# New mathematics curriculum

(to be effective in the Fall 2015 term)

Last edited: May 20, 2016

**Disclaimer:** while all efforts have been made to present an accurate information here, in case of discrepancy with the Academic Calendar, the Academic Calendar shall prevail.

Note: the table of contents in the electronic version of this document contains hyperlinks which can be used for quick navigation if opened with appropriate software.

# Table of Contents

# Summary

## Phases and time points of the review

**Phase 1 (to be implemented beginning Fall 2015) - Revision of mathematics programs and other mathematically involved (except Engineering) programs**

At this Phase, we plan to delete almost fifty mathematics courses except MATH 1200, MATH 1300, MATH 1500, MATH 1700, MATH 2720, and Engineering mathematics courses. At the same time, we plan to introduce 47 new mathematics courses. Key features of the revised curriculum are: elimination of duplication of the material (in particular, there is no multiple versions of the same course for major and honours students, such as, for example MATH 2300 and MATH 2352, MATH 2720 and MATH 2750, MATH 3740 and MATH 3760); a small set of core mathematics courses that would be required in any mathematics program to facilitate movements between programs and simplify student advising; increased overall level of exposition, new rigorous first-year mathematics courses.

This document describes the Phase 1 of the revision in detail. We would like to emphasize that Math 1300, Math 1500, Math 1700, Math 2720 (restricted to Actuarial Mathematics students only), and engineering mathematics courses will remain to be offered at this Phase, but may be revised in Phase 2.

**Phase 2 (to be implemented beginning with Fall 2017 or later) - Revision of remaining courses, in particular of MATH 1300, MATH 1500, MATH 1700, and Engineering mathematics courses.**

Details on what exactly will be changed during this phase depend on consultations with other units using these courses.

## Transition to new curriculum

Detailed transition plan for students who are currently in the programs is included in this document. All efforts will be made to transition such students to new programs without any need to repeat courses provided certain minimum grades have been achieved in already completed courses. An individualized degree completion plan will be developed for each student.

## Entry requirements and acceptability of MATH 1300, MATH 1500, MATH 1700 in the new programs

We proposed to simplify entry requirements for the new programs to be:

- MATH 1232 (B) or MATH 1690 (B) or MATH 1700 (A) for honours programs;
- MATH 1232 (C+) or MATH 1690 (C+) or MATH 1700 (B) for major programs.

Requirement of one course for program entry will be consistent with current practices in other departments of the Faculty of Science. No further grade requirements in any courses (except needed for some prerequisites) will be imposed compared to the Faculty of Science regulations (C in each course for Honours, and C in each program specific course for Majors). The current first year courses MATH 1300, MATH 1500 and MATH 1700 would continue to run, and will be accepted in new programs, but with higher grade requirements. For example, whenever MATH 1232 (C) is a prerequisite, MATH 1700

(B) can be used. Students in the new mathematics programs will be strongly advised to complete new first year mathematics courses. To help the students who entered our programs with the old (current) 1st year math courses instead of the new ones, we will introduce a web-based self-study resource that covers the difference of material, familiarizes with proofs, epsilon-deltas, etc., possibly includes some consultations by a faculty member or a grad student (help centre).

**Note:** for 2015/16 academic year only, the lower entry requirements MATH 1700 (B) and MATH 1700 (C+) for honours and majors programs respectively can be used. This will accommodate students who were planning on entering our programs and were not aware of the upcoming revision with higher requirements.

## Other remarks

**MATH 1690** remains in the calendar in Phase 1, but will not be offered in 2015/2016 academic year. Formal deletion will be carried out at Phase 2. We have not offered MATH 1690 since 2008. New courses MATH 1230 and MATH 1232 will serve the purpose of MATH 1690.

**MATH 1200** remains in the calendar in Phase 1, but will likely not be offered at all or offered with a smaller enrollment/section count in 2015/2016 academic year. Formal deletion will be carried out at Phase 2. Among the programs that are not specifically described in this document, MATH 1200 is a required course only in Physics four year major and Statistics honours and four year major programs. Physics and Statistics are proposing course and program modifications that will use MATH 1240 in place of MATH 1200. Several other programs have MATH 1200 as elective. Other courses satisfying such elective requirements (e.g., listing at least two of MATH 1300, MATH 1500, MATH 1700) will remain to be taught, so such elective requirements can be satisfied even if MATH 1200 is not offered. The department will inform and consult with the corresponding units and increase enrollment in MATH 1300, MATH 1500, MATH 1700 accordingly to compensate for possible reduction or cancellation of MATH 1200.

**MATH 2720** remains in the calendar in Phase 1, but is modified to be restricted to be used by students in Actuarial Mathematics programs only. The new multivariable calculus course MATH 2150 needs MATH 2080 as a prerequisite, but there is no room to require MATH 2080 in Actuarial Mathematics programs. Therefore, MATH 2720 will continue to be used by Actuarial Mathematics programs, but all other students will be taking the new MATH 2150 if multivariable calculus is required for their degree. In Phase 2, an applied multivariable calculus course may be developed that will replace the role of MATH 2720 in Actuarial Mathematics programs.

**Courses that are planned to be offered every second year** are specifically listed as required or elective courses only in the proposed Mathematics Honours program. The prerequisites and the offerings are structured in such a way that students can fulfill the requirements of the program regardless of whether they begin the program in an odd or an even year, see Mathematics Honours and Mathematics 4 Year Major section of this document for more details.

# Table of courses to be deleted

| | |
|---|---|
| MATH 1190 | Topics in Mathematics (full year) |
| MATH 2202 | Fundamentals of Mathematical Analysis |
| MATH 2300 | Linear Algebra 2 |
| MATH 2352 | Advanced Linear Algebra (full year) |
| MATH 2400 | Applied Graph Theory |
| MATH 2450 | Combinatorial Mathematics (full year) |
| MATH 2500 | Introduction to Number Theory |
| MATH 2552 | Geometry of the Plane (full year) |
| MATH 2600 | Numerical Mathematics 1 |
| MATH 2730 | Sequences and Series |
| MATH 2750 | Intermediate Calculus (full year) |
| MATH 2800 | Ordinary Differential Equations with Applications 1 |
| MATH 3130 | Linear Spaces for Physicists |
| MATH 3220 | Set Theory |
| MATH 3230 | Metric Spaces |
| MATH 3240 | Topology 1 |
| MATH 3300 | Modern Algebra 1 |
| MATH 3310 | Modern Algebra 2 |
| MATH 3350 | Advanced Algebra (full year) |
| MATH 3400 | Combinatorics 1 |
| MATH 3430 | Modern Geometry |
| MATH 3450 | Theory of Numbers (full year) |
| MATH 3530 | Mathematical Problems in the Biological Sciences |
| MATH 3600 | Numerical Mathematics 2 |
| MATH 3700 | Applied Complex Analysis |
| MATH 3710 | Complex Analysis 1 |
| MATH 3740 | Methods of Advanced Calculus (full year) |
| MATH 3760 | Advanced Calculus (full year) |
| MATH 3800 | Ordinary Differential Equations with Applications 2 |
| MATH 3810 | Partial Differential Equations 1 |
| MATH 3820 | Introduction to Mathematical Modelling |
| MATH 4200 | Topology 2 |
| MATH 4230 | Algebraic Topology |
| MATH 4250 | Mathematical Logic (full year) |
| MATH 4310 | Applied Matrix Analysis |
| MATH 4350 | Modern Algebra (full year) |
| MATH 4400 | Combinatorics 2 |
| MATH 4410 | Graphs, Codes and Designs |
| MATH 4420 | Finite Geometry |
| MATH 4430 | Introduction to Elliptic Curves |
| MATH 4610 | Introduction to Finite Elements and Boundary Elements |
| MATH 4700 | Applied Functional Analysis |
| MATH 4710 | Complex Analysis 2 |
| MATH 4730 | Tensor and Variational Calculus |
| MATH 4750 | Real Variables (full year) |
| MATH 4800 | Dynamical Systems: Theory and Applications |
| MATH 4810 | Partial Differential Equations 2 |

## Table of courses to be introduced

is a part of the Table of Contents of this document. For each course, we provide a tentative course offering, Aurora description, and detailed list of topics later in this document. **Note:** the detailed list of topics may be slightly different than listed here depending on instructor.

# Recommendation for students intending to obtain a B.Sc. General Degree with Major in Mathematics or Minor in Mathematics

New requirements for these degrees can be viewed in Changes to the B.Sc. General Degree and Minor Requirements (Faculty of Science) section of this document.

**Recommended 2000-level courses** are: MATH 2030, MATH 2040, MATH 2070, MATH 2090, MATH 2140, MATH 2160.

**Recommended 3000-level courses** are: MATH 3330 (after MATH 2090), MATH 3360 (after MATH 2030), MATH 3370 (after MATH 2070).

**MATH 1240 prerequisite will NOT be waived starting with Summer 2016, even if you previously completed MATH 1200.**

**MATH 2080 is not recommended** unless you are really mathematically inclined.

Some new courses have the same (or almost the same) title as some old courses, but different content and prerequisite requirements. More specifically:

- **MATH 2090 Linear Algebra 2** is more advanced than the old MATH 2300.
- **MATH 2150 Multivariable Calculus** is more advanced than the continuing MATH 2720. From now on, MATH 2720 will be restricted to students in Actuarial Mathematics programs and will **not** be available for general degree or minor in math. Also note that MATH 2180 requires completion of MATH 2080, which is a challenging course. It is generally advised to choose other 2000-level courses listed in the beginning of this page.
- **MATH 2170 Number Theory 1** is more advanced than the old MATH 2500 and requires MATH 2020 as a pre- or co-requisite, which requires MATH 2090. It is generally advised to choose other 2000-level courses listed in the beginning of this page.

# Recommendation for Engineering students intending to obtain a minor in mathematics

Here is the relevant portion of the University Calendar:
*A Minor in Mathematics is available to Engineering students. The minimum requirements are 24 credit hours of mathematics courses subject to the following constraints: (1) the students must notify their home department that they are pursuing the minor; (2) up to 12 credit hours of mathematics courses in a student's engineering program may be counted toward the minor; (3) the student must complete at least 6 credit hours of courses from the mathematics department at the 3000 level or higher that are not included as part of the curriculum in the student's engineering program; and (4) approval of the Department of Mathematics is required for courses outside of the regular engineering program.*

**2000-level courses** that can be considered are: MATH 2030, MATH 2040, MATH 2070, MATH 2090, MATH 2140, MATH 2160 (not to be held with MATH 2120 or another numerical analysis course). MATH 2080 would be very challenging, but interesting if you want to learn some fundamentals of mathematical analysis with proofs.

**3000/4000-level courses** that can be considered are: MATH 3330 (after MATH 2090), MATH 3360 (after MATH 2030), MATH 3370 (after MATH 2070), MATH 3420 (after MATH 2120, MATH 2130, and MATH 2090), MATH 3460 (after MATH 3132), MATH 3340 (after MATH 3132), MATH 4330 (after MATH 2120 and MATH 2080), MATH 4370 (after MATH 2090), MATH 4390 (after MATH 2120 and MATH 2130), MATH 4920 (with permission).

**Note on MATH 3460 and MATH 3340:** while they may seem to be the same as the old MATH 3810 and MATH 3700, this is actually not the case, and the new courses are more challenging and would follow a more theoretical approach.

**Other courses** may also be acceptable, but they may require extra prerequisites. If you are really interested in a specific math course, and you believe you have enough background to succeed in it, feel free to contact the instructor of the course to discuss your situation.

**Obtaining approval:** in general, you would need to contact the instructor of the course first (include a list of all mathematics courses that you completed with marks in your request), and after that contact the Associate Head Undergraduate (either instructor's signature on the dept. permission form or a copy of an email from the instructor indicating consent is needed).

# Transition plan

**NOTE: this plan will be used as a guide for transition to the new curriculum. Specific decisions on program and course substitutions will be made by departmental student advisors and may be different depending on various considerations.**

### Transition from Current to Revised Mathematics Curriculum

The Department of Mathematics is planning curriculum revision which will commence in September 2015. This first phase of the revision is focused on mathematics and joint mathematics programs. Most current 1000 level courses will remain to be taught and more advanced versions for mathematically inclined students will be offered. The structure of courses at the 2000, 3000, and 4000 levels will be quite different; however, the core material will remain the same. This document outlines the transition plan for affected students. There are currently 29 students in their second or third year in programs which are significantly affected (Mathematics Honours, Mathematics Four Year Major, Mathematics – Physics and Astronomy Joint Honours, Applied Mathematics with Economics/Computer Science/Statistics option, Mathematics – Computer Science Joint Honours, Statistics – Mathematics Joint Honours).

Currently students in these programs follow the program guide outlined in the university calendar but they have optional courses and electives in the upper years of the program which makes transition between programs less prescribed than might be found in the structured professional programs. Current and prospective students will receive notification about the revised curriculum as soon as possible following approval of the new curriculum. Students will be informed of how the Department plans to perform transition to the new curriculum. This notification will be made via class announcements during Winter 2015 and Summer 2015 terms, e-mails and notices on the Department of Mathematics website. In addition, there will be several information sessions for such students. The transition plan will also be discussed with the student advisors of the Faculty of Science.

There will be no gradual transition to new curriculum. Compared with the current curriculum, only 1000-level introductory courses (MATH 1300, MATH 1500, MATH 1700) and Engineering mathematics courses will be taught, while other mathematics courses will be deleted/discontinued and replaced with the new courses. MATH 2720 will remain to be taught, but enrollment will be restricted to students in Actuarial Mathematics programs only (more specifically, joint Statistics - Actuarial Mathematics honours program, Actuarial Mathematics program in the Faculty of Science and Actuarial Mathematics program in the School of Business). In other programs which require a multivariable calculus course, the new MATH 2150 will be used. General degree B.A. and B.Sc. students will have sufficient choice of courses on the second year level from the new curriculum without access to MATH 2720.

