

1 Term Project: (Due in class Monday April 6, 2020)

The term project part of the course asks you to choose one of the following list of classic subatomic papers and explain in your own words why it was important and what it was trying to convey. (These may or may not be the same thing.) Provide a concise assessment of the paper, such as you might read in *The Economist*. The goal is digested and well-argued information rather than a general fact-dump on the subject.

You should check through and choose which paper you will study by Thursday March 5. On that day you should officially submit your choice to the course TA (David). You may also suggest another paper you would like to do that is not on the attached list, but if so pass it be me for approval first. I seek papers in subatomic physics on which the field has built (or, if more speculative, were influential in the way the field developed).

You may work in groups if you wish, but if so when specifying which paper you must specify who else is in your group. Groups of more than one person will be expected to have commensurately more information in their report. Every member of the group should write and submit their own report.

Inevitably people ask how long the report should be. The answer is that it is not being marked by the pound so should not be too long. A scientific essay like this should start with a statement of the point; perhaps something like: *In this essay it is argued that X is true and this is important because of Y*. Then the rest of the essay is devoted to explaining these points and so should be just long enough to clearly and concisely make the points you wish to make and no more. (If you absolutely must have a number you might aim for around 5-10 pages of text, not including possible figures and references.)

List of possible papers

1. "Zum Unitätsproblem in der Physik," Theodor Kaluza, Sitzungsber. Preuss. Akad. Wiss. Berlin. (Math. Phys.) (1921) 966 and "Quantentheorie und fünfdimensionale Relativitätstheorie", Oskar Klein, Zeitschrift für Physik A 37, (1926) 895.
2. "Gehorchen die Stickstoffkerne der Boseschen Statistik?" ("Does the Nitrogen nucleus obey Bose statistics?") W. Heitler, G. Herzberg, Naturwiss. 17, 673 (1929).
3. "Über den Bau der Atomkerne" ("On the structure of atomic nuclei"), W. Heisenberg, Z. Phys. 77 (1932) 1.
4. "An attempt of a theory of beta radiation. 1.," E. Fermi, Z. Phys. 88 (1934) 161.
5. "On the Interaction of Elementary Particles I," H. Yukawa, Proc. Phys. Math. Soc. Jap. 17 (1935) 48 [Prog. Theor. Phys. Suppl. 1 1].
6. "Cloud Chamber Observations of Cosmic Rays at 4300 Meters Elevation and Near Sea-Level," C. D. Anderson and S. H. Neddermeyer, Phys. Rev. 50 (1936) 263 and "Note on the Nature of Cosmic Ray Particles," S. H. Neddermeyer and C. D. Anderson, Phys. Rev. 51 (1937) 884.

7. "Die Rotverschiebung von extragalaktischen Nebeln," F. Zwicky, *Helvetica Physica Acta* **6** (1933) 110127 and "On the Masses of Nebulae and of Clusters of Nebulae," F. Zwicky, *Astrophysical Journal* **86** (1937) 217.
8. "Processes Involving Charged Mesons," C. M. G. Lattes, H. Muirhead, G. P. S. Occhialini and C. F. Powell, *Nature* **159** (1947) 694 and "Observations on the Tracks of Slow Mesons in Photographic Emulsions. 1," C. M. G. Lattes, G. P. S. Occhialini and C. F. Powell, *Nature* **160** (1947) 453 and "Observations on the Tracks of Slow Mesons in Photographic Emulsions. 2," C. M. G. Lattes, G. P. S. Occhialini and C. F. Powell, *Nature* **160** (1947) 486.
9. "Space-time approach to nonrelativistic quantum mechanics," R. P. Feynman, *Rev. Mod. Phys.* **20** (1948) 367.
10. "The Origin of Chemical Elements," R.A. Alpher, H. Bethe and G. Gamow, *Physical Review* **73** (1948) 803.
11. "On the Origin of the Cosmic Radiation," E. Fermi, *Phys. Rev.* **75** (1949) 1169.
12. "The Theory of positrons," R. P. Feynman, *Phys. Rev.* **76** (1949) 749.
13. "Charge Independence for V-particles," T. Nakano and K. Nishijima, *Prog. Theor. Phys.* **10** (1953) 581 and "The interpretation of the new particles as displaced charge multiplets," M. Gell-Mann, *Nuovo Cim.* **4** (1956) S2, 848.
14. "On the Equivalence of Invariance under Time Reversal and under Particle-Antiparticle Conjugation for Relativistic Field Theories", G. Lüders, *Kongelige Danske Videnskabernes Selskab, Matematisk-Fysiske Meddelelser* **28** (1954) 1 and/or "Relativistic Field Theories of Elementary Particles," W. Pauli, *Rev. Mod. Phys.* **13** (1941) 203.
15. "Question of Parity Conservation in Weak Interactions," T. D. Lee and C. N. Yang, *Phys. Rev.* **104** (1956) 254.
16. "Conservation of Isotopic Spin and Isotopic Gauge Invariance," C. N. Yang and R. L. Mills, *Phys. Rev.* **96** (1954) 191.
17. "Theory of Fermi interaction," R. P. Feynman and M. Gell-Mann, *Phys. Rev.* **109** (1958) 193, and "Chirality invariance and the universal Fermi interaction," E. C. G. Sudarshan and R. e. Marshak, *Phys. Rev.* **109** (1958) 1860.
18. "Experimental Test of Parity Conservation in Beta Decay," C. S. Wu, E. Ambler, R. W. Hayward, D. D. Hoppes and R. P. Hudson, *Phys. Rev.* **105** (1957) 1413.
19. "Electron and Muon Neutrinos," B. Pontecorvo, *Sov. Phys. JETP* **10** (1960) 1236 [*Zh. Eksp. Teor. Fiz.* **37** (1959) 1751].
20. "The Eightfold Way: A Theory of strong interaction symmetry," M. Gell-Mann, *California Institute for Technology Synchrotron Laboratory Report CTSL-20* (1961) and "Derivation of Strong Interactions from a Gauge Invariance," Y. Ne'eman, *Nuclear Physics* **26** (1961) 222.

