

PHYS 111: Quantum Mechanics and You

Section A01
Fall 2021

Contact Information

- Instructor: Benjamin D. Smith
- Email: bdsmith@ualberta.ca
- Office: CCIS L2-063
- Course Website: eClass (<https://eclass.srv.ualberta.ca/>)
- Office Hours: TTh: 13:00-14:30 in CCIS L2-063

General questions about the course, assignments, or learning material can be asked on the eClass forum. If you are asking a question, chances are that others in the class have the same question too.

Regarding personal questions, there are two ways to reach me. The first method is via email. When you send me an email, please insert the course number ('111') at the start of the subject line so that I can more readily identify and respond to your message. Please begin each email with a formal greeting (e.g., dear, hello) and not 'hey', and include your full name.* I typically check and reply to emails only once per day, often in the morning. I rarely check emails on Saturdays, and never on Sundays. Because of this, please generally wait for at least 24 hours before expecting a reply.

Second, you are welcome to come to my office during the posted hours. Feel free to come with questions about the assignments or course material. Whereas I share my office with other colleagues, I ask you to please be respectful toward them and their space.

The TAs Jane and John will be available in their weekly tutorial session in room CCIS L2-080. On the first day of class, we will determine by vote which session day and time will benefit the most students possible.

Course Details and Format

- **Location:** CCIS L1-149
- **Dates:** September 01 - December 8, 2021
- **Time:** MWF 9:00 - 9:50 AM

This course is generally lecture-based interspersed with interactive activities for students to directly engage with the principles of quantum mechanics and their applications.

Course Description

A course combining qualitative and algebraic analysis of quantum mechanics foundations and applications for the modern world. Designed for students from all disciplines. General principles undergirding the scientific process. Basic quantum mechanical concepts, including discreteness, superposition, measurement, and entanglement. Explores modern applications of quantum mechanics in everyday devices and experiences; recent and upcoming quantum developments in computing, communication; the social and ethical implications of these technologies.

Prerequisites

Mathematics 30-1 or 30-2. Note: This course does not qualify as an equivalent to high school Physics 30.

My Mission Statement

Inspire learners to expand their potential with me. Encourage an attitude and climate of vulnerability and growth. Model a discipline of intentional practice.

Approach/Themes

Despite being the center of some of the “hottest” and most disruptive advancements of the 21st century, quantum mechanics has the reputation of being sterile, esoteric, and incomprehensible for the average human being. In truth, however, many of the problems people perceive in learning quantum mechanics stem from the language used to describe it and the apparent lack of meaningful associations.

In its essence, quantum mechanics is the set of principles describing the physical nature of the universe’s smallest bits of matter and energy. Discovering these rules, and applying them to make powerful predictions have - in a large part - enabled our modern world, and will continue to transform the human experience.

Quantum mechanics is currently at a watershed moment. Never before have there been so many accessible learning resources and real-world applications and opportunities. This course represents an attempt to open these learning opportunities to a wider audience. It is based on the assumption that anyone with interest and dedication can appreciate and begin to learn quantum mechanics. This course is organized in modules around (1) various quantum mechanical principles and (2) their applications, without getting into heavy mathematical formalisms.

I have taken an inclusive approach in designing this course. Quantum mechanics is not just for scientists and engineers, but a subject whose principles intersect all our lives in many different ways. Learning about these intersections can make a difference. As an example, one doesn't precisely need to understand how electricity works in order to benefit from it, say, flipping a light switch to illuminate a dark bedroom; however, even a basic understanding can be empowering and bring understanding in new situations or contexts. It can also provide new academic or employment opportunities. The same is true for quantum.

Course Learning Objectives

1. Expand knowledge of fundamental quantum mechanical principles that undergird so much of modern life and technology.
2. Foster wider interest in and engagement with quantum and physical sciences.
3. Contextualize upcoming 21st-century developments with quantum technologies.

Intended Learning Outcomes

1. **Describe** and **differentiate** between scientific fact, law, hypothesis, and theory.
2. **Examine** and **appraise** scientific data, claims, and concepts for making wise decisions affecting themselves and others.
3. **Explain** foundational quantum principles such as discreteness, superposition, probability, and entanglement.
4. **Identify** applications and operations of these principles in a variety of modern and future technologies.
5. **Calculate** physical quantities that are relevant to these applications.
6. **Distinguish** the operation and capabilities of classical and quantum computers.
7. **Assess** the social and ethical implications of upcoming quantum technologies.
8. **Express** and **reflect** on quantum mechanical ideas, applications, or open questions in writing and other formats.