Students who require transition to the revised curriculum will meet with a faculty member from the Department of Mathematics to develop an individualized completion plan. The department plans to assign three faculty member to serve as such advisors during the transition period. Most common scenarios are outlined below, but some decisions will be made on a case by case basis. Due to a small number of students involved, this is a practical way of handling the transition.

In 2015/16 academic year, the new courses will be taught for the first time, and all students will come with the current courses as prerequisites. Instructors of the new courses will make special arrangements

(handouts and online material, special lectures and/or tutorials) to cover the required minor differences in the background material. All faculty members of the Department of Mathematics have agreed to provide such special arrangements to facilitate transition to the new curriculum.

**1. Bridging students who completed introductory 1000-level courses to the new mathematics programs**

New mathematics programs will require four core courses at the first year level: MATH 1220, MATH 1230, MATH 1232, and MATH 1240. The following substitutions will be allowed, provided the corresponding grade requirement (as specified in the program chart) has been achieved:

| New course | Allowed substitution |
|---|---|
| MATH 1220 | MATH 1300 |
| MATH 1230 | MATH 1500 or MATH 1510 |
| MATH 1232 | MATH 1700 or MATH 1710 |

In same cases the grade required for substitution is higher than the current program requirement. Since students have not been notified of a change in requirement, the old requirement will be considered sufficient for students taking the introductory versions of the courses before 2015/16. For example, for a student taking MATH 1700 in Winter 2015, it would be sufficient to attain a mark of B to fulfill the requirement of MATH 1232 in Mathematics honours program. Starting with Fall 2015, a mark of A will need to be attained as per the proposed program chart.

Students who completed the introductory versions of the above courses will be referred to a web-based resource (which will be developed by July 1, 2015) covering difference of material between the more rigorous and the introductory versions of the course.

Students who have already completed MATH 1200 will not be required to complete MATH 1240, and will be referred to the above mentioned web-based resource. The prerequisite of MATH 1240 in MATH 2030, MATH 2070, and MATH 2080 will be waived for such students. MATH 1200 is planned not to be offered in 2015/16 academic year, and likely to be deleted in the future. The students who have not completed MATH 1200, will take MATH 1240.

**2. Transition for students who are already in a mathematics program**

Primary way to transition such students to the new programs will be the use of the following table. All courses below are 3 credit hour courses, except some current 6 credit hour courses indicated by "(6)". Completion of any revised program will require the same number of credit hours as in the corresponding current program. We anticipate that most transitioning students will be able to complete the new programs in the same amount of time as the corresponding current program, with exception of some course repetitions caused by low grades.

Certain combinations of courses from the current curriculum will replace certain combinations of courses from the new curriculum, as described in the comments column. In case there is no

correspondence to the new curriculum, a student will receive a credit for the corresponding level mathematics course which will be considered towards mathematics elective requirements, i.e., the requirements of certain number of credit hours of mathematics at certain level when no specific course numbers are listed in the program chart. In a rare case if a student completely fulfills such elective requirement at certain level and has an extra unallocated credit, the extra credit can be considered towards specific required courses and will be evaluated by a departmental student advisor.

| Completed course in the current curriculum | Will satisfy the program requirement of the following course(s) in the new curriculum | Comments |
|---|---|---|
| MATH 2202 | MATH 2080 | New applied mathematics with option (computer science/economics/statistics) programs will require MATH 2080, while currently these programs do not require the corresponding MATH 2202. Currently there are five required 2nd year courses in these programs: MATH 2300, MATH 2600, MATH 2720, MATH 2730, MATH 2800. If a student completed no more than three of these courses, they will be required to complete MATH 2080. Otherwise, it will be strongly recommended to complete MATH 2080, but an option will be given to replace MATH 2080 requirement with 3 credit hours of mathematics courses at 3000 or 4000 level. |
| MATH 2300 | MATH 2090 | |
| MATH 2352 (6) | MATH 2090 and 3 credit hours of 2nd year mathematics | |
| MATH 2400 | MATH 2070 | |
| MATH 2450 (6) | MATH 2030 and 3 credit hours of 2nd year mathematics | |
| MATH 2500 | MATH 2170 | |
| MATH 2552 (6) | 6 credit hours of 2nd year mathematics | |
| MATH 2600 | MATH 2160 | |
| MATH 2720 | MATH 2150 | If a mark of B or better has been achieved in MATH 2720* |

| | | |
|---|---|---|
| MATH 2730 | 3 credit hours of 2nd year mathematics | |
| MATH 2750 | MATH 2150 and 3 credit hours of 2nd year mathematics | |
| MATH 2800 | 3 credit hours of 2nd year mathematics | A different and more advanced differential equations course will be taught on the third year level as MATH 3440 |
| MATH 3220 | MATH 3480 | |
| MATH 3230 | MATH 2180 | |
| MATH 3240 | MATH 3390 | |
| MATH 3300 | 3 credit hours of 3rd year mathematics | If both MATH 3300 and MATH 3310 have been completed with a mark of B or better, the requirements of MATH 2020 and MATH 3320 will be considered satisfied* |
| MATH 3310 | 3 credit hours of 3rd year mathematics | If both MATH 3300 and MATH 3310 have been completed with a mark of B or better, the requirements of MATH 2020 and MATH 3320 will be considered satisfied* |
| MATH 3350 (6) | MATH 2020 and MATH 3320 | |
| MATH 3400 | MATH 2030 or 3 credit hours of 3rd year mathematics | |
| MATH 3430 | 3 credit hours of 3rd year mathematics | |
| MATH 3450 (6) | MATH 4450 and 3 credit hours of 3rd year mathematics | |
| MATH 3530 | MATH 4380 | |
| MATH 3600 | MATH 3420 | |
| MATH 3700 | MATH 3340 | If a mark of B+ or better has been achieved in MATH 3700* |
| MATH 3710 | MATH 3340 | |
| MATH 3740 (6) | MATH 3470 and MATH 3472 | If a mark of B+ or better has been achieved in MATH 3740* |

| | | |
|---|---|---|
| MATH 3760 (6) | MATH 3470 and MATH 3472 | |
| MATH 3800 | MATH 3440 | |
| MATH 3810 | MATH 3460 | |
| MATH 3820 | MATH 2140 | |
| MATH 4200 | 3 credit hours of 4th year mathematics | |
| MATH 4230 | MATH 4270 | |
| MATH 4250 (6) | MATH 3410 and 3 credit hours of 4th year mathematics | |
| MATH 4310 | MATH 4370 | |
| MATH 4350 (6) | 6 credit hours of 4th year mathematics | |
| MATH 4400 | MATH 3360 | |
| MATH 4410 | 3 credit hours of 4th year mathematics | |
| MATH 4420 | 3 credit hours of 4th year mathematics | |
| MATH 4430 | 3 credit hours of 4th year mathematics | |
| MATH 4610 | 3 credit hours of 4th year mathematics | |
| MATH 4700 | 3 credit hours of 4th year mathematics | |
| MATH 4710 | MATH 4290 | |
| MATH 4730 | MATH 4360 | |
| MATH 4750 (6) | MATH 4260 and MATH 4280 | |
| MATH 4800 | MATH 4320 | |
| MATH 4810 | MATH 4460 | |
| MATH 4920 | | Students who completed a topics course with material corresponding to a course in the new |

| | | |
|---|---|---|
| | | curriculum will receive credit for the corresponding new course. |

*For all program substitutions requiring certain grade as described in the table, if a student has not achieved the required grade and has not completed any subsequent courses listing the course in question as a prerequisite, the student will need to repeat the course by taking the new version of the course. If a student has not achieved the required grade but has completed at least one subsequent course listing the course in question as a prerequisite, the program substitution will be granted.

**3. Transition for B.Sc. or B.A. general and Education programs**

The requirements in these programs are not course specific and require certain number of mathematics courses at a certain level. Students will be able to take courses from new curriculum using already completed courses from current curriculum as prerequisites. New curriculum offers a greater variety of courses at the second year level, which will be particularly suitable for students in these programs. Students will be contacted by e-mail through their Faculties and will be referred to the corresponding section of the website of the department of mathematics describing their options in the new curriculum.

**4. Transition for joint Statistics - Actuarial Mathematics Honours program, Actuarial Mathematics program in the Faculty of Science and Actuarial Mathematics program in the School of Business**

In Year 1 of their programs the students will complete MATH 1220, MATH 1230, MATH 1232 or the allowed substitutions as per program description and the table in Section 1 of this document. Year 2 requirement will change from “MATH 2300, MATH 2720 and MATH 2730” to “MATH 1240 and MATH 2720”. Students beginning Year 2 in 2015/16 academic year, will complete the new requirement. Students in higher years will have the mathematics requirement completed by current curriculum; either of MATH 2300 or MATH 2730 can be considered as fulfilling the requirement of MATH 1240 in these programs. The programs do not require any mathematics courses in Years 3 and 4. There are approximately 150 students in these programs every year, they will be notified of the changes in program requirements by e-mail through their Faculty/School and through class announcements in MATH 2720, which will run exclusively for students in these programs in 2015/16.

**5. Transition for Honours and Major Statistics programs**

For Year 1 of these programs, transition can be performed as described in Section 1 of this document (“MATH 1200, MATH 1300, MATH 1500, MATH 1700” requirement will be changed to “MATH 1220, MATH 1230, MATH 1232, MATH 1240”). In Year 2, “MATH 2300, MATH 2720, MATH 2730” requirement will be changed to “MATH 2030, MATH 2080, MATH 2150” and in Years 3 and 4, “6 credit hours from MATH 2202, MATH 2600, MATH 2800, MATH 3230, MATH 3540, MATH 3600, MATH 3700, MATH 3740 (6), MATH 3800, MATH 3810” requirement will be changed to “6 credit hours from MATH 2140, MATH 2160, MATH 2180, MATH 3340, MATH 3440, MATH 3460, MATH 3470, MATH 3472”. For Years 2-4, transition can be performed following Section 2 of this document. There are 29 affected students, who will be notified by e-mail through the Department of Statistics.

## 6. Concluding remarks

This transition plan will address most of the current or prospective students in the affected programs. The structure of these programs often allows options and electives on various levels, including higher years. While all the efforts have been made to cover most situations, in some circumstances the department Head or the Dean may approve program completion by substituting courses or other means.

## 7. Sample completion plan

There are currently 6 students who are about to complete their 2nd year of Applied Mathematics with Economics option Program, which is the largest group of students in a specific year of a Mathematics program who will need to be transitioned to the new curriculum. (There are 5 students in their 2nd year and 1 student in his 3rd year of Mathematics honours program. There are 4 students in their 2nd year and 2 students in their 3rd year of Mathematics 4 year major program.) The table below contains a hypothetical completion plan for mathematics courses for such a student made following Sections 1 and 2 of this document, assuming the grades do not require course repetitions. The student would have yet to complete 30 credit hours of mathematics in the current program (3 credit hours from: MATH 2450 (6), MATH 2500, MATH 2552 (6), or any 3000 / 4000 level MATH course; and MATH 2400, MATH 3600, MATH 3700, MATH 3740 (6), MATH 3800, MATH 3810, MATH 3820, MATH 4310), and the completion plan also has 30 credit hours of mathematics courses to complete.

| Completed courses from current program | Requirements in new program | Comments |
|---|---|---|
| MATH 1200 | MATH 1240 | fulfilled, prerequisite of MATH 1240 in MATH 2070 and MATH 2080 will be waived |
| MATH 1300 | MATH 1220 | fulfilled |
| MATH 1500 | MATH 1230 | fulfilled |
| MATH 1700 | MATH 1232 | fulfilled |
| MATH 2300 | MATH 2090 | fulfilled |
| MATH 2600 | MATH 2160 | fulfilled |
| MATH 2720 | MATH 2150 | fulfilled |
| MATH 2730 | 3 credit hours of “6 credit hours from:<br>MATH 2030, MATH 2170, MATH 2040, or any 3000 / 4000 level MATH course” | fulfilled |
| MATH 2800 | 3 credit hours of “6 credit hours | fulfilled |

| | | |
|---|---|---|
| | from:<br>MATH 2030, MATH 2170, MATH 2040, or any 3000 / 4000 level MATH course” | |
| Fall 2015 | | |
| | MATH 2080 | strongly recommended to be completed, but can be replaced with 3 credit hours of mathematics courses at 3000 or 4000 level; |
| | MATH 2140 | |
| | MATH 4370 | can be taken in Fall 2016 |
| Winter 2016 | | |
| | MATH 2070 | |
| | MATH 2180 | |
| | MATH 3420 | can be taken in Winter 2017 |
| Fall 2016 | | |
| | MATH 3440 | |
| | MATH 3470 | |
| Winter 2017 | | |
| | MATH 3340 | |
| | MATH 3460 | |

# General remarks to be included in the Department of Mathematics' introductory section of the calendar:

The following courses may not be offered every year, but are usually offered once every second year: MATH 3370, MATH 3410, MATH 3480, MATH 4240, MATH 4300, MATH 4320, MATH 4330, MATH 4340, MATH 4360, MATH 4380, MATH 4390, MATH 4460, and MATH 4470. Please refer to Aurora Student for courses offered in the current year and to the website of the Department of Mathematics for the planned schedule of future course offerings.

All courses (unless otherwise specified) may be taken in a different year than indicated. Each program chart indicates one possible arrangement of courses and is meant to be a guide around which students can plan their programs with a view to satisfying the prerequisites of the required courses.

The website of the Department of Mathematics has specific suggestions regarding selection of mathematics electives depending on student's interests and future plans. In particular, certain courses are recommended for students interested in pursuing a graduate degree in mathematics.

