PC3130

Quantum Mechanics II

Introduction

- Lecturer: Assoc Prof Quek Su Ying
- Office: S16-06-16
- Email: phyqsy@nus.edu.sg

- Teaching Assistant: Zhang Jingda
- Email: jingda@u.nus.edu

To send Prof Quek email on class matters, please either:

(a) Use the email function on Canvas (PC3130), OR

(b) Write to phyqsy@nus.edu.sg with “PC3130” in the subject line

Expectations

- Participation in class is important
- Be comfortable with one another, be respectful (everyone makes mistakes)
- A medical certificate or other university-approved reason with documentation is required to obtain credit for missed assessments
- All assignments and quizzes should be handed in on time. No marks for late submission.
- Bring paper for submission of in-class quizzes.

Assessments

- Quizzes (15%)

- 3% will be allocated to class polls (effort)
- 12% will be allocated to quizzes (including in-class quizzes)

- Problem sets (15%) – primarily graded for effort; but presenting something close to an accurate answer is also important. It does not mean that just by writing something you can get the full mark. In particular, answers that are simply a copy of the question does not warrant any marks. Be sure to show detailed steps for questions asking you to prove a statement – do not just restate the statement.

- Project work (15%)

- Final exam (4 December 2024, 9am) (55%)

In-class quizzes – how it works

- Quizzes make up 12% of your total score. The lowest quiz score will be dropped.

- Absence due to valid reasons –

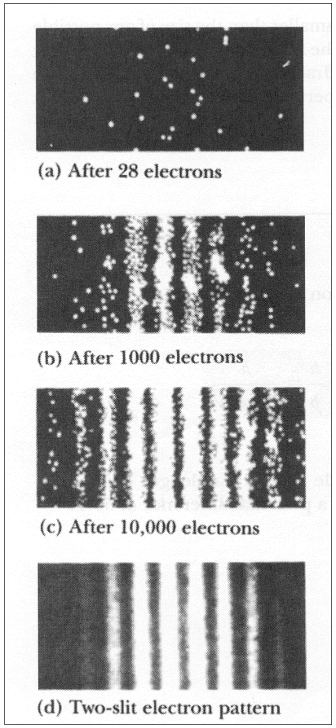
(a) A student who is absent due to a valid reason from class and misses an in-class quiz will score a zero for the quiz and this zero score will be the lowest quiz score that is dropped. This is irrespective of whether the student presents a medical certificate. For example, a student who misses only one quiz and presents a medical certificate will drop this quiz from the total score.

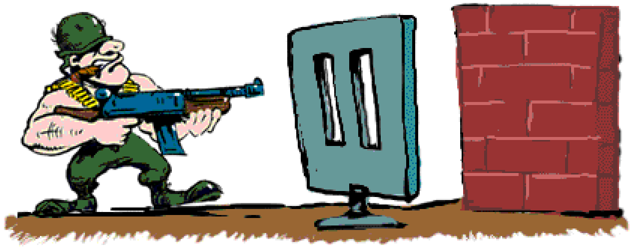
(b) If a student misses more than one in-class quiz, the medical certificate will make a difference. In particular, if a student misses both Quiz 3 and Quiz 4 due to illness with a medical certificate, one of the quizzes will be dropped from the total score automatically. The second quiz will also not be taken into consideration (an average is taken over the remaining valid quizzes) because the student presented a medical certificate.

In-class quizzes – how it works; in short

- Being in class is important for the in-class quizzes.
- If you are unwell, please stay home and rest.
- Please submit a medical certificate to me and Jingda if you are unwell (see note on Slide 2 on how to make sure the email reaches me).
- If you have missed more than one quiz already, the medical certificate will make a difference to your total score.