Required materials

There is no required textbook for this course. All reading and reference material will be available on eClass.

Schedule (with ILO)

| Module | # of days | Dates | ILO | Assignment Due dates |
|---|-----------|-------------------|---------------|----------------------|
| Unit 1: Quantum Principles #1 | | | | |
| <u>Module 1</u> - Parsing Science | 3 | Sept. 1 - 8 | 1, 2, 8 | Sept. 10 |
| <u>Module 2</u> - “Energy is lumpy”: Discreteness of energy | 3 | Sept. 10 - 15 | 2, 3, 4, 5 | Sept. 17 |
| <u>Module 3</u> - “Particles are jumpy”: Discreteness of matter | 3 | Sept. 17 - 22 | 2, 3, 4, 5 | Sept. 24 |
| <u>Module 4</u> - “How did the particle cross the road?”: Tunneling | 2 | Sept. 24 - 27 | 2, 3, 4, 5 | Oct. 1 |
| <i>Principles Quiz #1</i> | | Oct. 4-5 | | |
| Unit 2: Quantum Principles #2 | | | | |
| <u>Module 5</u> - “Quantum casinos”: Randomness & quantum measurement | 3 | Sept. 29 - Oct. 6 | 2, 3, 4, 5 | Oct. 8 |
| <u>Module 6</u> - “A particle walks into two bars,...”: Quantum superposition | 2 | Oct. 8 - 13 | 2, 3, 4, 5 | Oct. 15 |
| <u>Module 7</u> - “The world is boring”: Decoherence | 1 | Oct. 15 | 2, 3, 5 | Oct. 22 |
| <u>Module 8</u> - Open questions | 2 | Oct. 18 - 20 | 1, 2, 3 | |
| <i>Principles Quiz #2</i> | 1 | Oct. 27-28 | | |
| Unit 3: Future Applications | | | | |
| <u>Module 9</u> - “Mums the word”: quantum entanglement and cryptography. | 5 | Oct. 22 - Nov. 3 | 3, 4, 7 | Nov. 5 |
| <u>Module 10</u> - “A bit of this...”: Computing with classical | 3 | Nov. 5 - 17 | 5, 6 | Nov. 19 |
| <u>Module 11</u> - “...and a bit of that”: Computing with quantum | 4 | Nov. 19 - 26 | 3, 4, 5, 6, 7 | Nov. 26 |

| | | | | |
|---|---|---------------------|------|--|
| <u>Module 12</u> - Ethics and social implications of quantum technologies | 3 | Nov. 29 - Dec. 3 | 7, 8 | |
| <i>Principles Quiz #3</i> | | Dec. 15 (tentative) | | |

Total instructional days: 38

Grades

Grade weighting distribution

Grades will be determined by percentage scores and not by standard distribution. Scores for assignments and evaluations will be expressed in raw marks throughout the course. Grades (e.g. A, B-, C+) will be assigned only to the final distribution of marks for the course.

The scores for the various assignments, quizzes, and projects will be weighted as shown in the following table:

| Grade Component | Weight % | Date | Notes |
|-----------------|----------|-----------------------------|---|
| Participation | 10 | - | Four absences dropped. |
| Assignments | 20 | - | 10 assignments, 2% each. Drop lowest two. |
| Quiz #1 | 15 | Mon. Oct. 4-5 | |
| Quiz #2 | 15 | Mon. Oct. 27-28 | |
| Quiz #3 | 15 | Wed. Dec. 15 (tentative) | |
| The UnEssay | 25 | Wed. Dec. 8 | |

The final raw percentage score will be converted (without rounding) to a final letter grade using the grade brackets below.

| Min. % | Letter |
|--------|--------|
| 97.0 | A+ |

| | |
|------|----|
| 93.0 | A |
| 90.0 | A- |

| | |
|------|----|
| 87.0 | B+ |
| 83.0 | B |
| 80.0 | B- |

| | |
|-------|----|
| 73.0 | C |
| 70.0 | C- |
| 65.0 | D+ |
| 60.0 | D |
| <60.0 | F |

| Min. % | Letter |
|--------|--------|
| 77.0 | C+ |

Grades are unofficial until approved by the Department and/or Faculty offering the course.

Attendance & Participation

Due to the interactive nature of this course, students are expected to attend and participate actively in class discussions and activities. Attendance will be taken at the beginning of each class period. Because unexpected events occur, students may miss up to four days throughout the semester without penalty.