Mathematics courses that are not currently offered or credit transfers from other institutions may be accepted for credit in any program of the Department of Mathematics, if specifically approved by the Department. Note that old non-honours courses or credit transfers of particularly applied mathematics courses will normally not be accepted in honours programs. Students can contact an advisor in the Department to assess their specific situation.

# Changes to the B.Sc. Honours Degree in Mathematics

## New Mathematics Honours program requirements:

**To enter** the Honours program in Mathematics, a student must have completed at least 24 credit hours with a minimum GPA of 3.00, and also obtained a minimum grade of "B" in either MATH 1232 or MATH 1690, or a minimum grade of "A" in MATH 1700.

**To continue** in the Mathematics Honours program, students must maintain a minimum GPA of 3.00, and complete a minimum of 9 credit hours during each Fall and Winter Term.

**To graduate** with the B. Sc. Honours degree, a student must maintain a minimum 3.00 GPA and achieve a minimum grade of "C" in all courses that make up the 120 credit hours of the degree.

**List of Year 2 Mathematics electives** (of which two are required for the core requirements): MATH 2030, MATH 2040, MATH 2070, MATH 2140, MATH 2160,MATH 2170.

**Other electives normally allowed are:**

Statistics: STAT 2000, STAT 2400, STAT 3470, STAT 3480, STAT 3400 (STAT 3500), STAT 3800 (STAT 3600), STAT 4100 (STAT 4140), STAT 4520, STAT 4530, STAT 4580, STAT 4590, STAT 4600, STAT 4620, STAT 4630,STAT 4690.

Physics: PHYS 2380, PHYS 2600, PHYS 2610, PHYS 2650, PHYS 3670, PHYS 3680, PHYS 3650, PHYS 3660, PHYS 3630, PHYS 3640, PHYS 3380, PHYS 4390, PHYS 4620, PHYS 4640, PHYS 4650.

Chemistry: CHEM 2280, CHEM 2290, CHEM 3360, CHEM 3370, CHEM 4640, CHEM 4650.

Economics: ECON 2010, ECON 2030, ECON 3010, ECON 3030, ECON 4040, ECON 4042.

Mechanical Engineering: MECH 3490.

Other courses may be chosen with permission of the department. Students are required to obtain the approval of the department concerning their choice of electives.

## Proposed Mathematics Honours Program Chart:

<table>
<tr><td colspan="4">4.9.2 Mathematics</td></tr>
<tr><td>YEAR 1</td><td>YEAR 2</td><td>YEAR 3</td><td>YEAR 4</td></tr>
<tr><td colspan="4">MATHEMATICS HONOURS 120 CREDIT HOURS</td></tr>
<tr><td>MATH 1220[1],<br>MATH 1230[1],<br>MATH 1232[1],<br>MATH 1240</td><td>MATH 2020, MATH 2080, MATH 2090, MATH 2150, MATH 2180<br><br>6 credit hours from the following list:<br>MATH 2030, MATH 2040, MATH 2070, MATH 2140, MATH 2160[2], MATH 2170</td><td colspan="2" rowspan="2">36 credit hours of Mathematics courses, which must include the following:<br><br>MATH 3320, MATH 3340, MATH 3390, MATH 3440, MATH 3470, MATH 3472;<br><br>and one of the two concentrations listed below:<br><br>Applied and Computational Mathematics Concentration:<br><br>MATH 3420, MATH 3460, MATH 4370;<br>and additional 9 credit hours to be chosen from:<br>MATH 3322, MATH 3330, MATH 4280, MATH 4320[3], MATH 4330[3], MATH 4380[3], MATH 4390[3], MATH 4440, MATH 4460[3]<br><br>Pure Mathematics Concentration:<br>MATH 3322, one of (MATH 3410[3] or MATH 3480[3]), MATH 4260, and one of (MATH 4300[3] or MATH 4340[3] or MATH 4360[3]);<br>and additional 6 credit hours to be chosen from: MATH 3360, MATH 4240[3], MATH 4270, MATH 4280, MATH 4290, MATH 4450, MATH 4470[3].</td></tr>
<tr><td colspan="2">STAT 1000, COMP 1010</td></tr>
<tr><td colspan="2">The following must be completed in Year 1 or Year 2:<br><br>6 credit hours from the Faculty of Arts, which should include the required “W” course</td><td colspan="2">12 credit hours of electives from: MATH 2030, MATH 2070, MATH 2160 (if not taken as a required 2nd year elective), MATH 2170 and all Year 3 and 4 mathematics courses</td></tr>
<tr><td colspan="2">15 credit hours of electives (review above list for acceptable electives)</td><td colspan="2">12 credit hours of approved (not necessarily mathematics) electives (review above list for acceptable electives)</td></tr>
<tr><td>30 credit hours</td><td>30 credit hours</td><td>30 credit hours</td><td>30 credit hours</td></tr>
</table>

NOTES:

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (A) in place of MATH 1220, MATH 1500 (A) or MATH 1510 (A) in place of MATH 1230, MATH 1700 (A) or MATH 1710 (A) in place of MATH 1232, MATH 1690 (B) in place of MATH 1230 and MATH 1232.

2 Department strongly recommends choosing MATH 2160 as one of the electives in Year 2.

3 These courses may not be offered every year, but are usually offered once every second year. Please refer to Aurora Student for courses offered in the current year and to the website of the Department of Mathematics for the planned schedule of future course offerings.

## Old Mathematics Honours Program Requirements:

**To enter** the Honours program in Mathematics, a student must have completed at least 24 credit hours with a minimum GPA of 3.00, and also obtained a minimum grade of "B" in the following courses: MATH 1300; and one of MATH 1700 or MATH 1690 (or equivalent).

**To continue i**n the Mathematics Honours program, students must maintain a minimum GPA of 3.00, and complete a minimum of 9 credit hours during each Fall and Winter Term.

**To graduate** with the B. Sc. Honours degree, a student must maintain a minimum 3.00 GPA and achieve a minimum grade of "C" on all courses that make up the 120 credit hours of the degree.

The program for students who elect Honours in Mathematics is as follows:

Year 2 Mathematics courses as indicated in the chart below and nine (9) credit hours from such fields as physics, chemistry, actuarial mathematics, computer science, statistics, philosophy, or economics. Other fields may be elected with the approval of the department.

Year 3 Mathematics courses as indicated in the chart below and electives to be chosen from the subject fields below or a third or forth year Mathematics course not already elected. Students performing satisfactorily in Year 2 may obtain permission to take an additional course.

Year 4 Mathematics courses as indicated in the chart below and electives to be chosen from the subject fields below or a third or forth year Mathematics course not already elected. Students performing satisfactorily in Year 3 may obtain permission to take an additional course.

**Electives** normally allowed are:

Statistics: STAT 2000, STAT 2400, STAT 3470, STAT 3480, STAT 3400 (STAT 3500), STAT 3800 (STAT 3600), STAT 4100 (STAT 4140), STAT 4520, STAT 4530, STAT 4580, STAT 4590, STAT 4600, STAT 4620, STAT 4630,STAT 4690.

Physics: PHYS 2380, PHYS 2600, PHYS 2610, PHYS 2650, PHYS 3670, PHYS 3680, PHYS 3650, PHYS 3660, PHYS 3630, PHYS 3640, PHYS 3380, PHYS 4390, PHYS 4620, PHYS 4640, PHYS 4650.

Chemistry: CHEM 2280, CHEM 2290, CHEM 3360, CHEM 3370, CHEM 4640, CHEM 4650.

Economics: ECON 2530, ECON 2700, ECON 3700, ECON 3730, ECON 4120, ECON 4130.

Mechanical Engineering: MECH 3490.

Other courses may be chosen with permission of the department. Students are required to obtain the approval of the department concerning their choice of electives.

## Old Mathematics Honours Program Chart:

<table>
<tr><td colspan="4">4.9.2 Mathematics</td></tr>
<tr><td>YEAR 1</td><td>YEAR 2</td><td>YEAR 3</td><td>YEAR 4</td></tr>
<tr><td colspan="4">MATHEMATICS HONOURS[4] 120 CREDIT HOURS</td></tr>
<tr><td>MATH 1300[1] (B)<br><br>MATH 1690 (6) (B) (or MATH 1500[1] and MATH 1700[1] (B))</td><td>MATH 2202, MATH 2352 (6),MATH 2600, MATH 2750 (6),MATH 2800</td><td colspan="2" rowspan="2">48 credit hours[3] of 3000 and 4000 level Mathematics[4] courses, which must include the following:<br><br>MATH 3230, MATH 3400, MATH 3760 (6), MATH 3800; and one of the two concentrations listed below:<br><br>Applied and Computational Mathematics Concentration:<br><br>MATH 3300 or MATH 3350 (6); MATH 3700 or MATH 3710; and at least 12 credit hours from the former 136.351, MATH 3600, MATH 3810, MATH 3820, MATH 4310, MATH 4610, MATH 4800 or MATH 4810<br><br>Pure Mathematics Concentration:<br><br>MATH 3350 (6), MATH 3710 and at least 12 credit hours from MATH 3240, MATH 4200, MATH 4350 (6), MATH 4410 or MATH 4420, MATH 4710, MATH 4750 (6)</td></tr>
<tr><td colspan="2">The following can be completed in Year 1 or Year 2:<br><br>STAT 1000[2] , COMP 1010[2]<br><br>6 credit hours from the Faculty of Arts, which should include the required “W” course</td></tr>
<tr><td colspan="2">18 credit hours of electives (review above list for acceptable electives)</td><td colspan="2">12 credit hours of approved electives (review above list for acceptable electives)</td></tr>
<tr><td>30 credit hours</td><td>30 credit hours</td><td>30 credit hours</td><td>30 credit hours</td></tr>
</table>

NOTES:

1 MATH 1510 or MATH 1520 may be taken in place of MATH 1500; MATH 1310 may be taken in place of MATH 1300; MATH 1710 may be taken in place of MATH 1700. MATH 1690 may be taken in place of both MATH 1500and 1700).

2 STAT 1000 and COMP 1010 must be completed by the end of Year 2.

3 Students considering graduate work in pure mathematics should note that many graduate schools may require a student to rectify any deficiencies in MATH 4200, MATH 4210, MATH 4350, MATH 4710, MATH 4720 and MATH 4750.

4 MATH 3200, MATH 3210, MATH 3740 and MATH 3910 cannot be used in an Honours program.

5 IMPORTANT: The four year Major programs need not be completed in the manner prescribed in the charts above. Each chart indicates one possible arrangement of the required courses and is meant to be a guide around which students can plan their programs with a view to satisfying the prerequisites of the required courses. Please refer to the text above for the minimum requirements for entry to a four year Major.

(Letters in brackets indicate minimum prerequisite standing for further study. The number 6 in brackets indicates a 6 credit hour course.)

# Changes to the B.Sc. Four Year Major Degree in Mathematics

## New Four Year Major Requirements:

**To enter** the Four Year Major in Mathematics, a student must have a minimum grade of "C+" in either MATH 1232 or MATH 1690, or a minimum grade of "B" in MATH 1700, and to have satisfied all Faculty requirements for entry to the program.

**To continue** in the Mathematics Major degree program students must maintain a minimum DGPA of 2.00.

**To graduate** with the B. Sc. Major degree, a student must achieve a minimum GPA of 2.00 on the 120 credit hours that contribute to the degree, and a minimum grade of “C” in each of the Major Program Specific courses (see below).

**Major Program Specific Courses**

MATH 1220, MATH 1230, MATH 1232, MATH 1240, MATH 2020, MATH 2030, MATH 2080, MATH 2090, MATH 2150, MATH 2160, MATH 2180, MATH 3320, MATH 3322, MATH 3340, MATH 3360, MATH 3390, MATH 3440, MATH 3460

**List of Year 2 Mathematics Electives** (of which two are required for the core requirements): MATH 2030, MATH 2040, MATH 2070, MATH 2140, MATH 2160,MATH 2170.

**Other electives** can be chosen from the general list of approved electives, as in the honours program. Students can also use mathematics courses as electives. For advice on these points, students should talk to a faculty member in the department.

## New Mathematics Major Program Chart:

<table>
<tr><td colspan="3">MATHEMATICS FOUR YEAR MAJOR 120 CREDIT HOURS</td></tr>
<tr><td>MATH 1220[1],<br>MATH 1230[1],<br>MATH 1232[1],<br>MATH 1240</td><td>MATH 2020, MATH 2080, MATH 2090, MATH 2150, MATH 2180<br><br>6 credit hours from the following:<br>MATH 2030, MATH 2040, MATH 2070, MATH 2140, MATH 2160, MATH 2170</td><td>A total of 48 credit hours from MATH 2030, MATH 2070, MATH 2160, MATH 2170 and any 3000/4000 level Mathematics courses, which must include:<br><br>MATH 2030 (if not already taken as Year 2 elective), MATH 2160 (if not already taken as Year 2 elective), MATH 3320, MATH 3322, MATH 3340, MATH 3360, MATH 3390, MATH 3440, MATH 3460</td></tr>
<tr><td colspan="2">STAT 1000, COMP 1010<br><br>15 credit hours of approved electives<br><br>The following must be completed in Year 1 or Year 2:<br><br>6 credit hours from the Faculty of Arts, which should include the required “W” course</td><td>12 credit hours of approved electives</td></tr>
</table>

NOTES:

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (B) in place of MATH 1220, MATH 1500 (B) or MATH 1510 (B) in place of MATH 1230, MATH 1700 (B) or MATH 1710 (B) in place of MATH 1232, MATH 1690 (C+) in place of MATH 1230 and MATH 1232.

## Old Four Year Major Requirements:

**To enter** the four year Major in Mathematics, a student must have a "C+" in either MATH 1690 or in two of MATH 1300, MATH 1500 and MATH 1700 or any equivalent and have satisfied all Faculty requirements for entry to the program.

