STS-UY.2294 Quantum Mechanics and Information Department of Technology, Culture and Society NYU-Tandon

Prof: Jonathan Bain jon.bain@nyu.edu research.engineering.nyu.edu/~jbain/qm Off. Hr: Zoom, Tues 12:30-1:30pm remote, or by appt. Office: 2Metrotech, 9th Fl., Rm929 Spring 2023 RH317 M/W 12:00-1:50pm

<u>I. Instructional Format</u>: Instruction will be conducted in-class, unless circumstances require otherwise. Please be aware of the NYU policy on face masks at nyu.edu/life/safety-health-wellness/coronavirus-information/covid-related-guidance/protective-equipment.html. Masks are not required but welcome.

II. Description: Quantum mechanics is the best-confirmed theory of particle dynamics in existence today. Not only is it the basis for all digital technologies, it also serves as the theoretical foundation for our best-confirmed theories of matter (quantum field theories). On the other hand, since its inception, it has been beset with conceptual problems. In particular, there is no current consensus on just how to interpret it: What would the world be like, if it were true? In this course, we will first develop the theory from a conceptual and elementary mathematical perspective, and then canvass a number of proposals as to how it should be interpreted. A central part of the course will be devoted to conceptual issues surrounding quantum information theory and such current applications as quantum teleportation, quantum computing, and quantum cryptography. This course is geared towards students with minimal background in mathematics, physics, or philosophy.

III. Objectives

HuSS (Humanities and Social Sciences) General Education Objectives

Think critically, creatively and independently; demonstrate information literacy; demonstrate skills in inquiry and analysis; demonstrate effective oral communication skills; demonstrate effective writing skills; bring the perspectives of HuSS to bear on technical discourse; demonstrate ethical reasoning.

STS (Science, Technology and Society) Cluster Objectives

- Demonstrate a basic understanding of the following:
 - How sci & tech shape society (in historical, philosophical, sociological, cultural, and technical ways).
 - How social processes frame sci and tech enterprises, including theory construction, invention, and innovation.
 - The relation between the content of sci/tech knowledge, and the social context in which it is created.
- Demonstrate technical proficiency in a field in the natural sciences or engineering.
- Demonstrate ability to critically analyze and communicate issues involving interactions among sci, tech, & society.

IV. Reading

A. At Bookstore or online via Bobst:

- 1. [A] Albert, D. (1992) Quantum Mechanics and Experience, Harvard Univ. Press.
- 2. [H] Hughes, R. I. G. (1989) The Structure and Interpretation of Quantum Mechanics, Harvard Univ. Press.

B. Online at course website:

- 3. [Ba] Barrett, J. (1999), The Quantum Mechanics of Minds and Worlds, Oxford Univ. Press, pp. 221-242.
- 4. [Bu] Bub, J. (2019) "Quantum Entanglement and Information", *The Stanford Encyclopedia of Philosophy*, Edward N. Zalta (ed.), plato.stanford.edu/entries/qt-entangle.
- 5. [LD] Lombarid, O. & D. Dieks (2021) "Modal Interpretations of Quant Mechanics", *The Stanford Encyclopedia* of *Philosophy*, Edward N. Zalta (ed.), *plato.stanford.edu/entries/qm-modal*.
- 6. [F] French, S. (2019) "Identity and Individuality in Quantum Theory", *The Stanford Encyclopedia of Philosophy*, Edward N. Zalta (ed.), plato.stanford.edu/entries/qt-idind.
- 7. [RP] Rieffel, E. and W. Polak (2000) "An Introduction to Quantum Computing for Non-Physicists", lanl.arxiv.org/abs/quantu-ph/9809016.

<u>V. Requirements</u>: This course has two websites: A Brightspace website, **brightspace.nyu.edu**, accessible only to enrolled students, and a public website, **research.engineering.nyu.edu/~jbain/philqm**.

1. **12 homework assignments**. These are posted in the Contents section in Brightspace. Please submit them by their due dates to links in the Brightspace Assignments folder. Your final homework grade will be calculated from the best 10 of your 12 assignment grades. Two optional extra credit assignments may also be submitted and will count towards your final homework grade.

Homework submission format: The preferred file type is .pdf. Please label the file you submit using the following format:

<assignment number>.<last name> <first initial>.<file type>

Example: Mona Ashiya's .pdf submission for homework #7 should be labeled:

07.Ashiya M.pdf

- 2. One paper of 5-7 pages (typed, 10- or 12-point, double-spaced, spell-checked!). Suggested topics are posted in the Contents section in Brightspace. The paper should conform to guidelines that are posted in the Contents section of Brightspace. Late paper policy: Late papers will be accepted up to the date of the final.
- 3. One midterm and one final. Each exam will consist of 8 short answer questions, of which you will be asked to pick 6 to respond to; and 3 short essay questions, of which you will be asked to pick 2 to respond to. A response to a short answer question should be no more than 1 paragraph in length (~3-4 sentences), and a response to a short essay question should be no more than 1 page in length (~3-4 paragraphs). Both the midterm and the final will be open-book, open-notes, take-home exams and should be submitted to the relevant link in the Brightspace Assignments folder. For the policy on makeup exams, please see Section VII.3.ii below.