Quizzes

The three Quizzes have a hybrid format in three sections. The first section of each quiz will take place in class and lasts for 30 minutes. It consists of paper multiple-choice and short-answer questions. At the end of the 30 minutes, students will submit their individual answers to the instructor for marking.

In the second section of the quiz, students gather in groups of three or four. Then each group completes the same questions together on a single quiz paper. The group comes to a consensus about each response and submits their work at the end of the remaining 15-20 minutes.[‡]

The third section of the quiz will take place outside of class and consists of three questions with long-answer written responses. Students will choose two of the three questions to answer. A given response will generally be one to two paragraphs in length. These responses will be due for submission on eClass near the end of the following day (8:00 pm). Any external resources referenced in writing these responses should be properly paraphrased and cited.

The total mark for the quiz will be a combination of the scores for the in-class questions, the out-of-class questions, and the long-answer questions, weighted as follows:

| | |
|----------------------|-----|
| Individual Responses | 65% |
| Group Responses | 15% |

| | |
|---------------------------|-----|
| (2) Long-answer Responses | 20% |
|---------------------------|-----|

In the unexpected case that your individual responses score higher than your group's, your individual score will carry the combined 80% of the total mark. In other words, your group's performance can only help you, not hurt you.

Quiz #3 will be different from the first two in that it will take place during the scheduled final exam time, tentatively on December 15th at 14:00. Please double-check the final exam schedule as the end of the semester approaches. Quiz #3 is not comprehensive and will only assess material not previously covered in the other quizzes. The long-answer section of this quiz will be completed during the final exam time.

Past Evaluative Material

In preparing and studying for the quizzes note that quiz questions will be similar in form and content to those seen on the prior assignments.

The UnEssay

Creativity is an essential, but often overlooked, aspect of science, particularly quantum study and research. For that reason, the culminating project for the course will be what's called an "UnEssay". This is an opportunity for students to delve into the subject matter in a personally meaningful way. Students will select a topic related to the course material that interests them, research it, and then represent their findings in a creative manner.[§]

There are three parts to this project: The first part is the Topic Selection Document. This is a short, five-paragraph written description of the intended UnEssay topic. It demonstrates understanding of the topic, outlines a plan for how it will be represented, and identifies several relevant and properly referenced sources to be consulted throughout the research process. The due date for this part is placed in the semester to give you enough time to think about what you would like to work on.

The second and main part of the UnEssay is your topic's representation. Although it should demonstrate an understanding of the topic, the format is very open. You may choose to present a traditional research paper/essay format, but you may also choose something very different. For example, you might create:

- A comic strip
- A music video
- A knitted object
- A comedy sketch or monologue
- A watercolor painting
- A Minecraft creation
- A sportscast-like interview
- ...

The final day of class will be dedicated to sharing and presenting everyone's projects. Students will submit a digital-friendly version of their work (e.g. photo, video, document, audio recording) to eClass for grading.

The third part is the Reflection Document. This is a 1-2 page document that explains what you did, your motivation and rationale for choosing your topic and medium, and your process for completing the UnEssay.

The weights and due dates for the three parts of the UnEssay are as follows:

| Name | Weight % | Due Date |
|--------------------------|----------|----------|
| Topic Selection Document | 10 | Nov. 15 |
| Finished Product | 70 | Dec. 8 |
| Reflection Document | 20 | Dec. 8 |

Detailed rubrics for each part of the UnEssay will be available on eClass early in the semester. Final submissions for all components of the UnEssay will take place on eClass.

Missed/late work

Missed Assignments:

The 2 lowest assignment marks will be dropped when calculating the course mark. No late assignments will be accepted. Failure to complete an assignment on time for any reason will result in a mark of zero. Please note that you can miss 2 assignments without penalty.

Missed Quizzes

A student who cannot complete a quiz due to incapacitating illness, severe domestic affliction or other compelling reasons (including missing an in-person assessment due to the requirement to self-isolate when experiencing COVID-19 symptoms or with a positive test result) can apply for an excused absence. To apply for an excused absence, you must contact the instructor within two working days of missing the quiz or as soon as possible. If an excused absence is granted, then you will coordinate with the instructor a time and place for a makeup quiz. It will not be possible to replicate the group-response segment of the quiz, therefore your personal responses will count for the full 75% weight. An excused absence is a privilege and not a right. There is no guarantee that an absence will be excused. Misrepresentation of facts to gain an excused absence is a serious breach of the Code of Student Behaviour. In all cases, instructors may request adequate documentation to substantiate the reason for the absence at their discretion.