**To continue** in the Mathematics Major degree program students must maintain a minimum DGPA of 2.00.

**To graduate** with the B. Sc. Major degree, a student must achieve a minimum GPA of 2.00 on the 120 credit hours that contribute to the degree, and a minimum grade of "C" in each of the Major Program Specific courses (see below).

**Major Program Specific Courses**
MATH 1300, MATH 1500, MATH 1700, (or MATH 1690 in place of MATH 1500 and MATH 1700), MATH 2202, MATH 2352, MATH 2600, MATH 2750, MATH 2800, MATH 3300, MATH 3350, MATH 3400, MATH 3700, MATH 3710,MATH 3740, MATH 3760, and MATH 3800.

It is suggested that among their electives, students might choose courses in which mathematics is extensively used, for example, courses in physics, chemistry and certain courses in economics. For advice on this point students should talk to a faculty member in the department.

## Old Mathematics Major Program Chart:

<table>
<tr><td colspan="3">5<br>MATHEMATICS FOUR YEAR MAJOR 120 CREDIT HOURS</td></tr>
<tr><td>1<br>MATH 1300 , MATH 1500 , MATH 1700</td><td>MATH 2202, MATH 2352 (6),MATH 2600, MATH 2750 (6),MATH 2800</td><td>MATH 3300 or MATH 3350 (6), MATH 3400, MATH 3700 or MATH 3710, MATH 3740 (6) or MATH 3760 (6), MATH 3800 and enough courses from MATH 2400, MATH 2500, STAT 2000 and all third and fourth year Mathematics courses to make 48 credit hours</td></tr>
<tr><td colspan="2">The following can be completed in Year 1 or Year 2:<br><br>2 2<br>STAT 1000 , COMP 1010<br><br>6 credit hours from the Faculty of Arts, which should include the required "W" course<br><br>18 credit hours of approved electives</td><td>12 credit hours of approved electives</td></tr>
</table>

NOTES:

1 MATH 1510 or MATH 1520 may be taken in place of MATH 1500; MATH 1310 may be taken in place of MATH 1300; MATH 1710 may be taken in place of MATH 1700. MATH 1690 may be taken in place of both MATH 1500and 1700).

2 STAT 1000 and COMP 1010 must be completed by the end of Year 2.

3 Students considering graduate work in pure mathematics should note that many graduate schools may require a student to rectify any deficiencies in MATH 4200, MATH 4210, MATH 4350, MATH 4710, MATH 4720 and MATH 4750.

4 MATH 3200, MATH 3210, MATH 3740 and MATH 3910 cannot be used in an Honours program.

5 IMPORTANT: The four year Major programs need not be completed in the manner prescribed in the charts above. Each chart indicates one possible arrangement of the required courses and is meant to be a guide around which students can plan their programs with a view to satisfying the prerequisites of the required courses. Please refer to the text above for the minimum requirements for entry to a four year Major.

(Letters in brackets indicate minimum prerequisite standing for further study. The number 6 in brackets indicates a 6 credit hour course.)

# Changes to the B.Sc. Double Honours Degree in Mathematics

### New Mathematics Double Honours Program:

**Double Honours**: A student may elect Honours in Mathematics and one other field, subject to the approval of both departments. The Mathematics prescription for a Double Honours program is as indicated in the table below.

| **MATHEMATICS HONOURS DOUBLE** MINIMUM 120 CREDIT HOURS (comprising courses listed in chart below, and the required courses from the other department) | | | |
|---|---|---|---|
| MATH 1220[1],<br>MATH 1230[1],<br>MATH 1232[1],<br>MATH 1240<br><br>STAT 1000<br><br>COMP 1010<br><br>Plus 6 credit hours from the Faculty of Arts, which should include the required "W" course | MATH 2020, MATH 2080, MATH 2090, MATH 2150, MATH 2180<br><br>6 credit hours from the following list:<br>MATH 2030, MATH 2040, MATH 2070, MATH 2140, MATH 2160, MATH 2170 | MATH 3320, MATH 3340, MATH 3390, MATH 3440, MATH 3470, MATH 3472 | 15 credit hours from: MATH 2030, MATH 2070, MATH 2160 (if not taken as a required 2nd year elective), MATH 2170; and all Year 3 and 4 mathematics courses of which at least 9 credit hours must be 4000 level. |
| | | | |

NOTES:

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (A) in place of MATH 1220, MATH 1500 (A) or MATH 1510 (A) in place of MATH 1230, MATH 1700 (A) or MATH 1710 (A) in place of MATH 1232, MATH 1690 (B) in place of MATH 1230 and MATH 1232.

## Old Double Honours Degree in Mathematics Program:

**Double Honours**: A student may elect Honours in Mathematics and one other field, subject to the approval of both departments. The Mathematics prescription for a Double Honours program is as indicated in the table below.

| | | | |
|---|---|---|---|
| **MATHEMATICS HONOURS DOUBLE**[4] MINIMUM 120 CREDIT HOURS (comprising courses listed in chart below, and the required courses from the other department) | | | |
| MATH 1300[1] (B), MATH 1690(6) (B)<br><br>(or MATH 1500[1] and MATH 1700[1] (B))<br><br>STAT 1000[2]<br><br>COMP 1010[2]<br><br>Plus 6 credit hours from the Faculty of Arts, which should include the required "W" course | MATH 2202, MATH 2352 (6),MATH 2600, MATH 2750 (6),MATH 2800 | MATH 3230, MATH 3350 (6),MATH 3710, MATH 3760 (6) | MATH 3800<br><br>Plus 12 credit hours from MATH 4200, MATH 4210, MATH 4350,MATH 4710, MATH 4720, MATH 4750[3]<br><br>Plus at least an additional 3 credit hours from among the above and MATH 3220, MATH 3240, MATH 3400, MATH 3430, MATH 3450,MATH 4250, MATH 4400, MATH 4410, MATH 4420, MATH 4430,MATH 4800, MATH 4920, MATH 4960 |
| | | | |

NOTES:

1 MATH 1510 or MATH 1520 may be taken in place of MATH 1500; MATH 1310 may be taken in place of MATH 1300; MATH 1710 may be taken in place of MATH 1700. MATH 1690 may be taken in place of both MATH 1500and 1700).

2 STAT 1000 and COMP 1010 must be completed by the end of Year 2.

3 Students considering graduate work in pure mathematics should note that many graduate schools may require a student to rectify any deficiencies in MATH 4200, MATH 4210, MATH 4350, MATH 4710, MATH 4720 andMATH 4750.

4 MATH 3200, MATH 3210, MATH 3740 and MATH 3910 cannot be used in an Honours program.

5 IMPORTANT: The four year Major programs need not be completed in the manner prescribed in the charts above. Each chart indicates one possible arrangement of the required courses and is meant to be a guide around which students can plan their programs with a view to satisfying the prerequisites of the required courses. Please refer to the text above for the minimum requirements for entry to a four year Major.

# Changes to the B.Sc. Major in Applied Mathematics with Computer Science Option

## New Four Year Major in Applied Mathematics with Computer Science Option requirements:

These programs provide a sound general knowledge of applied mathematics together with a significant number of courses in the option area. Courses in the Computer Science option provide training in aspects of computer science that are most useful to the practicing mathematician. Courses in the Computer Sciences, Economics, and Statistics options are fundamental to each area and provide a strong, mathematical basis for further study.

**To enter** the four year Major in Applied Mathematics with one of the above three options, a student must have a minimum grade of "C+" in either MATH 1232 or MATH 1690, or a minimum grade of "B" in MATH 1700, and have satisfied all faculty requirements for entry to the program.

**To continue** in the Applied Mathematics Major degree programs, students must maintain a minimum DGPA of 2.00.

**To graduate** with the B. Sc. Major degree, a student must achieve a minimum GPA of 2.00 on the 120 credit hours that contribute to the degree, and a minimum grade of “C” in each of the Major Program Specific courses (see below).

**Applied Mathematics Major Program Specific Courses**

MATH 1220, MATH 1230, MATH 1232, MATH 1240, MATH 2070, MATH 2080, MATH 2090, MATH 2140, MATH 2150, MATH 2160, MATH 2180, MATH 3340, MATH 3420, MATH 3440, MATH 3460, and MATH 3470.
It is recommended that students take all 12 credit hours of 1000 level mathematics courses in their initial 30 credit hours;

## New Applied Mathematics with Computer Science Option Program Chart:

<table>
<tr><td colspan="3">APPLIED MATHEMATICS FOUR YEAR MAJOR with COMPUTER SCIENCE OPTION 120 CREDIT HOURS</td></tr>
<tr><td>MATH 1220[1],<br>MATH 1230[1],<br>MATH 1232[1],<br>MATH 1240<br><br>COMP 1010, COMP 1020</td><td>MATH 2080, MATH 2090, MATH 2150, MATH 2160, MATH 2180<br><br>COMP 2140</td><td>MATH 2070, MATH 2140, MATH 3340, MATH 3420, MATH 3440, MATH 3460, MATH 3470</td></tr>
<tr><td rowspan="2">6 credit hours from the Faculty of Arts, which should include the required “W” course<br><br>6 credit hours of approved electives</td><td colspan="2">STAT 1000 and STAT 2000<br><br>9 credit hours chosen from:<br><br>MATH 2030, MATH 2040, MATH 2170, or any 3000 / 4000 level MATH course<br><br>One of the following patterns (9 credit hours):<br><br>Graphics: COMP 2190, COMP 3490, COMP 4490<br><br>Software: COMP 2150, COMP 2160; and one of: COMP 3380, COMP 3440, or COMP 3020<br><br>Theoretical Computer Science: COMP 2080, and two of: COMP 3030, COMP 3170, COMP 3820, or COMP 4420<br><br>Hardware: COMP 2160, COMP 2280; and one of: COMP 3370 or COMP 3430<br><br>Artificial Intelligence: COMP 3190; and two of: COMP 4180, COMP 4190, COMP 4200, COMP 4360</td></tr>
<tr><td colspan="2">27 credit hours of electives taken during years 2, 3 and 4</td></tr>
</table>

NOTES:

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (B) in place of MATH 1220, MATH 1500 (B) or MATH 1510 (B) in place of MATH 1230, MATH 1700 (B) or MATH 1710 (B) in place of MATH 1232, MATH 1690 (C+) in place of MATH 1230 and MATH 1232.

## Old Four Year Major in Applied Mathematics with Computer Science Option requirements:

These programs provide a sound general knowledge of applied mathematics together with a significant number of courses in the option area. Courses in the Computer Science option provide training in aspects of computer science which are most useful to the practicing mathematician. Courses in the Computer Sciences, Economics, and Statistics options are fundamental to each area and provide a strong, mathematical basis for further study.

**To enter** the four year Major in Applied Mathematics with one of the above three options, a student must have a “C+” in either MATH 1690 or two of MATH 1200, MATH 1300, MATH 1500, or MATH 1700, one of which must be either MATH 1500, or MATH 1700, and have satisfied all faculty requirements for entry to the program.

**To continue** in the Applied Mathematics Major degree programs, students must maintain a minimum DGPA of 2.00.

**To graduate** with the B. Sc. Major degree, a student must achieve a minimum GPA of 2.00 on the 120 credit hours that contribute to the degree, and a minimum grade of “C” in each of the Major Program Specific courses (see below).

**Applied Mathematics Major Program Specific Courses**

MATH 1200, MATH 1300, MATH 1500, MATH 1700 (or MATH 1690 in place of MATH 1500 and MATH 1700), MATH 2300, MATH 2400, MATH 2600, MATH 2720, MATH 2730, MATH 2800, MATH 3500, MATH 3600, MATH 3700,MATH 3740, MATH 3800, MATH 3810, and MATH 3820.

It is recommended that students take all 12 credit hours of 1000 level mathematics courses in their initial 30 credit hours; however, students should take at least MATH 1300, MATH 1500 and MATH 1700. See the individual charts below for additional requirements for each option.

**Options List:** MATH 2450, MATH 2500, MATH 2552, the former MATH 2550, or any 3rd or 4th year Mathematics course.

## Old Applied Mathematics with Computer Science Option Program Chart:

<table>
<tr><td colspan="3">APPLIED MATHEMATICS FOUR YEAR MAJOR with COMPUTER SCIENCE OPTION [5] 120 CREDIT HOURS</td></tr>
<tr><td>MATH 1200, MATH 1300 [1],MATH 1500 [1], MATH 1700<br><br>COMP 1010, COMP 1020</td><td>MATH 2300, MATH 2600,MATH 2720, MATH 2730,MATH 2800<br><br>COMP 2140</td><td>MATH 2400, MATH 3600, MATH 3700, MATH 3740 (6), MATH 3800, MATH 3810, MATH 3820</td></tr>
<tr><td rowspan="2">6 credit hours from the Faculty of Arts, which should include the required “W” course<br><br>6 credit hours of approved electives</td><td colspan="2">STAT 1000 and STAT 2000<br><br>6 credit hours chosen from:<br><br>MATH 2450 (6), MATH 2500, MATH 2552 (6), or any 3000 / 4000 level MATH course<br><br>One of the following patterns (9 credit hours):<br><br>Graphics: COMP 2190, COMP 3490, COMP 4490<br><br>Software: COMP 2150, ~~COMP 3440~~; and one of: ~~COMP 2160~~, COMP 3380, or COMP 3020<br><br>Theoretical Computer Science: COMP 2080, ~~COMP 2130~~; and one of: COMP 3170 or ~~COMP 4530~~<br><br>Hardware: COMP 2160, COMP 2280; and one of: COMP 3370 or COMP 3430<br><br>Artificial Intelligence: COMP 3190; and two of: COMP 4180, COMP 4190, COMP 4200, COMP 4360</td></tr>
<tr><td colspan="2">27 credit hours of electives taken during years 2, 3 and 4</td></tr>
</table>

NOTES:

1 MATH 1510 or MATH 1520 may be taken in place of MATH 1500; MATH 1310 may be taken in place of MATH 1300; MATH 1710 may be taken in place of MATH 1700. MATH 1690 may be taken in place of both MATH 1500 and 1700).

