

# INTRODUCTION TO QUANTUM INFORMATION PROCESSING WINTER 2021

CO 481 / CS 467 / PHYS 467

## CLASS SCHEDULE

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Section	Location	Time	Instructor(s)
CO 481 041	None	Tuesdays & Thursdays 11:30 a.m. - 12:50 p.m.	Ashwin Nayak anayak@uwaterloo.ca
CS 467 041	None	Tuesdays & Thursdays 11:30 a.m. - 12:50 p.m.	
PHYS 467 041	None	Tuesdays & Thursdays 11:30 a.m. - 12:50 p.m.	

## INSTRUCTOR / TA INFORMATION

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	Name	Email	Office hours
<b>Instructor</b>	Ashwin Nayak	anayak@uwaterloo.ca	Tuesdays 9:30 - 10:30 pm Wednesdays 11:30 am - 12:30 pm
<b>TA</b>	Tina Chen	q243chen@uwaterloo.ca	Thursdays 2 - 3 am Thursdays 2:30 - 3:30 pm
<b>TA</b>	Alex Kerzner	akerzner@uwaterloo.ca	
<b>TA</b>	Sabrina Lato	smlato@uwaterloo.ca	

Office hours and discussion on Piazza will be available for additional help. Office hours will

begin the week of Jan. 18.

The live lectures and office hours will be conducted on MS Teams, in the "Lectures" and "Office hours" channels, respectively. Recordings of the lectures will be available on MS Teams as well as Learn. If you registered early, you will receive the invitation to join the corresponding meetings. If not, please see the MS Teams section below to join. Due to the reading week and scheduled pause in March, there are multiple invitations.

## COURSE DESCRIPTION

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### *Calendar Description for CO 481*

Basics of computational complexity; basics of quantum information; quantum phenomena; quantum circuits and universality; relationship between quantum and classical complexity classes; simple quantum algorithms; quantum Fourier transform; Shor factoring algorithm; Grover search algorithm; physical realization of quantum computation; error-correction and fault-tolerance; quantum key distribution. [Offered: W]

Prereq: One of MATH 114, 115, 235, 245; Level at least 4A

The field of Quantum Information Processing seeks to exploit quantum mechanical principles to provide a qualitatively different and more powerful way of processing information than is allowed by classical physics. This course aims to introduce the basics of the field and some of its foundational results. This is a multidisciplinary subject, and the course will cover basic concepts in mathematics, theoretical computer science, and physics in addition to introducing core quantum information topics.

In order to follow the course, a solid background in linear algebra and basic discrete probability is required. By the fourth year of your studies, you are likely to have been exposed to these topics through courses beyond the prerequisites. You may brush up your knowledge through the [open course](https://open.math.uwaterloo.ca) (<https://open.math.uwaterloo.ca>) on Math 235, Linear Algebra 2, and the [course notes](http://www.math.uwaterloo.ca/~dlmcleis/s230/) (<http://www.math.uwaterloo.ca/~dlmcleis/s230/>) for Stat 230, Probability.

# LEARNING OUTCOMES

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**By the end of this course students should be able to:**

Explain what quantum bits, states, and operations are
Explain what quantum algorithms are
Describe basic quantum algorithms and information processing protocols
Compare the power of classical and quantum algorithms formally
Describe algorithms for quantum Fourier transform, phase estimation, integer factorization, and unordered search
Analyze the efficiency and correctness of quantum algorithms and protocols
Design new quantum algorithms and protocols building upon the ones taught in class
Argue why quantum algorithms cannot "generically" solve NP-hard problems efficiently
Explain why quantum states do not "generically" store exponentially more information
Explain what quantum error-correction codes are, and how computation may be made fault-tolerant
Describe some basic quantum cryptographic protocols

# TENTATIVE COURSE SCHEDULE

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The lecture schedule will be posted on the course website on Learn as the course progresses.