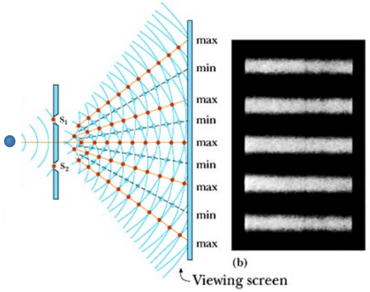
Two-Slit Experiment using Electrons



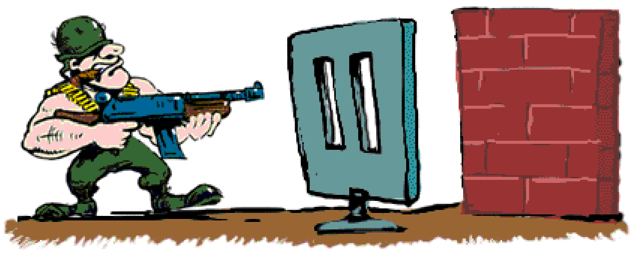


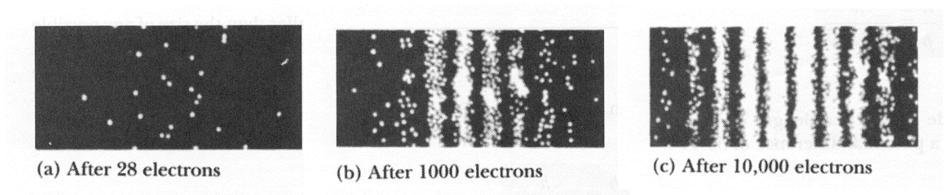
(a), (b), and (c) are computer simulations of an interference pattern for electrons.

(d) is a photograph of a double slit interference pattern, which confirms the wave-like properties of electrons.



Probability and Statistics





The interference pattern is the *statistical* result of *many electrons* in the same experiment!

The electrons are detected as particles at a spot at some instant of time, but the *probability* of arrival at that spot is determined by finding the *intensity* of the two interfering electron waves.

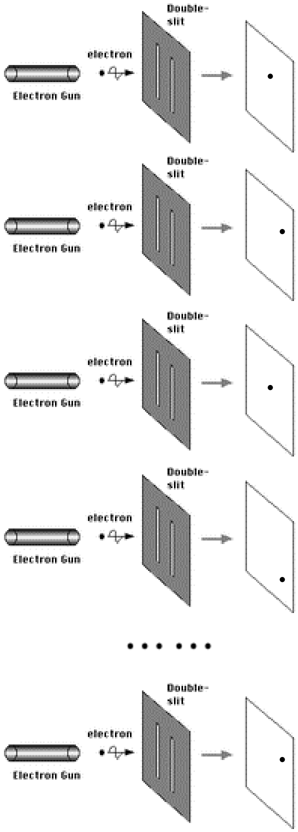
Probability and Statistics

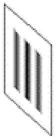
Consider a large number of identical experimental set ups (double slits). One electron is fired in each set up.

You see a dot on the screen in each case. But you cannot tell which slit the electron goes through and cannot predict where it would land precisely on the screen.

When the films are superimposed, an interference pattern emerges.

The wave property (interference) of the electron can be interpreted as the statistical results of many repetitions of the same experiment with the electron.

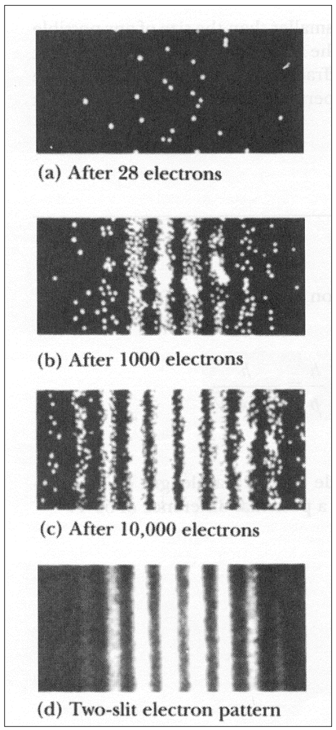




The interference pattern is also the *statistical* result of *many repetitions* of the same experiment with one electron.

Two-Slit Experiment using Light

- Light is an electromagnetic wave, and we expect a diffraction pattern
- But we can also think of light as being comprised of photons, which are massless particles