21. “Broken symmetries, massless particles and gauge fields,” P. W. Higgs, Phys. Lett. **12** (1964) 132 and “Broken Symmetries and the Masses of Gauge Bosons,” P. W. Higgs, Phys. Rev. Lett. **13** (1964) 508.
22. “Observation of a Hyperon with Strangeness -3,” V. E. Barnes *et al.*, Phys. Rev. Lett. **12** (1964) 204.
23. “Evidence for the 2π Decay of the K_2^0 Meson,” J. H. Christenson, J. W. Cronin, V. L. Fitch and R. Turlay, Phys. Rev. Lett. **13** (1964) 138.
24. “Photons and gravitons in perturbation theory: Derivation of Maxwell’s and Einstein’s equations,” S. Weinberg, Phys. Rev. **138** (1965) B988.
25. “A Model of Leptons,” S. Weinberg, Phys. Rev. Lett. **19** (1967) 1264.
26. “Search for neutrinos from the sun,” R. Davis, Jr., D. S. Harmer and K. C. Hoffman, Phys. Rev. Lett. **20** (1968) 1205.
27. “Neutrino Experiments and the Problem of Conservation of Leptonic Charge,” B. Pontecorvo, Sov. Phys. JETP **26** (1968) 984 [Zh. Eksp. Teor. Fiz. **53** (1967) 1717].
28. “All Possible Symmetries of the S Matrix,” S. R. Coleman and J. Mandula, Phys. Rev. **159** (1967) 1251.
29. “Very high-energy collisions of hadrons,” . P. Feynman, Phys. Rev. Lett. **23** (1969) 1415 and “Inelastic Electron Proton and gamma Proton Scattering, and the Structure of the Nucleon,” J. D. Bjorken and E. A. Paschos, Phys. Rev. **185** (1969) 1975.
30. “Axial vector vertex in spinor electrodynamics,” S. L. Adler, Phys. Rev. **177** (1969) 2426.
31. “Rotation of the Andromeda Nebula from a Spectroscopic Survey of Emission Regions,” V.C. Rubin and W. Kent Ford Jr, Astrophysical Journal **159** (1970) 379.
32. “Weak Interactions with Lepton-Hadron Symmetry,” S. L. Glashow, J. Iliopoulos and L. Maiani, Phys. Rev. D **2** (1970) 1285.
33. “Effects of a neutral intermediate boson in semileptonic processes,” S. Weinberg, Phys. Rev. D **5** (1972) 1412.
34. “Regularization and Renormalization of Gauge Fields,” G. ’t Hooft and M. J. G. Veltman, Nucl. Phys. B **44** (1972) 189.
35. “Critical exponents in 3.99 dimensions,” K. G. Wilson and M. E. Fisher, Phys. Rev. Lett. **28** (1972) 240.
36. “Ultraviolet Behavior of Nonabelian Gauge Theories,” D. J. Gross and F. Wilczek, Phys. Rev. Lett. **30** (1973) 1343, and, “Reliable Perturbative Results for Strong Interactions?,” H. D. Politzer, Phys. Rev. Lett. **30** (1973) 1346.