# TEXTS / MATERIALS

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## Text book

Title / Name	Notes / Comments	Required
"An Introduction to Quantum Computing", by P. Kaye, R. Laflamme, and M. Mosca. Oxford University Press.	Electronic version is available through the UW library, and paper copies are available through the UW Bookstore.	Yes

<b>Title / Name</b>	<b>Notes / Comments</b>	<b>Required</b>
"Quantum Computation and Quantum Information", by M. Nielsen and I. Chuang. Cambridge University Press.	Optional, for reference.	No

### **Additional resources**

- [Video lectures](https://www.youtube.com/channel/UCfEnDrJhpxyIF85Efw3hhWw/videos) (https://www.youtube.com/channel/UCfEnDrJhpxyIF85Efw3hhWw/videos) for QIC 710 by Richard Cleve.
- [Lecture notes](https://cs.uwaterloo.ca/~watrous/QC-notes/) (https://cs.uwaterloo.ca/~watrous/QC-notes/) by John Watrous.
- Recording of [live lectures](http://pirsa.org/C14010) (http://pirsa.org/C14010) by Andrew Childs.

## **STUDENT ASSESSMENT**

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<b>Component</b>	<b>Value</b>
Assignments (8, short, roughly weekly)	60%
Midterm exam	15%
Final exam	20%
Participation (Piazza)	5%

The assessment schedule is listed below.

<b>Assessment</b>	<b>Date of posting</b>	<b>Due date</b>
Assignment 1	Jan. 15	Jan. 22
Assignment 2	Jan. 22	Jan. 29
Assignment 3	Jan. 29	Feb. 5

<b>Assessment</b>	<b>Date of posting</b>	<b>Due date</b>
Assignment 4	Feb. 5	Feb. 12
Practice exercises 1	Feb. 12	N/A
<b>Midterm exam</b>	Feb. 26	Mar. 5
Assignment 5	Mar. 5	Mar. 12
Assignment 6	Mar. 12	Mar. 19
Assignment 7	Mar. 26	Apr. 2
Assignment 8	Apr. 2	Apr. 9
Practice exercises 2	Apr. 9	N/A
<b>Final exam</b>	Apr. 17	Apr. 24

### **Assignments and exams:**

There will be eight short assignments, one midterm, and one final exam, which will be mailed out to you via [Crowdmark](https://crowdmark.com). (https://crowdmark.com) The assignments will also be posted on the course website on Learn. The assignments and exams are **due at 11:59 pm, Waterloo, ON, local time** on the due date. This is a hard deadline.

Crowdmark lets you upload solutions as many time as you wish before the deadline. We suggest the following strategy, especially to avoid last-minute glitches:

- Upload the solution to a question as soon as you have completed it.
- Do not try to submit your assignment close to the deadline.

Remark requests are due within one week of receiving the graded work. Please email the TAs for regarding this, with a concise message explaining why you think you received an erroneous mark.

You are allowed and encouraged to discuss the assignment questions with fellow students on Piazza or MS Teams or with the instructional team, as long as you do not ask for or reveal the crux of the solution. For example, you may point to the relevant lectures or other course materials, or you may clear ambiguity.

You are not allowed to discuss the exams with anyone other than the instructional team. Further information on the exams will be posted in due course.

See the sections on Piazza and academic integrity for more details.

## **Illness and INC:**

Please see the [Math accommodations webpage](https://uwaterloo.ca/math/accommodations) (https://uwaterloo.ca/math/accommodations ) for accommodations due to illness and other extenuating circumstances. We will try to accommodate such situations as best as we can. For example, in case of a short period of illness and a strong performance in the course, we expect to shift the weight to the remaining assessments.

To be eligible to receive an INC we require that you complete at least **five out of eight assignments and the midterm**, and that you obtained an **average of at least 60%** on these assessments.

## **ASSIGNMENT SCREENING**

Indications of violation of the course policies on assignments and exams will be noted by the graders, and passed on to the instructor for further action.

## **ADMINISTRATIVE POLICY**

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### **Lectures:**

The instructor will be delivering the lectures live on MS Teams during the scheduled lecture slots. The live lectures and office hours will be conducted on MS Teams, in the "Lectures" channel. If you registered early, you will receive the invitation to join the corresponding meetings. Due to the reading week and scheduled pause in March, there are multiple invitations. Information for attending the lectures will be posted on the course website. If possible in your time zone, and feasible with the technology available to you, we recommend that you attend the live lectures. In addition to giving some structure to your study schedule, this will also give you the opportunity to ask questions live. To ask questions, you may speak up if you consent to being recorded, or you may type your question.

The lectures will be recorded and posted on the course website and in the "Lectures" channel on MS Teams. You may follow the recording if the scheduled lecture slots are not compatible with your time zone. We recommend blocking off regular weekly slots to view the lectures, and to attend the office hours if you would like to ask questions about the lectures live.