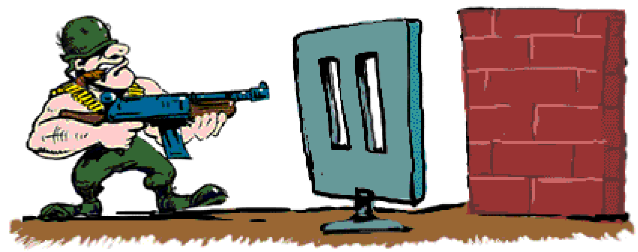


(a) After 28 electrons

(b) After 1000 electrons

(c) After 10,000 electrons

(d) Two-slit electron pattern



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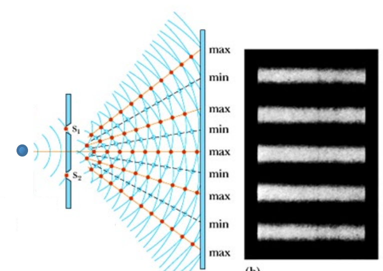
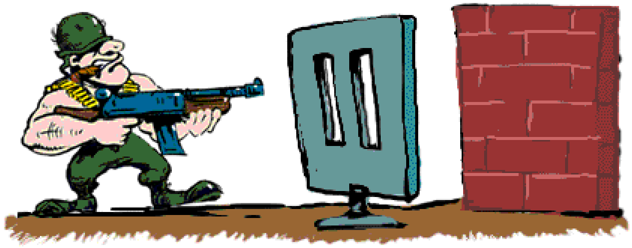
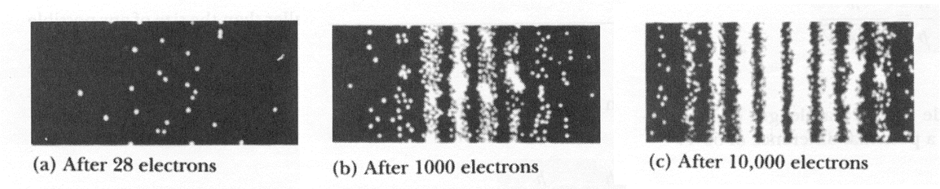


You can replace "electrons" with "photons" in the above illustration.

Probability and Statistics





The interference pattern is the *statistical* result of *many photons* in the same experiment!

The photons are detected as particles at a spot at some instant of time, but the *probability* of arrival at that spot is determined by finding the *intensity* of the two interfering light waves.

- https://www.youtube.com/watch?v=vpnhtQwq0Ug

Do we understand
everything about QM?

No… (in my opinion).
But, we understand enough to make use of QM
for many important applications.
E.g. using colour centres in 2D materials as
qubits, making superconductors, maglev trains,
the world's most precise clocks, etc..

IBM Quantum Computer

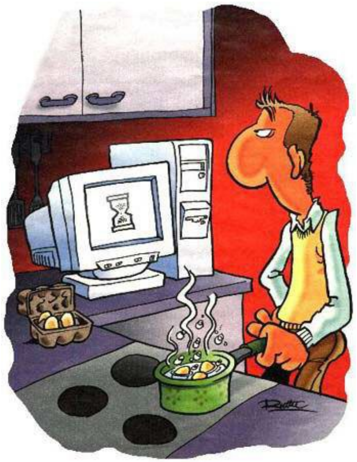
Science and Ethics

https://www.youtube.com/watch?v=-gBYU5SFnx8

What we will learn in PC3130

- Section 1: Angular momentum and Identical Particles –
  - What is angular momentum
  - Angular momenta as generators of rotations
  - Spin angular momentum
  - Addition of angular momenta
  - Implications on H atom
  - Implications on multi-electron systems

- Section 2: Approximation Methods –
  - Focus on Perturbation theory and its applications, including scattering
  - Variational principle



Broad Learning Outcomes

- Develop a good working knowledge of the topics covered
- Master basic mathematical skill sets required to solve the problems
- Develop the confidence and ability to take your knowledge forward and learn more QM/physics yourself in future
- Understand the concepts and their implications more deeply

How to make the most of this course

- Attend lectures and clarify doubts
- Take notes during class
  - Lecture slides are primarily to provide figures.
- Read textbooks (use the <u>Index</u> and <u>Contents</u> pages)
  - Recommended textbooks:

    Introduction to Quantum Mechanics by Griffiths (e-copy available)

    Introductory Quantum Mechanics by Liboff (one in RBR, two on main shelves)
  - Reference textbooks (e.g. for extra reading, projects):

    Quantum Mechanics, by Cohen-Tannoudji, Diu and Laloe

    Quantum Mechanics by Eugen Merzbacher

    Modern Quantum Mechanics by Sakurai

    Quantum Mechanics: A Modern Development by Ballentine
- Refer to “Course Readings” on Canvas. I will sometimes scan pages from textbooks other than Griffiths, for PC3130 students only.
- Do the quizzes and problem sets
- Have fun with the project – start early