37. "Confinement of Quarks," K. G. Wilson, *Phys. Rev. D* **10** (1974) 2445.
38. "Unity of All Elementary Particle Forces," H. Georgi and S. L. Glashow, *Phys. Rev. Lett.* **32** (1974) 438.
39. "Hierarchy of Interactions in Unified Gauge Theories," H. Georgi, H. R. Quinn and S. Weinberg, *Phys. Rev. Lett.* **33** (1974) 451.
40. "Magnetic Monopoles in Unified Gauge Theories," G. 't Hooft, *Nucl. Phys. B* **79** (1974) 276 and "Pseudoparticle Solutions of the Yang-Mills Equations," A. A. Belavin, A. M. Polyakov, A. S. Schwartz and Y. S. Tyupkin, *Phys. Lett. B* **59** (1975) 85.
41. "Experimental Observation of a Heavy Particle J," J. J. Aubert *et al.* [E598 Collaboration], *Phys. Rev. Lett.* **33** (1974) 1404 and "Discovery of a Narrow Resonance in e^+e^- Annihilation," J. E. Augustin *et al.* [SLAC-SP-017 Collaboration], *Phys. Rev. Lett.* **33** (1974) 1406 [*Adv. Exp. Phys.* **5** (1976) 141].
42. "Jets from Quantum Chromodynamics," G. F. Sterman and S. Weinberg, *Phys. Rev. Lett.* **39** (1977) 1436.
43. "Spontaneously Broken Supersymmetric Theories of Weak, Electromagnetic and Strong Interactions," P. Fayet, *Phys. Lett. B* **69** (1977) 489.
44. "Phenomenological Lagrangians," S. Weinberg, *Physica A* **96** (1979) 327.
45. "CP Conservation in the Presence of Instantons," R. D. Peccei and H. R. Quinn, *Phys. Rev. Lett.* **38** (1977) 1440.
46. "A New Light Boson?," S. Weinberg, *Phys. Rev. Lett.* **40** (1978) 223, and "Problem of Strong p and t Invariance in the Presence of Instantons," F. Wilczek, *Phys. Rev. Lett.* **40** (1978) 279.
47. "Mass Without Scalars," S. Dimopoulos and L. Susskind, *Nucl. Phys. B* **155** (1979) 237.
48. "Baryon and Lepton Nonconserving Processes," S. Weinberg, *Phys. Rev. Lett.* **43** (1979) 1566.
49. "Evidence for Anomalous Lepton Production in e^+e^- Annihilation," M. L. Perl *et al.*, *Phys. Rev. Lett.* **35** (1975) 1489.
50. "The Inflationary Universe: A Possible Solution to the Horizon and Flatness Problems," A. H. Guth, *Phys. Rev. D* **23** (1981) 347.
51. "Why The Renormalization Group Is A Good Thing," S. Weinberg, In *Cambridge 1981, Proceedings, Asymptotic Realms Of Physics*, 1-19.
52. "Further Evidence for Charged Intermediate Vector Bosons at the SPS Collider," G. Arnison *et al.* [UA1 Collaboration], *Phys. Lett. B* **129** (1983) 273.

53. “Direct Evidence for Two Neutrino Double Beta Decay in ^{82}Se ,” S. R. Elliott, A. A. Hahn and M. K. Moe, *Phys. Rev. Lett.* **59** (1987) 2020.
54. “Observation of B^0 - anti- B^0 Mixing,” H. Albrecht *et al.* [ARGUS Collaboration], *Phys. Lett. B* **192** (1987) 245.
55. “Observational evidence from supernovae for an accelerating universe and a cosmological constant,” A. G. Riess *et al.* [Supernova Search Team Collaboration], *Astron. J.* **116** (1998) 1009 and “The High Z supernova search: Measuring cosmic deceleration and global curvature of the universe using type Ia supernovae,” B. P. Schmidt *et al.* [Supernova Search Team Collaboration], *Astrophys. J.* **507** (1998) 46.
56. “The Hierarchy problem and new dimensions at a millimeter,” N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, *Phys. Lett. B* **429** (1998) 263.
57. “Measurement of the rate of $\nu_e + d \rightarrow p + p + e^-$ interactions produced by ^8B solar neutrinos at the Sudbury Neutrino Observatory,” Q. R. Ahmad *et al.* [SNO Collaboration], *Phys. Rev. Lett.* **87** (2001) 071301 and “Direct evidence for neutrino flavor transformation from neutral current interactions in the Sudbury Neutrino Observatory,” Q. R. Ahmad *et al.* [SNO Collaboration], *Phys. Rev. Lett.* **89** (2002) 011301.
58. “Final Report of the Muon E821 Anomalous Magnetic Moment Measurement at BNL,” G. W. Bennett *et al.* [Muon g-2 Collaboration], *Phys. Rev. D* **73** (2006) 072003.
59. “Observation of Gravitational Waves from a Binary Black Hole Merger,” B. P. Abbott *et al.* [LIGO and Virgo Scientific Collaborations], *Phys. Rev. Lett.* **116** (2016) 061102.