. (1975) "Concept of nonintegrable phase factors and global formulation of gauge fields." *Physical Review D* **12**(12), pp. 3845–3857.♦[2]

Trautman, A. (1980) "Fiber Bundles, Gauge Fields, and Gravitation." In *General Relativity and Gravitation*, A. Held ed. (New York: Plenum Press), pp. 287–308.♦

Meeting 5: The Cotton Eye Joe Question 1: Where does gauge come from? — 25 October 2012

Required reading:

Martin, C. (2003) "On Continuous Symmetries and the Foundations of Modern Physics." In Brading and Castellani (2003), pp. 29–60.

Earman, J. (2003) "Tracking Down Gauge: An Ode to the Constrained Hamiltonian Formalism." In Brading and Castellani (2003), pp. 140–162.

Redhead, M. (2003) "The Interpretation of Gauge Symmetry." In Brading and Castellani (2003), pp. 124–139.

Meeting 6: (Gauge) Symmetry, Ontology, and (Superfluous?) Structure — 1 November 2012

Required reading:

Ismael, J. and van Fraassen, B. (2003) "Symmetry as a Guide to Superfluous Theoretical Structure." In Brading and Castellani (2003), pp. 371–392.

Saunders, S. (2003) "Physics and Leibniz's Principles." In Brading and Castellani (2003), pp. 289–308.

Belot, G. (2012) "Symmetry and Equivalence." To appear in *The Oxford Handbook of Philosophy of Physics*, R. Batterman ed. (New York: Oxford University Press).♦

Supplemental reading:

Weatherall, J. (201x) "Are Newtonian Gravitation and Geometrized Newtonian Gravitation Theoretically Equivalent?"♦

Meeting 7: The Aharonov-Bohm Effect: Non-separability in Electromagnetism? — 8 November 2012

Required reading:

Healey (2007), Ch. 2.

Belot, G. (1998) "Understanding Electromagnetism." *British Journal for the Philosophy of Science* **49**(4), pp. 531–555.♦

Nounou, A. (2003) "A Fourth Way to the Aharonov-Bohm Effect." In Brading and Castellani (2003), pp. 174–200.

Meeting 8: Interpreting Gauge Quantities 1: Localized Gauge Properties — ?? November 2012

Required reading:

Maudlin (2007), Ch. 3.

Arntzenius (2012), Ch. 6.

[2]This article, often referred to as the "Wu-Yang Dictionary", was one of the earliest to make explicit the relationship between the theory of connections on principle bundles (as developed by geometers) and the theory of gauge fields (as developed independently by physicists). In addition to its clear exposition of the topics at hand, it is of considerable historic importance.

Leeds, S. (1999) "Gauges: Aharonov, Bohm, Yang, Healey." *Philosophy of Science* **66**(4), pp. 606–627.♦

Earman and Norton (1988) "What Price Spacetime Substantivalism? The Hole Story." *British Journal for the Philosophy of Science* **38**(4), pp. 515–525.♦

Meeting 9: Interpreting Gauge Quantities 2: Non-localized Gauge Properties ?? November 2012

Required reading:

Healey (2007), Ch. 4.

Belot, G. (2003) "Symmetry and Gauge Freedom." *Studies in History and Philosophy of Modern Physics* **34**(2), pp. 189–225.♦

Supplemental reading:

Barrett, J. W. (1992) "Holonomy and path structures in general relativity and Yang-Mills theory." *International Journal of Theoretical Physics.* **30**(9), pp. 1171–1215.♦

Meeting 10: The Cotton Eye Joe Question 2: And where does it go? ?? December 2012

Required reading:

Earman, J. (2004) "Curie's Principle and Spontaneous Symmetry Breaking." *International Studies in the Philosophy of Science* **18**(2–3), pp. 173–198.♦

Morrison, M. (2003) "Spontaneous Symmetry Breaking: Theoretical Arguments and Philosophical Problems." In Brading and Castellani (2003), pp. 347–364.

Smeenk, C. (2006) "The Elusive Higgs Mechanism." *Philosophy of Science* **73**(5), pp. 487–499.

Struyve, W. (2011) "Gauge Invariant Accounts of the Higgs Mechanism." *Studied in History and Philosophy of Modern Physics* **42**(4), pp. 226–236.♦

Supplemental reading:

Castellani, E. (2003) "On the Meaning of Symmetry Breaking." In Brading and Castellani (2003), pp. 321–334.

Meeting 11: The Gauge Argument and Noether's Theorems ?? December 2012

Required reading:

Teller, P. (2000) "The Gauge Argument." *Philosophy of Science* **67**(S3), pp. 466–481.♦

Martin, C. (2002)"Gauge Principles, Gauge Arguments and the Logic of Nature." *Philosophy of Science* **69**(S3), pp. 221–234.♦

Healey (2007), §6.3

Brading, K. and Brown, H. (2003) "Symmetries and Noether's Theorems." In Brading and Castellani (2003), pp. 89–109.