2 STAT 1000 and COMP 1010 must be completed by the end of Year 2.

3 Students considering graduate work in pure mathematics should note that many graduate schools may require a student to rectify any deficiencies in MATH 4200, MATH 4210, MATH 4350, MATH 4710, MATH 4720 and MATH 4750.

4 MATH 3200, MATH 3210, MATH 3740 and MATH 3910 cannot be used in an Honours program.

5 IMPORTANT: The four year Major programs need not be completed in the manner prescribed in the charts above. Each chart indicates one possible arrangement of the required courses and is meant to be a guide around which students can plan their programs with a view to satisfying the prerequisites of the required courses. Please refer to the text above for the minimum requirements for entry to a four year Major.

(Letters in brackets indicate minimum prerequisite standing for further study. The number 6 in brackets indicates a 6 credit hour course.)

# Changes to the B.Sc. Major in Applied Mathematics with Economics Option

**The Department of Economics plans a comprehensive curriculum revision to be implemented starting with Fall 2015. The proposed program includes the corresponding changes in the Economics portion of the program, as proposed by the Department of Economics.**

## New Four Year Major in Applied Mathematics with Economics Option requirements:

These programs provide a sound general knowledge of applied mathematics together with a significant number of courses in the option area. Courses in the Computer Science option provide training in aspects of computer science that are most useful to the practicing mathematician. Courses in the Computer Sciences, Economics, and Statistics options are fundamental to each area and provide a strong, mathematical basis for further study.

**To enter** the four year Major in Applied Mathematics with one of the above three options, a student must have a minimum grade of "C+" in either MATH 1232 or MATH 1690, or a minimum grade of "B" in MATH 1700, and have satisfied all faculty requirements for entry to the program.

**To continue** in the Applied Mathematics Major degree programs, students must maintain a minimum DGPA of 2.00.

**To graduate** with the B. Sc. Major degree, a student must achieve a minimum GPA of 2.00 on the 120 credit hours that contribute to the degree, and a minimum grade of “C” in each of the Major Program Specific courses (see below).

**Applied Mathematics Major Program Specific Courses**

MATH 1220, MATH 1230, MATH 1232, MATH 1240, MATH 2070, MATH 2080, MATH 2090, MATH 2140, MATH 2150, MATH 2160, MATH 2180, MATH 3340, MATH 3420, MATH 3440, MATH 3460, and MATH 3470.
It is recommended that students take all 12 credit hours of 1000 level mathematics courses in their initial 30 credit hours;

## New Applied Mathematics with Economics Option Program Chart:

<table>
<tr><td colspan="3">APPLIED MATHEMATICS FOUR YEAR MAJOR with ECONOMICS OPTION 120 CREDIT HOURS</td></tr>
<tr><td>MATH 1220[1],<br>MATH 1230[1],<br>MATH 1232[1],<br>MATH 1240<br><br>ECON 1010 and ECON 1020, or ECON 1210 and ECON 1220</td><td>MATH 2080, MATH 2090, MATH 2150, MATH 2160, MATH 2180</td><td>MATH 2070, MATH 2140, MATH 3340, MATH 3420, MATH 3440, MATH 3460, MATH 3470, MATH 4370</td></tr>
<tr><td rowspan="2">9 credit hours of electives</td><td colspan="2">STAT 1000, STAT 2000<br><br>COMP 1010<br><br>ECON 2030<br>ECON 3030<br><br>6 credit hours from:<br><br>MATH 2030, MATH 2040, MATH 2170, or any 3000 / 4000 level MATH course<br><br>6 credit hours from:<br><br>ECON 2010<br>ECON 2020<br>ECON 3010<br>ECON 3020</td></tr>
<tr><td colspan="2">24 credit hours of approved electives taken during years 2, 3 and 4</td></tr>
<tr><td colspan="2">3 credit hour “W” course must be taken in Year 1 or Year 2</td><td></td></tr>
</table>

NOTES:

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (B) in place of MATH 1220, MATH 1500 (B) or MATH 1510 (B) in place of MATH 1230, MATH 1700 (B) or MATH 1710 (B) in place of MATH 1232, MATH 1690 (C+) in place of MATH 1230 and MATH 1232.

## Old Four Year Major in Applied Mathematics with Economics Option requirements:

These programs provide a sound general knowledge of applied mathematics together with a significant number of courses in the option area. Courses in the Computer Science option provide training in aspects of computer science which are most useful to the practicing mathematician. Courses in the Computer Sciences, Economics, and Statistics options are fundamental to each area and provide a strong, mathematical basis for further study.

**To enter** the four year Major in Applied Mathematics with one of the above three options, a student must have a "C+" in either MATH 1690 or two of MATH 1200, MATH 1300, MATH 1500, or MATH 1700, one of which must be either MATH 1500, or MATH 1700, and have satisfied all faculty requirements for entry to the program.

**To continue** in the Applied Mathematics Major degree programs, students must maintain a minimum DGPA of 2.00.

**To graduate** with the B. Sc. Major degree, a student must achieve a minimum GPA of 2.00 on the 120 credit hours that contribute to the degree, and a minimum grade of "C" in each of the Major Program Specific courses (see below).

**Applied Mathematics Major Program Specific Courses**

MATH 1200, MATH 1300, MATH 1500, MATH 1700 (or MATH 1690 in place of MATH 1500 and MATH 1700), MATH 2300, MATH 2400, MATH 2600, MATH 2720, MATH 2730, MATH 2800, MATH 3500, MATH 3600, MATH 3700,MATH 3740, MATH 3800, MATH 3810, and MATH 3820.

It is recommended that students take all 12 credit hours of 1000 level mathematics courses in their initial 30 credit hours; however, students should take at least MATH 1300, MATH 1500 and MATH 1700. See the individual charts below for additional requirements for each option.

**Options List:** MATH 2450, MATH 2500, MATH 2552, the former MATH 2550, or any 3rd or 4th year Mathematics course.

## Old Applied Mathematics with Economics Option Program Chart:

<table>
<tr><td colspan="3">APPLIED MATHEMATICS FOUR YEAR MAJOR with ECONOMICS OPTION [5] 120 CREDIT HOURS</td></tr>
<tr><td>MATH 1200, MATH 1310 [1], MATH 1500 [1], MATH 1700<br><br>ECON 1010, ECON 1020 (or ECON 1210, ECON 1220)</td><td>MATH 2300, MATH 2600, MATH 2720, MATH 2730, MATH 2800</td><td>MATH 2400, MATH 3600, MATH 3700, MATH 3740 (6), MATH 3800, MATH 3810, MATH 3820, MATH 4310</td></tr>
<tr><td rowspan="2">9 credit hours of electives</td><td colspan="2">STAT 1000, STAT 2000<br><br>COMP 1010<br><br>ECON 2530, ECON 3730<br><br>3 credit hours from:<br><br>MATH 2450 (6), MATH 2500, MATH 2552 (6), or any 3000 / 4000 level MATH course<br><br>6 credit hours from:<br><br>ECON 2450, ECON 2460, ECON 2470 and ECON 2480</td></tr>
<tr><td colspan="2">24 credit hours of approved electives taken during years 2, 3 and 4</td></tr>
<tr><td colspan="2">3 credit hour “W” course must be taken in Year 1 or Year 2</td><td></td></tr>
</table>

NOTES:

1 MATH 1510 or MATH 1520 may be taken in place of MATH 1500; MATH 1310 may be taken in place of MATH 1300; MATH 1710 may be taken in place of MATH 1700. MATH 1690 may be taken in place of both MATH 1500and 1700).

2 STAT 1000 and COMP 1010 must be completed by the end of Year 2.

3 Students considering graduate work in pure mathematics should note that many graduate schools may require a student to rectify any deficiencies in MATH 4200, MATH 4210, MATH 4350, MATH 4710, MATH 4720 and MATH 4750.

4 MATH 3200, MATH 3210, MATH 3740 and MATH 3910 cannot be used in an Honours program.

5 IMPORTANT: The four year Major programs need not be completed in the manner prescribed in the charts above. Each chart indicates one possible arrangement of the required courses and is meant to be a guide around which students can plan their programs with a view to satisfying the prerequisites of the required courses. Please refer to the text above for the minimum requirements for entry to a four year Major.

(Letters in brackets indicate minimum prerequisite standing for further study. The number 6 in brackets indicates a 6 credit hour course.)

# Changes to the B.Sc. Major in Applied Mathematics with Statistics Option

## New Four Year Major in Applied Mathematics with Statistics Option requirements:

These programs provide a sound general knowledge of applied mathematics together with a significant number of courses in the option area. Courses in the Computer Science option provide training in aspects of computer science that are most useful to the practicing mathematician. Courses in the Computer Sciences, Economics, and Statistics options are fundamental to each area and provide a strong, mathematical basis for further study.

**To enter** the four year Major in Applied Mathematics with one of the above three options, a student must have a minimum grade of "C+" in either MATH 1232 or MATH 1690, or a minimum grade of "B" in MATH 1700, and have satisfied all faculty requirements for entry to the program.

**To continue** in the Applied Mathematics Major degree programs, students must maintain a minimum DGPA of 2.00.

**To graduate** with the B. Sc. Major degree, a student must achieve a minimum GPA of 2.00 on the 120 credit hours that contribute to the degree, and a minimum grade of “C” in each of the Major Program Specific courses (see below).

**Applied Mathematics Major Program Specific Courses**

MATH 1220, MATH 1230, MATH 1232, MATH 1240, MATH 2070, MATH 2080, MATH 2090, MATH 2140, MATH 2150, MATH 2160, MATH 2180, MATH 3340, MATH 3420, MATH 3440, MATH 3460, and MATH 3470.
It is recommended that students take all 12 credit hours of 1000 level mathematics courses in their initial 30 credit hours;

## New Applied Mathematics with Statistics Option Program Chart:

| **APPLIED MATHEMATICS FOUR YEAR MAJOR with STATISTICS OPTION** 120 CREDIT HOURS | | |
|---|---|---|
| MATH 1220[1],<br>MATH 1230[1],<br>MATH 1232[1],<br>MATH 1240<br><br>STAT 1000 | MATH 2080, MATH 2090, MATH 2150, MATH 2160, MATH 2180<br><br>STAT 2000 | MATH 2070, MATH 2140, MATH 3340, MATH 3420, MATH 3440, MATH 3460, MATH 3470<br><br>STAT 2400, STAT 3400, STAT 3470, STAT 3480, STAT 3800 |
| 6 credit hours from the Faculty of Arts, which should include the required "W" course | COMP 1010<br><br>9 credit hours from:<br><br>MATH 2030, MATH 2040, MATH 2170, or any 3000 / 4000 level MATH course<br><br>6 credit hours of 3000 or 4000 level Statistics courses | |
| 9 credit hours of electives | 18 credit hours of approved electives taken during years 2, 3 and 4 | |

NOTES:

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (B) in place of MATH 1220, MATH 1500 (B) or MATH 1510 (B) in place of MATH 1230, MATH 1700 (B) or MATH 1710 (B) in place of MATH 1232, MATH 1690 (C+) in place of MATH 1230 and MATH 1232.

## Old Four Year Major in Applied Mathematics with Statistics Option requirements:

These programs provide a sound general knowledge of applied mathematics together with a significant number of courses in the option area. Courses in the Computer Science option provide training in aspects of computer science which are most useful to the practicing mathematician. Courses in the Computer Sciences, Economics, and Statistics options are fundamental to each area and provide a strong, mathematical basis for further study.

**To enter** the four year Major in Applied Mathematics with one of the above three options, a student must have a “C+” in either MATH 1690 or two of MATH 1200, MATH 1300, MATH 1500, or MATH 1700, one of which must be either MATH 1500, or MATH 1700, and have satisfied all faculty requirements for entry to the program.

**To continue** in the Applied Mathematics Major degree programs, students must maintain a minimum DGPA of 2.00.

**To graduate** with the B. Sc. Major degree, a student must achieve a minimum GPA of 2.00 on the 120 credit hours that contribute to the degree, and a minimum grade of “C” in each of the Major Program Specific courses (see below).

**Applied Mathematics Major Program Specific Courses**

MATH 1200, MATH 1300, MATH 1500, MATH 1700 (or MATH 1690 in place of MATH 1500 and MATH 1700), MATH 2300, MATH 2400, MATH 2600, MATH 2720, MATH 2730, MATH 2800, MATH 3500, MATH 3600, MATH 3700,MATH 3740, MATH 3800, MATH 3810, and MATH 3820.

It is recommended that students take all 12 credit hours of 1000 level mathematics courses in their initial 30 credit hours; however, students should take at least MATH 1300, MATH 1500 and MATH 1700. See the individual charts below for additional requirements for each option.

**Options List:** MATH 2450, MATH 2500, MATH 2552, the former MATH 2550, or any 3rd or 4th year Mathematics course.

## Old Applied Mathematics with Statistics Option Program Chart:

| **APPLIED MATHEMATICS FOUR YEAR MAJOR with STATISTICS OPTION** [5] 120 CREDIT HOURS | | |
|---|---|---|
| MATH 1200, MATH 1300 [1], MATH 1500 [1], MATH 1700 [1]<br><br>STAT 1000 | MATH 2300, MATH 2600, MATH 2720, MATH 2730, MATH 2800<br><br>STAT 2000 | MATH 2400, MATH 3600, MATH 3700, MATH 3740 (6), MATH 3800, MATH 3810, MATH 3820<br><br>STAT 2400, STAT 3400, STAT 3470, STAT 3480, STAT 3800 |
| 6 credit hours from the Faculty of Arts, which should include the required "W" course | COMP 1010<br><br>6 credit hours from:<br><br>MATH 2450 (6), MATH 2500, MATH 2552 (6), or any 3000 / 4000 level MATH course<br><br>6 credit hours of 3000 or 4000 level Statistics courses | |
| 9 credit hours of electives | 18 credit hours of approved electives taken during years 2, 3 and 4 | |

NOTES:

1 MATH 1510 or MATH 1520 may be taken in place of MATH 1500; MATH 1310 may be taken in place of MATH 1300; MATH 1710 may be taken in place of MATH 1700. MATH 1690 may be taken in place of both MATH 1500 and 1700).