Missed Assessments Where the Cause is a Religious Belief

For an excused absence where the cause is a religious belief, a student must contact the instructor within two weeks of the start of Fall or Winter classes to request an accommodation for the term (including the final exam, where relevant). Instructors may request adequate documentation to substantiate the student's request. Students who failed at the start of term to

request exam accommodations for religious beliefs are expected to follow the deferred final examination process outlined below.

Appropriate Collaboration

Students are not permitted to copy solutions on homework assignments. Here are some tips to avoid copying on assignments:

1. Do not write down something that you cannot explain to your instructor.
 2. When you are helping other students, avoid showing them your work directly. Instead, explain your solution verbally. Students whose work is copied also receive academic sanctions.
 3. If you find yourself reading another student's solution, do not write anything down. Once you understand how to solve the problem, remove the other person's work from your sight and then write up the solution to the question yourself. Looking back and forth between someone else's paper and your own paper is almost certainly copying and will result in academic sanctions for both you and your fellow student.
 4. If the instructor or TA writes down part of a solution in order to help explain it to you or the class, you cannot copy it and hand it in for credit. Treat it the same way you would treat another student's work with respect to copying, that is, remove the explanation from your sight and then write up the solution yourself.
 5. There is often more than one way to solve a problem. Choose the method that makes the most sense to you rather than the method that other students happen to use. If none of the ideas in your solution are your own, there is a good chance it will be flagged as copying.
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Resources

Student well-being is very important to me. While I am unable to address many of your challenges and concerns, there are ample resources available at the university to help. For your reference, I have included some of these listed below. If you feel a need in any of these areas, I encourage you to seek them out.

Accessibility

Eligible students have both rights and responsibilities with regard to accessibility-related accommodations. Consequently, scheduling exam accommodations in accordance with [Accessibility Resources](#) deadlines and procedures is essential. Please note adherence to procedures and deadlines is required for U of A to provide accommodations. Contact [Accessibility Resources](#) for further information.

Academic Success Center

The [Academic Success Centre](#) provides professional academic support to help students strengthen their academic skills and achieve their academic goals. Individual advising, appointments, and group workshops are available year-round in the areas of Accessibility, Communication, Learning, and Writing Resources. Modest fees apply for some services.

Decima Robinson Support Centre

The [Decima Robinson Support Centre for Mathematical and Statistical Sciences](#) is a resource for help with mathematics and statistics in 100- or 200- level courses. They provide primer courses and drop-in help. They are located at **528 CAB**.

Centre for Writers

The [Centre for Writers](#) (C4W) offers a variety of help and support for student writing. In addition to workshops and peer tutoring, they also provide one-on-one live or remote tutoring sessions. You can book an appointment at their website. They are located at **1-42 Assiniboia Hall**.

Feeling Stressed, Anxious, or Upset?

It's normal for us to have different mental health experiences throughout the year, particularly as we adjust to returning to campus as we move through a pandemic. Know that there are people who want to help. You can reach out to your friends and access a variety of supports available on and off campus at the [Need Help Now](#) webpage or by calling the 24-hour Distress Line: 780-492-4357 (HELP).

Counselling and Clinical Services

“[Counselling & Clinical Services](#) (CCS) provides psychological treatment services to the students at the University of Alberta using a short-term therapy model. The intention is to help students cope with situations that impact their current level of mental health or illness to assist them to function successfully during their University experience.”

CCS helps students with mental health concerns such as depression, anxiety, relationship issues, stress management, suicidal thoughts, self-esteem, perfectionism, family issues, and trauma. After a brief initial consultation, they may recommend a number of resources including therapy, treatment, or casual drop-in workshops. Their [website](#) even contains some good mental health resources. To book a consultation, call **780-492-5205** or visit **2-600 SUB** (temporarily relocated to 0-11 SUB through July 2022).

Peer Support Centre

“The [Peer Support Centre](#) is a Students’ Union service that offers non-judgemental support in a safe and confidential space to students and the campus community.” You can book an appointment on their website to meet with a peer support person. They are located in **2-707 SUB**, and offer sessions in Hindi, Gujarati, Urdu, Nigerian Pidgin, French, Spanish, Cantonese, Marwari, Tagalog, and Ukrainian.