## **Office hours:**

The time for the office hours have been chosen to accommodate all time zones which the students indicated. The office hours will be held on MS Teams, in the "Office hours" channel. If you registered early, you will receive the invitation to join the corresponding meetings. Due to the reading week and scheduled pause in March, there may be multiple invitations.

## **MS Teams:**

Download the MS Teams app for your device, and log in using your UW credentials to access the team for the course.

Students enrolled by Jan. 9 would have been added to the team for the course automatically. If not, join the team for the course by using the code: **2nz6ouu** . You may meet fellow students for live discussions on MS Teams in the "Student discussions" channel. Students may independently start separate meetings by clicking the "Meet now" icon in this channel. Please give your meeting a name, so that interested students can easily identify your meeting.

The rules for discussion of assignments or exams are as mentioned before, and in the sections for Piazza and academic integrity.

## **Piazza:**

We will use Piazza for asynchronous discussion. We have already invited you to join the Piazza discussion board if you enrolled by Jan. 9. You can also sign up at the [Piazza page](https://piazza.com/uwaterloo.ca/winter2021/co481cs467phys467) (<https://piazza.com/uwaterloo.ca/winter2021/co481cs467phys467>) for the course; please use your UW email to sign up.

We will use Piazza to discuss course material, assignments, and organizational issues. A part of your course mark will be based on your participation on Piazza. We will take into account the level of involvement as well as the quality of your questions and answers. Please be respectful and polite. Discussions on assignment questions are allowed, as long as you do not give away solutions. For example, you may point to the relevant lectures or other course materials, or you may clear ambiguity. If you are unsure if your post on Piazza gives away too much of a solution, please post it as a private post, i.e., visible to instructors only. We may then choose to make the post public if it is appropriate. You can freely discuss the material in the lectures and the textbook.

## **Contacting the instructor or TAs:**

Please email the instructor or TAs only for matters of a personal nature. Please post questions about course material, assignments, or general organization on Piazza so that all students can benefit from the answers. Due to the increased volume of emails during this period of online instruction, we will not respond to emails of the latter nature. When writing to us, use your UWaterloo email account, include the course number in the subject line, and include your full name and UWaterloo student number in the email. Note that for privacy reasons we are unable to answer emails from personal accounts.

## **Additional information on Academic Integrity:**

Education at Waterloo is valued highly also because of the high standards of academic integrity all of us jointly uphold. It is even more important in times of difficulty such as these, to adhere to these standards. In case you are in doubt about some course of action, consult one of the instructional team members, or the online [Academic Integrity Tutorial](https://uwaterloo.ca/library/research-supports/academic-integrity). (<https://uwaterloo.ca/library/research-supports/academic-integrity>) The tutorial explains what academic integrity means, with concrete examples.

While you may discuss the the assignments on Piazza or MS Teams, you are expected to complete the work you submit on your own. You are not allowed to discuss the exams on any forum with anyone other than the instructor or the TAs.

Here are some examples of behaviour that constitute cheating:

- discussing assignments with other students anywhere but Piazza or MS Teams,
- getting any help on an assignment or exam from anyone other than the instructor or the TAs,
- using any resources not provided by the instructors to help you with an assessment,
- joining/setting up a discussion forum other than Piazza or MS Teams for the purpose discussing or sharing material related to the course.

Note that helping someone by sharing your assignment is also considered cheating. You are not allowed to download old solutions to assignments, or consult outside textbooks, notes, research papers, etc., with the aim of finding a solution to a question on an assessment.

Here are some examples of behaviour that are perfectly fine:

- discussing course material with anyone,
- using outside resources to help you understand the course material,
- asking on Piazza for clarification or help getting started on assignment questions; we encourage you to do so,
- emailing the instructor and TAs for questions about the exams.

We will follow standard university procedures in case of a violation of academic integrity.



## **Mental Health Support:**

There are a number of resources available if you find yourself in a difficult situation. Please seek help if needed.

### On-campus Resources:

- Campus Wellness <https://uwaterloo.ca/campus-wellness/> (<https://uwaterloo.ca/campus-wellness/>)
- Counselling Services: [counselling.services@uwaterloo.ca/](mailto:counselling.services@uwaterloo.ca) ([mailto:counselling.services@uwaterloo.ca/](mailto:counselling.services@uwaterloo.ca)) 519-888-4567 ext 32655
- MATES: one-to-one peer support program offered by Federation of Students (FEDS) and Counselling Services: [mates@uwaterloo.ca](mailto:mates@uwaterloo.ca) (<mailto:mates@uwaterloo.ca>)
- Health Services: located across the creek from the Student Life Centre, 519-888-4096.