2 STAT 1000 and COMP 1010 must be completed by the end of Year 2.

3 Students considering graduate work in pure mathematics should note that many graduate schools may require a student to rectify any deficiencies in MATH 4200, MATH 4210, MATH 4350, MATH 4710, MATH 4720 and MATH 4750.

4 MATH 3200, MATH 3210, MATH 3740 and MATH 3910 cannot be used in an Honours program.

5 IMPORTANT: The four year Major programs need not be completed in the manner prescribed in the charts above. Each chart indicates one possible arrangement of the required courses and is meant to be a guide around which students can plan their programs with a view to satisfying the prerequisites of the required courses. Please refer to the text above for the minimum requirements for entry to a four year Major.

(Letters in brackets indicate minimum prerequisite standing for further study. The number 6 in brackets indicates a 6 credit hour course.)

# Changes to the B.Sc. General Degree and Minor Requirements (Faculty of Science):

### New Mathematics General Degree and Minor Requirements:

| **THREE YEAR GENERAL** (90 CREDIT HOURS) | |
|---|---|
| MATH 1220[1], MATH 1230[1], MATH 1232[1], MATH 1240[1] | 18 credit hours of 2000, 3000, and (or) 4000 level Mathematics courses (subject to the Faculty requirement that of the 36 credit hours to be completed in the two advanced level Science areas, at least 6 credit hours must be at the 3000/4000 level.)" |
| **MINOR** | |
| MATH 1220[1], MATH 1230[1], MATH 1232[1] plus a minimum of 9 credit hours from: MATH 1240[1] and 2000 and (or) 3000 level Mathematics courses | |

1 MATH 1500 or MATH 1510 may be taken in place of MATH 1230; MATH 1300 may be taken in place of MATH 1220; MATH 1700 or MATH 1710 may be taken in place of MATH 1232. MATH 1200 may be taken in place of MATH 1240, but these courses are not equivalent, i.e., students should note that MATH 1240 is a prerequisite to some 2nd year mathematics courses for which MATH 1200 is not a prerequisite.

### Old Mathematics General Degree and Minor Requirements:

| **THREE YEAR GENERAL** (90 CREDIT HOURS) | |
|---|---|
| | 18 credit hours of 2000, 3000, and (or) 4000 level Mathematics courses (subject to the Faculty requirement that of the 36 credit hours to be completed in the two advanced level Science areas, at least 6 credit hours must be at the 3000/4000 level.)" |
| **MINOR** | |
| MATH 1300[1], MATH 1500[1], MATH 1700[1] plus a minimum of 9 credit hours from: MATH 1200 and 2000 and (or) 3000 level Mathematics courses | |

1 MATH 1510 or MATH 1520 may be taken in place of MATH 1500; MATH 1310 may be taken in place of MATH 1300; MATH 1710 may be taken in place of MATH 1700. MATH 1690 may be taken in place of both MATH 1500and 1700).

# Changes to the BSc. Joint Honours in Mathematics – Computer Science

### New Mathematics - Computer Science Joint Honours Program (combined with Computer Science proposal):

**Mathematics - Computer Science Joint Honours Program (Including Co-op if selected)**

The departments of Computer Science and Mathematics offer a joint Honours program for in-depth study in both Computer Science and Mathematics.

**Honours Requirements**

**To enter** the Joint Honours Computer Science-Mathematics program, the student must have a minimum grade of "B" in each of COMP 1020, either MATH 1232 or MATH 1690 (or a minimum grade of "A" in MATH 1700), and have satisfied the Faculty of Science requirements for entry to the honours program. It is recommended that STAT 2000 be completed in Year 1 as an elective.

| YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 |
|---|---|---|---|
| **JOINT HONOURS (Including Cooperative Option if selected)** 120 CREDIT HOURS | | | |
| COMP 1010 and COMP 1020(B)<br><br>MATH 1220[1],<br>MATH 1230[1],<br>MATH 1232[1],<br>MATH 1240<br><br>STAT 1000 (C)<br><br>6 credit hours from the Faculty of Arts, which should include the required 3 credit hour "W" course<br><br>3 credit hours of approved electives | 2<br>COMP 2080 , COMP 2140,COMP 2160, COMP 2280<br><br>MATH 2020, MATH 2080, MATH 2090, MATH 2150, MATH 2180<br><br>3 credit hours of approved electives | COMP 3030, COMP 3170, COMP 3370, COMP 3430<br><br>Three of: **COMP 3010**, COMP 3020, COMP 3290, COMP 3350, COMP 3380, **COMP 3190, COMP 3440**, **COMP 3490, COMP 3820**<br><br>**Three of:** COMP 4020, **COMP 4140, COMP 4180, COMP 4190,** COMP 4290, **COMP 4300, COMP 4340**, COMP 4350, **COMP 4360,** COMP 4380, **COMP 4490, COMP 4510, COMP 4580, COMP 4690, COMP 4710**<br><br>MATH 2030, MATH 2160, MATH 3320, MATH 3322, MATH 3440, MATH 3470, MATH 3472<br><br>9 credit hours from MATH 2070, MATH 2170, any 3000 or 4000 level Mathematics courses, of which at least 3 credit hours must be 4000 level | |
| | **Work Term (if Co-op Selected) : 3**<br><br>COMP 2980 | **Work Term (if Co-op Selected) : 3**<br><br>COMP 3980 | **Work Term (if Co-op Selected) : 3**<br><br>COMP 4980 |
| 30 Hours | 30 Hours | 30 Hours | 30 Hours |

**NOTES**:

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (A) in place of MATH 1220, MATH 1500 (A) or MATH 1510 (A) in place of MATH 1230, MATH 1700 (A) or MATH 1710 (A) in place of MATH 1232, MATH 1690 (B) in place of MATH 1230 and MATH 1232.

2 Students in this program will not take COMP 2130. COMP 2130 is waived as a prerequisite for students in this program.

3 When chosen, the Cooperative Option work terms (2980, 3980, 4980) will normally be completed during the Summer Terms following years 2, 3, and 4 respectively.

(Letters in brackets indicate minimum grade required for further study. The number 6 in brackets indicates a 6 credit hour course.)

## Old Mathematics – Computer Science Joint Honours Program:

**Mathematics - Computer Science Joint Honours Program (Including Co-op if selected)**

The departments of Computer Science and Mathematics offer a joint Honours program for in-depth study in both Computer Science and Mathematics.

**Honours Requirements**

**To enter** the Joint Honours Computer Science-Mathematics program, the student must have a minimum grade of "B" in each of COMP 1020, MATH 1300 and MATH 1700 (or any equivalent), and have satisfied the Faculty of Science requirements for entry to the honours program. It is recommended that STAT 2000 be completed in Year 1 as an elective.

| YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 |
|---|---|---|---|
| **JOINT HONOURS (Including Cooperative Option if selected)** 120 CREDIT HOURS | | | |
| COMP 1010 and COMP 1020(B)<br>MATH 1300 (B), MATH 1690(6) (B),<br>(or MATH 1500 and MATH 1700 (B))<br>STAT 1000 (C)<br>6 credit hours from the Faculty of Arts, which should include the required 3 credit hour "W" course<br>6 credit hours of electives | COMP 2080 , COMP 2140,COMP 2160, COMP 2280<br>MATH 2202, MATH 2352 (6),MATH 2750 (6)<br>one of: MATH 2600 or MATH 2800 | COMP 3030, COMP 3170, COMP 3370, COMP 3430, ~~COMP 4310 (or COMP 4420)~~<br>Three of: COMP 3020, COMP 3290, COMP 3350, COMP 3380,~~COMP 3720~~<br>Two of: COMP 4020,~~ COMP 4050~~, COMP 4290, COMP 4350,COMP 4380, ~~COMP 4720~~<br>MATH 3740 (6) or MATH 3760 (6); and MATH 3350 (or MATH 3300 and MATH 3310) (6); and MATH 3400; and whichever of MATH 2600 or MATH 2800 not yet taken<br>12 credit hours of 3000 or 4000 level Mathematics courses, of which at least 3 credit hours must be 4000 level | |
| | **Work Term (if Co-op Selected) :**<br>COMP 2980 | **Work Term (if Co-op Selected) :**<br>COMP 3980 | **Work Term (if Co-op Selected) :**<br>COMP 4980 |
| 30 Hours | 30 Hours | 30 Hours | 30 Hours |

**NOTES**:

1 MATH 1510 or MATH 1520 may be taken in place of MATH 1500; MATH 1310 may be taken in place of MATH 1300; MATH 1710may be taken in place of MATH 1700.

2 As there are no electives in Year 2 of the program, students should complete the written English requirement in Year 1. If not completed in Year 1, a "W" course must be completed prior to Year 3 in addition to the required Year 2 courses.

3 Students in this program will not take COMP 2130 or COMP 3130. COMP 2130 is waived as a prerequisite for students in this program.

4 When chosen, the Cooperative Option work terms (2980, 3980, 4980) will normally be completed during the Summer Terms following years 2, 3, and 4 respectively. (Letters in brackets indicate minimum prerequisite standing for further study. The number 6 in brackets indicates a 6 credit hour course.)

# Changes to the B.Sc. Joint Honours in Mathematics – Economics

**The Department of Economics plans a comprehensive curriculum revision to be implemented starting with Fall 2015. The proposed program includes the corresponding changes in the Economics portion of the program, as proposed by the Department of Economics.**

**New Mathematics – Economics Joint Honours Program - (combined with Economics proposal):**

<table>
<tr><td colspan="4">The Department of Mathematics along with the Department of Economics (Faculty of Arts) offer a joint Honours program for students wishing in depth study in Mathematics and Economics. For Economics course listings, refer to the Faculty of Arts chapter in the Calendar.</td></tr>
<tr><td colspan="4">To enter the Joint Honours Mathematics - Economics program, the student must have a minimum grade of “B” in: ECON 1010 and ECON 1020 (or ECON 1210 and ECON 1220), either MATH 1232 or MATH 1690 (or a minimum grade of "A" in MATH 1700), and have satisfied the Faculty of Science requirements for entry to the honours program.</td></tr>
<tr><td>YEAR 1</td><td>YEAR 2</td><td>YEAR 3</td><td>YEAR 4</td></tr>
<tr><td colspan="4">JOINT HONOURS 120 CREDIT HOURS</td></tr>
<tr><td>Both ECON 1010 and ECON 1020, or both ECON 1210 and ECON 1220<br><br>MATH 1220[1], MATH 1230[1], MATH 1232[1], MATH 1240<br><br>2<br>STAT 1000<br><br>2<br>COMP 1010</td><td>ECON 2010<br>ECON 2020<br><br>MATH 2020, MATH 2080, MATH 2090, MATH 2150, MATH 2180</td><td rowspan="2">ECON 3010<br>ECON 3020<br>ECON 3040[2]<br><br>MATH 2030, MATH 2160, MATH 3320, MATH 3340, MATH 3440, MATH 3470, MATH 3472,<br><br>24 credit hours of approved Economics courses[3]<br><br>3 credit hours from MATH 2140, MATH 3420, MATH 3460, MATH 4370, or any Mathematics course at the 4000 level.<br><br>3 credit hours of Mathematics courses at the 3000 or 4000 level.</td><td rowspan="2"></td></tr>
<tr><td>6 credit hours of electives, including the required “W” course.</td><td>9 credit hours of approved electives</td></tr>
<tr><td>30 Hours</td><td>30 Hours</td><td>30 Hours</td><td>30 Hours</td></tr>
<tr><td colspan="4">NOTES:</td></tr>
</table>

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (A) in place of MATH 1220, MATH 1500 (A) or MATH 1510 (A) in place of MATH 1230, MATH 1700 (A) or MATH 1710 (A) in place of MATH 1232, MATH 1690 (B) in place of MATH 1230 and MATH 1232.

2 Some courses may be taken in a different year than indicated; STAT 1000, COMP 1010, ECON 3040 may be taken in Year 2. The normal prerequisite for ECON 3040 is ECON 2040 [or the former ECON 3170 (018.317)], which will be waived for students in this program who have completed Year 1.

3 Of the 24 credit hours in electives in Economics in Years 3 and 4, no more than 6 credit hours may be at the 2000 level or below and at least 6 credit hours must be at the 4000 level. Students are encouraged to take ECON 4010, ECON 4020 and ECON 4040.

## Old Mathematics – Economics Joint Honours Program:

The Department of Mathematics along with the Department of Economics (Faculty of Arts) offer a joint Honours program for students wishing in depth study in Mathematics and Economics**.** For Economics course listings, refer to the Faculty of Arts chapter in the Calendar.