First People’s House

The [First People’s House](#) is a University service to provide an “environment of empowerment for First Nations, Métis, and Inuit (FNMI) learners to achieve personal and academic growth.” In addition to academic and financial resources, they have information on housing, physical and mental wellness, spiritual and cultural support, and more. They are located in **2-400 SUB** and are open Monday to Friday from 8:30 AM to 4:30 PM (closed between 12-1 PM).

University Course Policies

Learning and working environment

The Faculty of Science is committed to ensuring that all students, faculty and staff are able to work and study in an environment that is safe and free from discrimination and harassment. It does not tolerate behaviour that undermines that environment.

If you are experiencing harassment, discrimination, fraud, theft or any other issue and would like to get confidential advice, please contact any of these campus services:

- [Office of Safe Disclosure & Human Rights](#): A safe, neutral and confidential space to disclose concerns about how the University of Alberta policies, procedures or ethical standards are being applied. They provide strategic advice and referral on matters such as discrimination, harassment, duty to accommodate and wrong-doings. Disclosures can be made in person or online using the [Online Reporting Tool](#).
- [University of Alberta Protective Services](#): Peace officers dedicated to ensuring the safety and security of U of A campuses and community. Staff or students can contact UAPS to make a report if they feel unsafe, threatened, or targeted on campus or by another member of the university community.
- [Office of the Student Ombuds](#): A confidential and free service that strives to ensure that university processes related to students operate as fairly as possible. They offer information, advice, and support to students, faculty, and staff as they deal with academic, discipline, interpersonal, and financial issues related to student programs.

- [Office of the Dean of Students](#): They can assist students in navigating services to ensure they receive appropriate and timely resources. For students who are unsure of the support they may need, are concerned about how to access services on campus, or feel like they may need interim support while you wait to access a service, the Dean of Students office is here to help.

Discrimination, Harassment, and Duty to Accommodate Policy

I am committed to providing a safe and productive learning environment for all students. Statements below are taken from the University's [Discrimination, Harassment and Duty to Accommodate Policy](#). Further details can be found by following the link to the policy.

Discrimination:

“A distinction, whether or not intentional, based on a characteristic or perceived characteristic referenced in the protected grounds that has the effect of imposing on an individual or group of individuals burdens, obligations or disadvantages that are not imposed on others, or of withholding or limiting access to opportunities, benefits and advantages available to other individuals in society.”

Harassment:

“A single or repeated incident of objectionable or unwelcome conduct, comment, bullying or action by a person that the person knows or ought to reasonably know will or would cause offence or humiliation to a worker or adversely affects the worker’s health and safety, and includes:

- a) Conduct, comment, bullying or action because of race, religious beliefs, colour, physical disability, mental disability, age, ancestry, place of origin, marital status, source of income, family status, gender, gender identity, gender expression and sexual orientation.
- b) A sexual solicitation or advance but excludes any reasonable conduct of an employer or supervisor in respect of the management of workers or a work site.

“Harassment includes bullying, which is a form of aggression that may include physical, verbal or emotional abuse. Bullying poisons the work, study or living environment of the person it targets. It can include persistent, offensive, abusive, intimidating or insulting behavior, abuse of power, and/or unfair sanctions which make the individual feel threatened, humiliated and/or vulnerable.”

“*Sexual harassment* may be broadly defined as unwelcome conduct or comment of a sexual nature which detrimentally affects the work, study or living environment or otherwise leads to adverse consequences for the person who is the target of the harassment.”

“*Racial harassment* involves unwanted or unwelcome comments, conduct or behavior that humiliates, intimidates, excludes or isolates an individual or group by focusing on their race, ethnicity, origin or religion. Overall, racial harassment undermines self-esteem and is a violation of the dignity and security of the individual or group(s) that it targets.”

Duty to Accommodate:

“The duty to accommodate obligates the university to make reasonable adjustments, to the point of undue hardship or as required by law, to the delivery of services (including teaching and the method of evaluation)... to reduce or eliminate the impact of discriminatory rules, policies, practices, standards, terms of employment or decisions, which have an adverse impact on an individual or group of individuals based on a characteristic or perceived characteristic referenced in the protected grounds.”

“Accommodation is a shared responsibility between the university and the individual in need of accommodation and is assessed on the unique circumstances of each individual.”

Requests for accommodations are made through the [University Academic Success Centre](#).