VI. Grade Distribution: Homework: 25% total Midterm: 25% Paper: 20% Final: 30%

VII. Reminders on University Policies

- 1. Inclusion Statement. NYU values an inclusive and equitable environment for all students. I hope to foster a sense of community in this class and consider it a place where individuals of all backgrounds, beliefs, ethnicities, national origins, gender identities, sexual orientations, religious and political affiliations, and abilities will be treated with respect. It is my intent that all learning needs be addressed both in and out of class, and that the diversity that students bring to this class be viewed as a resource, strength and benefit. If this standard is not being upheld, please feel free to speak with me.
- 2. Moses Statement. If you are student with a disability who is requesting accommodations, please contact the Moses Center for Students with Disabilities (CSD) at 212-998-4980, mosescsd@nyu.edu, nyu.edu/csd, 726 Broadway, 2nd Flr. You must be registered with CSD to receive accommodations.
- 3. Standards and Procedures. The NYU-Tandon Office of Student Affairs maintains a Community Standards and Procedures website at engineering.nyu.edu/life/student-affairs/community-standards-procedures. It contains information relevant to:
 - (i) Incompletes. It is NYU-Tandon policy that incompletes can be given only in extenuating circumstances (medical emergencies, accidents, etc.). An incomplete cannot be given because of a heavy course load, job commitments, or because you've simply fallen behind. For this reason, you should attend every lecture and make sure you're aware of assignment deadlines and exam dates. If you find yourself falling behind during the semester, do not hesitate to contact me. If you think you qualify for an incomplete grade at the end of the semester, see the procedure in (ii) below.
 - (ii) Excuses due to illness or circumstances. If you are experiencing an illness or any other situation that might affect your academic performance in a class (for instance, if you have to miss a lecture or an exam), please email Deanna Rayment, Coordinator of Student Advocacy, Compliance and Student Affairs, Dibner Hall Room LC 240C, eng.studentadvocate@nyu.edu. Deanna can reach out to your instructors on your behalf when warranted.
 - (iii) University Honor System. Please be aware of the university policy on cheating and plagiarism in the Student Code of Conduct. Cheating on an exam, or plagiarizing on an essay assignment, are sufficient reasons for receiving an F in the course. The Code of Conduct can be downloaded from the Office of Student Affairs website listed above.

S

U

W

F Failing (0.0)

- 4. University Policy on Grading. The following is NYU-Tandon's grading policy for all undergrad classes:
 - А Excellent (4.0) C+

A-

B+

В

B-

- Passing (2.3) Excellent (3.7) С Passing (2.0)
 - C-Deficient, but passing (1.7)
- Good (3.3) D+ Deficient, but passing (1.3) Good (3.0)
- Good (2.7) D Deficient, but passing (1.0)
 - Incomplete
- Satisfactory NR Р Unsatisfactory
- Passing Withdrawal

AUD

MR Must Repeat

Audit

Not Received

VIII. Class Schedule The following schedule may be subject to revision over the course of the semester. Reading assignments should be completed by the date on which they appear.