**To enter** the Joint Honours Mathematics - Economics program, the student must have a minimum grade of "B" in: ECON 1010 and ECON 1020 (or ECON 1210 and ECON 1220), MATH 1300[1], MATH 1700[1] and have satisfied the Faculty of Science requirements for entry to the honours program.

| YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 |
|---|---|---|---|
| **JOINT HONOURS** 120 CREDIT HOURS | | | |
| ECON 1010, ECON 1020 (or ECON 1210 and ECON 1220)<br><br>MATH 1300[1], MATH 1500[1,2], MATH 1700[1,2]<br><br>STAT 1000[3]<br><br>COMP 1010[3] | ECON 2700, ECON 2800<br><br>MATH 2202, MATH 2352 (6), MATH 2750 (6), MATH 2800 | ECON 3700, ECON 3800, ECON 3180[7] (or STAT 2000)[3]<br><br>MATH 2600[3], MATH 3230, MATH 3300[5], MATH 3400, MATH 3700(or MATH 3710), MATH 3740 (or MATH 3760) (6)<br><br>24 credit hours of approved Economics courses[4]<br><br>6 credit hours of Mathematics courses at the 3000 or 4000 level, which must include at least one of MATH 3510, MATH 3600, MATH 3810, MATH 3820, MATH 4310, or any Mathematics course at the 4000 level. | |
| 9 credit hours of electives[6], including the required "W" course. | 6 credit hours of approved electives[6] | | |
| 30 Hours | 30 Hours | 30 Hours | 30 Hours |

**NOTES**:

1 MATH 1310 may be taken in place of MATH 1300; MATH 1510, or MATH 1520 may be taken in place of MATH 1500; MATH

1710may be taken in place MATH 1700.

2 The combination of MATH 1500[1] and MATH 1700[1] may be replaced by MATH 1690.

3 Some courses may be taken in a different year than indicated; STAT 1000, COMP 1010, MATH 2600 and ECON 3180 (or STAT 2000) may be taken in Year 2.

4 Of the 24 credit hours of electives in Economics in Years 3 and 4, no more than 6 credit hours may be at the 2000 level (with the exception of ECON 2530) and at least 6 credit hours must be at the 4000 level.

5 MATH 3300, plus 3 of the 6 unallocated credit hours in Mathematics in Years 3 and 4, may be replaced by MATH 3350.

6 Students are encouraged to consider useful courses in Computer Science and Statistics as electives.

7 The prerequisite of ECON 3170 is waived for students in this program.

(The number 6 in brackets indicates a 6 credit hour course.)

# Changes to the B.Sc. Joint Honours in Mathematics – Physics and Astronomy Program

## New Mathematics – Physics and Astronomy Joint Honours Program (combined with Physics and Astronomy proposal):

**Honours Requirements**

**To enter** the Joint Honours Mathematics – Physics Honours program the student must have a minimum grade of "B" in: either MATH 1232 or MATH 1690 (or a minimum grade of "A" in MATH 1700), PHYS 1050 (or "B+" in PHYS 1020) and PHYS 1070.

**To continue** in the Honours program, students must maintain a minimum GPA of 3.00, complete a minimum of 9 credit hours during each Fall and Winter Term.

**To graduate** with the B. Sc. Honours degree, a student must achieve a minimum DGPA of 3.00, and a minimum grade of "C+" in each of the Honours Program Specific courses, and a minimum grade of "C" on all remaining courses that contribute to the 129 credit hours of the degree. See the Calendar entry for each of the Department of Mathematics and the Department of Physics and Astronomy for the Honours Program Specific courses.

| YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 |
|---|---|---|---|
| **JOINT HONOURS** 129 CREDIT HOURS (129 credit hours) | | | |
| MATH 1220[1], MATH 1230[1], MATH 1232[1] (B), MATH 1240<br><br>PHYS 1050 (B) (or PHYS 1020[2](B+)) and PHYS 1070 (B)<br><br>STAT 1000<br><br>COMP 1010<br><br>6 credit hours from the Faculty of Arts, which should include the required "W" course[4] | PHYS 2260, PHYS 2380,PHYS 2600, PHYS 2610,PHYS 2650[3]<br><br>MATH 2020, MATH 2080, MATH 2090, MATH 2150, MATH 2180 | MATH 3320, MATH 3340, MATH 3440, MATH 3460, MATH 3470, MATH 3472<br><br>PHYS 3670, PHYS 3680,PHYS 3650 , PHYS 3630 , PHYS 3380<br><br>3 credit hours from 3000 and 4000 level Physics Honours courses | MATH 3322<br><br>12 credit hours from: MATH 2030, MATH 2070, MATH 2160, MATH 2170, or any 3000 or 4000 level Mathematics courses, of which 3 credit hours must be at the 4000 level<br><br>PHYS 3430 (6), PHYS 3640 ,PHYS 3660, PHYS 4390[5]<br><br>3 credit hours from 3000 and 4000 level Physics Honours courses |
| 30 Hours | 30 Hours | 36 Hours | 33 Hours |

**NOTES**:

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (A) in place of MATH 1220, MATH 1500 (A) or MATH 1510 (A) in place of MATH 1230, MATH 1700 (A) or MATH 1710 (A) in place of MATH 1232, MATH 1690 (B) in place of

MATH 1230 and MATH 1232.

2 PHYS 1030 is not suitable for entry to the program. Students must also take PHYS 1070 if they have already taken PHYS 1030. Students can hold credit for both PHYS 1030 and PHYS 1070.

3 The corequisite of PHYS 2490 is waived. It is recommended that students audit PHYS 2390 and PHYS 2490 in second year.

4 As there are no electives in Year 2 of the program, students should complete the university written English requirement in Year 1. If not completed in Year 1, a *"W"* course must be completed prior to Year 3 in addition to the required Year 2 courses.

5 The prerequisite of PHYS 2490 is waived.

(Letters in brackets indicate minimum grade required for further study. The number 6 in brackets indicates a 6 credit hour course.)

## Old Mathematics – Physics and Astronomy Joint Honours Program:

**Honours Requirements**

**To enter** the Joint Honours Mathematics – Physics Honours program the student must have a minimum grade of "B" in: MATH 1300[1], MATH 1510[1], MATH 1710[1] (or MATH 1690), PHYS 1050 (or "B+" in PHYS 1020) and PHYS 1070.

**To graduate** with the B. Sc. Honours degree, a student must achieve a minimum DGPA of 3.00 and a minimum grade of "C+" in each of the Honours Program Specific courses, and a minimum grade of "C" on all remaining courses that contribute to the 129 credit hours of the degree. See the Calendar entry for each of the Department of Mathematics and the Department of Physics and Astronomy for the Honours Program Specific courses.

| YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 |
|---|---|---|---|
| **JOINT HONOURS** 129 CREDIT HOURS (129 credit hours) | | | |
| MATH 1300[1] (B), MATH 1510[1] (B), MATH 1710[1] (B)<br><br>PHYS 1050 (B) (or PHYS 1020[2](B+)) and PHYS 1070 (B)<br><br>STAT 1000<br><br>COMP 1010<br><br>6 credit hours from the Faculty of Arts, which should include the required "W" course[4] | PHYS 2260, PHYS 2380,PHYS 2600[3], PHYS 2610,PHYS 2650<br><br>MATH 2202, MATH 2352 (6),MATH 2750 (6), MATH 2800 | MATH 3230, MATH 3350 (6) (or MATH 3300 and MATH 3310),MATH 3700 or MATH 3710,MATH 3760 (6)<br><br>PHYS 3670, PHYS 3680,PHYS 3650, PHYS 3630, PHYS 3380<br><br>3 credit hours from 3000 and 4000 level Physics Honours courses | MATH 3800, MATH 4810[6]<br><br>9 credit hours of 3000 or 4000 level Mathematics courses, of which 3 credit hours must be at the 4000 level<br><br>PHYS 3430 (6), PHYS 3640[5] ,PHYS 3660, PHYS 4390<br><br>3 credit hours from 3000 and 4000 level Physics Honours courses |
| 27 Hours | 33 Hours | 36 Hours | 33 Hours |
| **NOTES**: | | | |

1 MATH 1310 may be taken in place of MATH 1300; MATH 1500, or MATH 1520 may be taken in place of MATH 1510; MATH 1700may be taken in place of MATH 1710. MATH 1690 may be taken in place of both MATH 1510 and 1710.

2 PHYS 1030 is not suitable for entry to the program. Students must also take PHYS 1070 if they have already taken PHYS 1030. Students can hold credit for both PHYS 1030 and PHYS 1070.

3 The corequisite of PHYS 2490 is waived. It is recommended that students audit PHYS 2390 and PHYS 2490 in second year.

4 As there are no electives in Year 2 of the program, students should complete the university written English requirement in Year 1. If not completed in Year 1, a *"W"* course must be completed prior to Year 3 in addition to the required Year 2 courses.

5 The prerequisite of PHYS 2490 is waived.

6 The prerequisite of MATH 3810 has been waived for students who have completed PHYS 3630, PHYS 3640 and PHYS 3380.

(Letters in brackets indicate minimum prerequisite standing for further study. The number 6 in brackets indicates a 6 credit hour course.)

# Changes to the B.Sc. Joint Honours in Mathematics – Statistics

## New Mathematics-Statistics Joint Honours Program

**Mathematics - Statistics Joint Honours Program**

The departments of Statistics and Mathematics offer a joint Honours program for students wishing in depth study in Statistics and Mathematics.

**To enter** the Honours program students must have satisfied the Faculty of Science requirements for entry to the program, and have obtained a minimum grade of "B" in STAT 1000, either MATH 1232 or MATH 1690 (or a minimum grade of "A" in MATH 1700).

**To graduate** with the B. Sc. Honours degree, a student must achieve a minimum DGPA of 3.00, a minimum grade of "C+" in each of the Honours Program Specific courses, and a minimum grade of "C" on all remaining courses that contribute to the 120 credit hours of the degree. See the Calendar entry for each of the Department of Statistics and the Department of Mathematics for the Honours Program Specific courses.

| YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 |
|---|---|---|---|
| **JOINT HONOURS** 120 CREDIT HOURS (comprising courses listed in chart below, and electives) | | | |
| MATH 1220[1],<br>MATH 1230[1],<br>MATH 1232[1] (B),<br>MATH 1240 | 2<br>STAT 2000 , STAT 2400<br><br>MATH 2020, MATH 2080, MATH 2090, MATH 2150, MATH 2160, MATH 2180 | STAT 3050, STAT 3470, STAT 3480, STAT 3400, STAT 3800 | STAT 4100, STAT 4520, STAT 4530 |
| The following courses must be taken in Year 1 or Year 2:<br><br>STAT 1000 (B), COMP 1010<br><br>6 credit hours from the Faculty of Arts, which should include the required "W" course<br><br>12 credit hours of approved electives | | MATH 2030, MATH 3320, MATH 3322, MATH 3340, MATH 3470, MATH 3472, MATH 3440, MATH 3460<br><br>3 credit hours from MATH 2070, MATH 2170 and any 3000 / 4000 level Mathematics courses<br><br>3 credit hours from any 4000 level Mathematics courses<br><br>6 credit hours of approved electives | |
| 30 Hours | 30 Hours | 30 Hours | 30 Hours |

**NOTES**:

1 Students are strongly advised to take MATH 1220, MATH 1230, and MATH 1232. The following substitutions are allowed (but not advised), provided the grades indicated in brackets are achieved: MATH 1300 (A) in place of MATH 1220, MATH 1500 (A) or MATH 1510 (A) in place of MATH 1230, MATH 1700 (A) or MATH 1710 (A) in place of MATH 1232, MATH 1690 (B) in place of MATH 1230 and MATH 1232.

2 STAT 2000 may be taken in Year 1.

Letters in brackets indicate minimum grade required for further study.

## Old Mathematics – Statistics Joint Honours Program:

**4.9.2.11 Mathematics - Statistics Joint Honours Program**

The departments of Statistics and Mathematics offer a joint Honours program for students wishing in depth study in Statistics and Mathematics.

**To enter** the Honours program students must have satisfied the Faculty of Science requirements for entry to the program, and have completed STAT 1000, MATH 1300 and either MATH 1690, or MATH 1500 and MATH 1700 or any equivalent with a minimum grade of "B" in each of STAT 1000 and MATH 1690 (or a "B" average in MATH 1500 and MATH 1700).

**To graduate** with the B. Sc. Honours degree, a student must achieve a minimum DGPA of 3.00 and a minimum grade of "C+" in each of the Honours Program Specific courses, and a minimum grade of "C" on all remaining courses that contribute to the 120 credit hours of the degree. See the Calendar entry for each of the Department of Statistics and the Department of Mathematics for the Honours Program Specific courses.

| YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 |
|---|---|---|---|
| **JOINT HONOURS** 120 CREDIT HOURS (comprising courses listed in chart below, and electives) | | | |
| 1<br>MATH 1300 (B), MATH 1690(6) (B) (or MATH 1500 1 and MATH 1700 1 (B)) | 2<br>STAT 2000 , STAT 2400<br><br>MATH 2202, MATH 2352 (6),MATH 2600, MATH 2750 (6),MATH 2800 | STAT 3050, STAT 3470, STAT 3480, STAT 3400, STAT 3800 | STAT 4100, STAT 4520, STAT 4530 |
| The following courses must be taken in Year 1 or Year 2:<br><br>STAT 1000 (B), COMP 1010<br><br>6 credit hours from the Faculty of Arts, which should include the required "W" course<br><br>12 credit hours of approved electives | | Plus a total of 30 credit hours from: MATH 2400 and any 3000 / 4000 level Mathematics courses, which must include at least 3 credit hours at the 4000 level and must also include MATH 3230, MATH 3740 (6)(or MATH 3760 (6)), MATH 3350 (6) (orMATH 3300), MATH 3700 (or MATH 3710), MATH 3400 andMATH 3800<br><br>6 credit hours of approved electives | |
| 30 Hours | 30 Hours | 30 Hours | 30 Hours |

**NOTES**:1 MATH 1310 may be taken in place of MATH 1300; MATH 1510 or MATH 1520 may be taken in place of MATH 1500; MATH 1710may be taken in place of MATH 1700.

2 STAT 2000 may be taken in Year 1.

(Letters in brackets indicate minimum prerequisite standing for further study. The number 6 in brackets indicates a 6 credit hour course.)