Sexual Violence Policy

“It is the policy of the University of Alberta that sexual violence committed by any member of the University community is prohibited and constitutes misconduct. Prohibited conduct includes: sexual violence, sexual assault, sexual harassment, stalking, indecent exposure, voyeurism, and distribution of intimate images.

“Any member of the University community who discloses having experienced sexual violence will have access to support, whether or not the sexual violence took place on University property or in relation to University activities. Where the University has jurisdiction, complaints will be addressed under the applicable policies or procedures, including, for example, the Code of Student Behaviour, the Postdoctoral Fellow Policy, NASA, AASUA or GSA collective agreements, or other applicable employment contracts and agreements.”

Further details on this policy are available on the U of A Policies and Procedures On-Line [Sexual Violence Policy](#).

Disruptions

In accordance with the [University of Alberta Code of Student Behavior](#), disruptions that interfere with the normal process of the session or of student learning will not be tolerated. Disrupting students may be asked to leave the classroom for up to three hours of instruction and the Dean of the College of Natural and Applied Sciences will be informed of the incident.

Use of Recording†

Audio or video recording, digital or otherwise, of lectures, labs, seminars or any other teaching environment by students is allowed only with the prior written consent of the instructor or as a part of an approved accommodation plan. Student or instructor content, digital or otherwise, created and/or used within the context of the course is to be used solely for personal study, and is not to be used or distributed for any other purpose without prior written consent from the content author(s).

Academic Integrity†

“The University of Alberta is committed to the highest standards of academic integrity and honesty. Students are expected to be familiar with these standards regarding academic honesty and to uphold the policies of the University in this respect. Students are particularly urged to familiarize themselves with the provisions of the Code of Student Behaviour (online at www.governance.ualberta.ca) and avoid any behaviour which could potentially result in suspicions of cheating, plagiarism, misrepresentation of facts and/or participation in an offence. Academic dishonesty is a serious offence and can result in suspension or expulsion from the University.”

“All forms of academic dishonesty are unacceptable at the University. Any suspected offence in this course will be reported to the Faculty of Science. The Faculty of Science is committed to student rights and responsibilities, and adheres to due process and administrative fairness as outlined in the Code of Student Behaviour. Anyone who is found in violation of the Code of Student Behaviour is likely to receive a sanction. Typical sanctions include conduct probation, a mark reduction or a mark of 0 on an assessment, a grade reduction or a grade of F in a course, a remark on the transcript, and a recommendation for suspension or expulsion.”

“Students are expected to familiarize themselves with the [Academic Integrity](#) resources (covering the topics of cheating, collaboration, plagiarism, and substantial assistance) on the website of the Office of the Dean of Students.”

Land acknowledgment

The University of Alberta respectfully acknowledges that we are situated on Treaty 6 territory, traditional lands of First Nations and Métis people.

Methods for alterations

Any alterations to this course outline or syllabus respecting grades, deadlines, and course materials will be communicated to students two different times: once at the beginning of a class session and once through an email notification.

Disclaimer

Any typographical errors in this Course Outline are subject to change and will be announced in class. The date of the final examination is set by the Registrar and takes precedence over the final examination date reported in this syllabus.

References

University of Alberta Faculty of Science Syllabus Template 2021-2022

† University of Alberta [Academic Regulations](#) 2021-2022

‡ PhysPort, "[Group Exams](#)", accessed March 29, 2022.

§ Mark Kissel, "[The UnEssay](#)," accessed April 28, 2022

Policy about course outlines can be found in [Course Requirements, Evaluation Procedures and Grading](#) of the University Calendar"

Additional Course Resources (for the Instructor)

Principles:

| Module | Tagline | Principle | Topics & Applications |
|---------------|--|--------------------------|--|
| 2 | “Energy is lumpy” | Discreteness of energy | Blackbody radiation, photoelectric effect |
| 3 | “Electrons are jumpy” | Discreteness of matter | Bohr model and spectra, clocks, neon signs, fireworks, aurora, lasers |
| 4 | “Why did the particle cross the road?” | Tunneling | Transistors, TEM, nuclear reactions, enzymes |
| 5 | “Quantum casinos” | Randomness & Measurement | Internet security, CHSH game, MRI, Bloch sphere |
| 6 | “A particle walks into two bars,…” | Superposition | Waves, light polarization, photosynthesis, Bloch sphere, interference, double-slit experiment. |
| 7 | “Why our world is boring.” | Decoherence | Why isn't everything quantum? |
| 9 | “I'm tied up at the moment” | Entanglement | QKD/BB84, bird navigation, CHSH |