### Off-campus Resources:

- Good2Talk (24/7): Free confidential help line for post-secondary students. Phone: 1-866-925-5454
- Here 24/7: Mental Health and Crisis Service Team. Phone: 1-844-437-3247
- OK2BME: set of support services for lesbian, gay, bisexual, transgender or questioning teens in Waterloo. Phone: 519-884-0000 extension 213

## **Diversity:**

It is our intent that students from all diverse backgrounds and perspectives be well served by this course, and that students' learning needs be addressed both in and out of class. We recognize the immense value of the diversity in identities, perspectives, and contributions that students bring, and the benefit it has on our educational environment. Your suggestions are encouraged and appreciated. Please let us know ways to improve the effectiveness of the course for you personally or for other students or student groups. In particular,

- We will gladly honour your request to address you by an alternate/preferred name or gender pronoun. Please advise us of this preference early in the semester so we may make appropriate changes to our records.
- We will honour your religious holidays and celebrations. Please inform of us these at the start of the course.
- We will follow AccessAbility Services guidelines and protocols on how to best support students with different learning needs.

**Academic integrity:** In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and

responsibility. [Check [the Office of Academic Integrity](https://uwaterloo.ca/academic-integrity/) (https://uwaterloo.ca/academic-integrity/) for more information.]

**Grievance:** A student who believes that a decision affecting some aspect of his/her university life has been unfair or unreasonable may have grounds for initiating a grievance. Read [Policy 70, Student Petitions and Grievances, Section 4](https://uwaterloo.ca/secretariat-general-counsel/node/100) (https://uwaterloo.ca/secretariat-general-counsel/node/100) . When in doubt, please be certain to contact the department’s administrative assistant who will provide further assistance.

**Discipline:** A student is expected to know what constitutes academic integrity to avoid committing an academic offence, and to take responsibility for his/her actions. [Check [the Office of Academic Integrity](https://uwaterloo.ca/academic-integrity/) (https://uwaterloo.ca/academic-integrity/) for more information.] A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about “rules” for group work/collaboration should seek guidance from the course instructor, academic advisor, or the undergraduate associate dean. For information on categories of offences and types of penalties, students should refer to [Policy 71, Student Discipline](https://uwaterloo.ca/secretariat-general-counsel/node/97) (https://uwaterloo.ca/secretariat-general-counsel/node/97) . For typical penalties, check [Guidelines for the Assessment of Penalties](https://uwaterloo.ca/secretariat-general-counsel/node/131) (https://uwaterloo.ca/secretariat-general-counsel/node/131) .

**Appeals:** A decision made or penalty imposed under [Policy 70, Student Petitions and Grievances](https://uwaterloo.ca/secretariat-general-counsel/node/100) (https://uwaterloo.ca/secretariat-general-counsel/node/100) (other than a petition) or [Policy 71, Student Discipline](https://uwaterloo.ca/secretariat-general-counsel/node/97) (https://uwaterloo.ca/secretariat-general-counsel/node/97) may be appealed if there is a ground. A student who believes he/she has a ground for an appeal should refer to [Policy 72, Student Appeals](https://uwaterloo.ca/secretariat-general-counsel/node/99) (https://uwaterloo.ca/secretariat-general-counsel/node/99) .

**Note for students with disabilities:** [AccessAbility Services](https://uwaterloo.ca/disability-services/) (https://uwaterloo.ca/disability-services/) , located in Needles Hall, Room 1401, collaborates with all academic departments to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations to lessen the impact of your disability, please register with AccessAbility Services at the beginning of each academic term.

**Turnitin.com:** Text matching software (Turnitin®) may be used to screen assignments in this course. Turnitin® is used to verify that all materials and sources in assignments are documented. Students' submissions are stored on a U.S. server, therefore students must be given an alternative (e.g., scaffolded assignment or annotated bibliography), if they are concerned about their privacy and/or security. Students will be given due notice, in the first week of the term and/or at the time assignment details are provided, about arrangements and alternatives for the use of Turnitin in this course.

It is the responsibility of the student to notify the instructor if they, in the first week of term or

at the time assignment details are provided, wish to submit alternate assignment.