| 1 | Mon 1/23. The 2-Slit Experiment | Weds 1/25. The 2-Path Experiment |
|----------------------------------|--|---|
| | | [A] Chap 1; [H] Intro. |
| 2 | 1/30. Vectors, Vector Spaces, Operators | 2/1. Principles of QM |
| | [A] pp. 17-30; [H] Chap 1. | [A] pp. 30-47; [H] Chaps 2, 3. hw1 due |
| 3 | 2/6. Entangled States | 2/8. EPR and Bell |
| | [A] pp. 47-60; [H] Chap 5. | [A] Chap 3; [H] pp. 155-164. hw2 due |
| 4 | 2/13. EPR and Bell, cont. | 2/15. Quantum Cryptography |
| | | [RP]; [Bu]. hw3 due |
| 5 | 2/20. NO CLASS (Presidents' Day) | 2/22. Quantum Dense Coding |
| | | hw4 due |
| 6 | 2/27. Dense Coding, cont. | 3/1. Quantum Teleportation |
| | | hw5 due |
| 7 | 3/6. Quantum Teleportation, cont. | 3/8. Quantum Computation |
| | | hw6 due |
| 8 | 3/13. SPRING BREAK | 3/15. SPRING BREAK |
| | | |
| 9 | 3/20. Quantum Error Correction | 3/22. Quantum Error Correction, cont. |
| | | hw7 due; Midterm handed out |
| 10 | 3/27. The Kochen-Specker Theorem | 3/29. The Measurement Problem |
| | Optional: [4] Chan 6 pp 16/ 175 | [A] Chap 4. [1] Chap 0 Midtarm due |
| | Optional. [11] Chap 0, pp. 104-175. | [A] Chap 4; [H] Chap 9. Midterm due |
| 11 | 4/3. <i>GRW</i> | 4/5. Many Worlds, Many Minds |
| 11 | 4/3. <i>GRW</i> [A] Chap 5. | [A] Chap 4, [A] Chap 9. Midderm due4/5. Many Worlds, Many Minds[A] Chap 6. hw8 due |
| 11 12 | 4/3. GRW [A] Chap 5. 4/10. Many Worlds, cont. | [A] Chap 4, [A] Chap 9. Midderm due4/5. Many Worlds, Many Minds[A] Chap 6. hw8 due4/12. The Bare Theory |
| 11 12 | 4/3. GRW [A] Chap 5. 4/10. Many Worlds, cont. | [A] Chap 4, [A] Chap 9. Midderm due 4/5. Many Worlds, Many Minds [A] Chap 6. hw8 due 4/12. The Bare Theory [Ba]. hw9 due |
| 11 12 13 | 4/3. GRW [A] Chap 5. 4/10. Many Worlds, cont. 4/17. Bohm | [A] Chap 4, [A] Chap 9. Midterm due 4/5. Many Worlds, Many Minds [A] Chap 6. hw8 due 4/12. The Bare Theory [Ba]. hw9 due 4/19. Bohm, cont. |
| 11 12 13 | 4/3. GRW [A] Chap 5. 4/10. Many Worlds, cont. 4/17. Bohm [A] Chap 7. | [A] Chap 4, [A] Chap 9. Midderm due 4/5. Many Worlds, Many Minds [A] Chap 6. hw8 due 4/12. The Bare Theory [Ba]. hw9 due 4/19. Bohm, cont. hw10 due |
| 11 12 13 14 | 4/3. GRW [A] Chap 5. 4/10. Many Worlds, cont. 4/17. Bohm [A] Chap 7. 4/24. Modal Interpretations | [A] Chap 4, [A] Chap 9. Midderm due 4/5. Many Worlds, Many Minds [A] Chap 6. hw8 due 4/12. The Bare Theory [Ba]. hw9 due 4/19. Bohm, cont. hw10 due 4/26. Quantum Logic |
| 11 12 13 14 | 4/3. GRW [A] Chap 5. 4/10. Many Worlds, cont. 4/17. Bohm [A] Chap 7. 4/24. Modal Interpretations [A] Appendix; [LD]. | [A] Chap 4, [A] Chap 9. Midterm due 4/5. Many Worlds, Many Minds [A] Chap 6. hw8 due 4/12. The Bare Theory [Ba]. hw9 due 4/19. Bohm, cont. hw10 due 4/26. Quantum Logic Optional: [H] Chap 7. hw11 due |
| 11 12 13 14 15 | 4/3. GRW [A] Chap 5. 4/10. Many Worlds, cont. 4/17. Bohm [A] Chap 7. 4/24. Modal Interpretations [A] Appendix; [LD]. 5/1. Decoherence, Consistent Histories | [A] Chap 4, [A] Chap 9. Midterm due 4/5. Many Worlds, Many Minds [A] Chap 6. hw8 due 4/12. The Bare Theory [Ba]. hw9 due 4/19. Bohm, cont. hw10 due 4/26. Quantum Logic Optional: [H] Chap 7. hw11 due 5/3. Quantum Identity and Individuality |
| 11 12 13 14 | 4/3. GRW [A] Chap 5. 4/10. Many Worlds, cont. 4/17. Bohm [A] Chap 7. 4/24. Modal Interpretations [A] Appendix; [LD]. 5/1. Decoherence, Consistent Histories [Ba]; [H] Chap 8.1, 8.3. | [A] Chap 4, [A] Chap 9. Middermidde 4/5. Many Worlds, Many Minds [A] Chap 6. hw8 due 4/12. The Bare Theory [Ba]. hw9 due 4/19. Bohm, cont. hw10 due 4/26. Quantum Logic Optional: [H] Chap 7. hw11 due 5/3. Quantum Identity and Individuality [F]. hw12 due |
| 11 12 13 14 15 16 | 4/3. <i>GRW</i> [A] Chap 5. 4/10. <i>Many Worlds, cont.</i> 4/17. <i>Bohm</i> [A] Chap 7. 4/24. <i>Modal Interpretations</i> [A] Appendix; [LD]. 5/1. <i>Decoherence, Consistent Histories</i> [Ba]; [H] Chap 8.1, 8.3. 5/8. <i>Quantum Identity and Individuality, cont.</i> | [A] Chap 4, [A] Chap 9. Midterm due 4/5. Many Worlds, Many Minds [A] Chap 6. hw8 due 4/12. The Bare Theory [Ba]. hw9 due 4/19. Bohm, cont. hw10 due 4/26. Quantum Logic Optional: [H] Chap 7. hw11 due 5/3. Quantum Identity and Individuality [F]. hw12 due |