## MATH 1220 Linear Algebra 1

(Winter term)

**Calendar description:** (Laboratory required) The course is intended for students in mathematically rich disciplines including those planning to enter an Honours or Major program in Mathematics or Statistics. An introduction to vectors, matrices, systems of linear equations and three-dimensional geometry. Not to be held with MATH 1210, MATH 1211, MATH 1300, MATH 1301, MATH 1310, or the former MATH 1680. Prerequisite: Pre-calculus Mathematics 40S (70%) or the former Mathematics 40S (300) (70%), or the Mathematical Skills course taught by Extended Education (B). Applied Mathematics 40S (70%) may be used as a prerequisite to this course.

**Detailed program:**
• Geometry of Euclidean vector spaces: norm of a vector, vector operations, dot product, projections, cross product, lines and planes in $R^3$, Euclidean $n$-space.
• Systems of linear equations and matrices: Gauss-Jordan elimination, matrix operations, elementary matrices, matrix inverses, classes of matrices.
• Determinants: Definitions, cofactor expansion, evaluation using row reduction, Cramer's rule.
• Linear transformations in $R^2$, $R^3$ and $R^n$.
• Complex numbers: basic properties, inverses, DeMoivre's theorem.
• Eigenvalues and eigenvectors in $R^2$, $R^3$ and $R^n$.
• Diagonalizing matrices and applications.

## MATH 1230 Differential Calculus

(Fall term)

**Calendar description:** (Laboratory required) The course is intended for students in mathematically rich disciplines including those planning to enter an Honours or Major program in Mathematics or Statistics. Rigorous treatment of limits, continuity, and differentiation (with epsilon-delta proofs), applications in optimization problems, related rates, l'Hopital's rule, curve sketching, Taylor polynomials. Not to be held with MATH 1500, MATH 1501, MATH 1510, MATH 1520, the former MATH 1680, or MATH 1690. Prerequisite: Pre-calculus Mathematics 40S (70%) or the former Mathematics 40S (300) (70%), or the Mathematical Skills course taught by Extended Education (B).

**Detailed program:**
• Brief review of real numbers (intervals, absolute value, inequalities with absolute values) and functions (domain, range, operations, graph, inverse, trig functions);
• Formal definition of limits (of functions with ε, δ, and of sequences with ε, $N$)
• Limit laws, limits involving infinity, one-sided limits, Squeeze Theorem, asymptotes;
• Continuity at a point, continuity on an interval, Intermediate Value Theorem, Min-Max Theorem;
• Definition of a derivative, differentiation rules, chain rule, derivatives of trig functions, higher order derivatives, Mean Value Theorem, implicit differentiation, antiderivative, tangent lines, velocity and acceleration;
• Exponential, logarithmic functions and their derivatives, inverse trigonometric functions and their derivatives, logarithmic differentiation;
• Applications of differentiation (related rates, l'Hopital's rule, max/min values, optimization problems, derivatives and increasing/decreasing/concavity of a function)
• Curve sketching
• Taylor polynomials (definition, Lagrange remainder, applications)

## MATH 1232 Integral Calculus

(Winter term)

**Calendar description:** (Laboratory required) The course is intended for students in mathematically rich disciplines including those planning to enter an Honours or Major program in Mathematics or Statistics. Integral calculus: theory and techniques of integration, curve sketching (parametric and polar), volume, arc length, surface area and partial derivatives. Sequences and series. Not to be held with MATH 1690, MATH 1700, MATH 1701, MATH 1710. Prerequisite: MATH 1230 (C) or MATH 1500 (B) or MATH 1501 (B) or MATH 1510 (B).

**Detailed program:**
• Brief review of antiderivatives.
• Sums and Sigma notation (if not covered in discrete math), areas as limits and sums, the definite integral (Riemann sums), properties of the definite integral, the Fundamental Theorem of Calculus.
• Integration techniques: substitution, integration by parts, integration of rational functions, trig integrals, inverse trig substitution.
• Improper integrals.
• Applications of integration: areas between curves, arc length, volumes by slicing, volumes of solids of revolution (washers and cylindrical shells), areas of surfaces of revolution.
• Parametric curves, polar coordinates and polar curves, arc length and areas of parametric and polar curves.
• Sequences and series: geometric, telescoping and harmonic series, Integral test, comparison test, ratio and root test.

## MATH 1240 Elementary Discrete Mathematics

(Fall term, Winter term) [this is a one-semester course]

**Calendar description:** (Laboratory required) The course is intended for students in mathematically rich disciplines including those planning to enter an Honours or Major program in Mathematics or Statistics. An introduction to Discrete Mathematics. Topics include mathematical induction, modular arithmetic, Boolean algebras, basic sentential logic, elementary set theory and functional notation, partial orders, basic graph theory, basic counting. Not to be held with MATH 3120. Prerequisite: Pre-calculus Mathematics 40S (60%) or the former Mathematics 40S (300) (60%), or the Mathematical Skills course taught by Extended Education (C).

**Detailed program:**
• Formal logic: logical forms, valid arguments, necessary and sufficient conditions, if and only if statements, boolean expressions, logical equivalence, contrapositive, truth tables, argument by contradiction, quantifiers and their negations.
• Basic set theory: Notation: subset, union, intersection, complement, containment, de Morgan's laws, Venn diagrams. partitions, power set, cartesian product, axioms (briefly).
• Relations on sets: Definitions, binary relations, reflexive, irreflexive, symmetric, asymmetric, anti-symmetric, transitive, intransitive, equivalence relations and equivalence classes, binary operator.
• Functions: A function as a special kind of a binary relation, one-to-one, onto, bijection, composition, definition of cardinality of a set, inverse functions, domain, range, co-domain.
• Mathematical induction: principle of mathematical induction, strong induction, alternate forms of induction, recursion as induction, Fibonacci numbers.
• Basic counting: Binomial coefficients, binomial theorem, counting subsets, basic combinations and permutations.
• Partial orders: Definitions, partial orders, Hasse diagrams, linear orders, chains, antichains, lexicographic order, meets, joins, lattices, lattice of subsets.
• Modular arithmetic: Equivalence classes, basic calculating, inverses, Fermat's little theorem and RSA encryption in a lab.
• Graphs and trees: introduction: notation and terminology (simple graph, multi-graph, path, trail, complete graph, cycle, directed graph, weighted graph, vertex, edge, degree, degree sequence, neighbourhood, connected, tree, rooted tree), a graph seen as a set with a relation.
• Digraphs and finite state automatoa: Directed graphs, weighted digraphs, loops, counting steps in processes. Small examples.
• Words: Alphabet, letter, word, palindromes, concatenation, permutations.
• Counting steps in algorithms: simple examples, big oh notation.

## MATH 2020 Algebra 1

(Winter term)

**Calendar description:** (Laboratory required) Groups, Rings, Fields: Elementary Concepts and Examples. Not to be held with the former MATH 3350. Prerequisite: MATH 2090 (C) or the former MATH 2352 (C) or the former MATH 2300 (B) or MATH 2301 (B).

**Detailed program:**
• Integers: Divisors; Primes; Congruences; Integers Modulo *n*; Euclidean Algorithm; GCD; LCM.
• Functions: Functions; Equivalence Relations; Permutations.
• Groups: Definition of a Group; subgroups and subgroup lattices; cyclic groups; definition and basic examples of abelian groups; permutations groups; homomorphism; isomorphisms; cosets; normal subgroups; modular lattices; factor groups; Lagrange Theorem.
• Rings: Commutative rings: the ring of integers, Polynomial rings; Integral domains; noncommutative rings: rings of linear operators on a vector space, rings of matrices, the ring of endomorphisms of an abelian group; ideals and factor rings.
• Fields: Basic examples, such as the fields of rational, real, and complex numbers; fields of quotients of integral domains; fields as homomorphic images of commutative rings; basics of finite fields.

## MATH 2030 Combinatorics 1

(Fall term)

**Calendar description:** (Laboratory required) Introductory combinatorics, including basic counting, permutations and combinations, enumeration, inclusion-exclusion, pigeonhole principle, solving basic recursions, relations, and derangements. Not to be held with the former MATH 3400. Prerequisites: MATH 1240 (C) or [the former MATH 2202 (C) and the former MATH 2352 (C)] or consent of instructor.

**Detailed program:**
• Basic counting: Rules (incl. Product rule, Sum rule), permutations, *r*-permutations, subsets, *r*-combinations,binomial coefficients, probability, sampling with replacement, occupancy problems (e.g., distinguishable balls into indistinguishable cells), Stirling numbers of the second kind, multinomial coefficients, binomial expansion, generating permutations and combinations, and pigeonhole principle.
• Principle of inclusion and exclusion: Counting derangements, number of objects having exactly m properties, hatcheck problem.
• Relations: Binary relations, order (linear, partial), interval orders, lattices and boolean algebras, distributive and complemented lattices, modular lattices, lexicographic order.
• Recurrence relations: Fibonacci numbers, derangements, method of characteristic roots.
• Other topics may include: Magic squares, Gray codes, algorithms and complexity, big oh notation, small Ramsey numbers, introduction to generating functions, partitions of integers, and Ferrer diagrams.

## MATH 2040 Curves and Surfaces

(Fall term)

**Calendar description:** (Laboratory required) Curves and surfaces in the plane and space. Intrinsic geometry of curves and surfaces: Serret Frenet frames, first and second fundamental forms, curvature and the Gauss map. Geodesics and parallel transport. Theorema Egregium and Gauss-Bonnet theorems. Prerequisites: [MATH 1232 (C) or MATH 1690 (C) or MATH 1700 (B) or MATH 1701 (B) or MATH 1710 (B)] and [MATH 1220 (C) or MATH 1300 (B) or MATH 1301 (B)]; or consent of instructor.

**Note:** Will be moved to Winter term starting with 2017/18 academic year, pre- or co-requisite of MATH 2150 or MATH 2720 will be added (subject to approval).

**Detailed program:**
• Curves: parametrized curves, Serret Frenet frames.
• Surfaces: parametrization, change of coordinates, tangent plane, first fundamental form, orientation, area.
• Gauss map: definition of Gauss map, properties, Gauss map in local coordinates, equations of Weingarten.
• Intrinsic geometry of surfaces: isometries, conformal maps, Gauss theorema egregium, parallel transport, geodesics, lcoal Gauss-Bonnet theorem, global Gauss-Bonnet theorem.

## MATH 2070 Graph Theory 1

(Winter term)

**Calendar description:** (Laboratory required) Introduction to graphs, digraphs, and multigraphs. Topics include trees, cycles and circuits, planarity, basic graph algorithms, and applications of graph theory to social and physical sciences. Not to be held with the former MATH 2400 or COMP 4340. Prerequisites: MATH 1240 (C) and [MATH 1220 (C) or MATH 1300 (B) or MATH 1301 (B)].

**Detailed program:**
• Basic graph theory: Definitions of graph and digraph, multigraph, labelled graphs, isomorphism, degree sequences, trees, paths, cycles, complete graphs, connectedness, bridges, regular graphs, strongly connected digraphs.
• Circuits and cycles: Eulerian graphs, Eulerian digraphs and multigraphs, Hamiltonian graphs, Ore's condition, Dirac's condition.
• Planar graphs: Euler's theorem for planar graphs and polyhedra.
• Graph colouring, the Four Colour Theorem, 2-colourable graphs, chromatic number, independent sets.
• Trees, spanning trees, equivalent conditions for a tree, Cayley's theorem for labelled trees and Prufer sequences.
• Graphs and matrices, incidence matrix and adjacency matrix, counting walks.
• Applications: Including minimum spanning trees, Kruskal's algorithm, Prim's algorithm, DeBruijn sequences, Gray codes, chemical trees, rotating drum problem, Robbin's theorem for one-way streets, irreducible Markov chains, Fleury's algorithm.

## MATH 2080 Introduction to Analysis

(Fall term)

**Calendar description:** (Laboratory required) Fundamental properties of the real number system as a complete ordered field, Archimedean property, existence of square roots, density of rational numbers, uncountability of real numbers. Sequences, subsequences, limit theorems, monotonicity, Bolzano-Weierstrass theorem, Cauchy sequences. Rigorous treatment of limits and continuity of functions of one and several variables. Uniform continuity. Applications. Not to be held with the former MATH 2202. Prerequisites: [MATH 1232 (C) or MATH 1690 (C) or MATH 1700 (B) or MATH 1701 (B) or MATH 1710 (B)] and [MATH 1220 (C) or MATH 1300 (B) or MATH 1301 (B)] and MATH 1240 (C).

**Detailed program:**
• The real numbers: field, order and completeness axioms, Archimedean property, density of rational numbers, nested intervals property, uncountability of real numbers;
• Sequences: (review of the limit definition), subsequences, accumulation points, monotonic sequences, Bolzano-Weierstrass theorem, Cauchy sequences;
• Limits of functions of one and several variables: (review of "epsilon-deltas"), sequential criteria for limits;
• Continuous functions: continuous functions on intervals ("Maximum-Minimum" theorem), Bolzano Intermediate Value theorem, Preservation of Intervals theorem, uniform continuity, Weierstrass Approximation theorem. Continuous functions of several variables.

## MATH 2090 Linear Algebra 2

(Fall term)

**Calendar description:** (Laboratory required) The course is intended for students in mathematically rich disciplines. Abstract vector spaces, linear transformations, bases and coordinatization, matrix representations, orthogonalization, diagonalization, principal axis theorem. Not to be held with the former MATH 2300, MATH 2301, or the former MATH 2352. Prerequisite: MATH 1220 (C) or MATH 1300 (B) or MATH 1301 (B).

**Detailed program:**
• Vector space examples: polynomials, $C^n$, matrices, linear transformations and operators, function spaces.
• Abstract vector spaces: definitons and first properties, subspaces, linear independence, spanning, bases, dimension. Direct sums. Dimension theorems.
• Coordinatization of finite dimensional vector spaces.
• Matrix representations of linear transformations and operators of an abstract vector space. Change of basis.
• Inner product spaces: length of and angles between vectors. Gram-Schmidt orthogonalization. Orthogonal projections and approximations.
• Diagonalization of matrices: real, symmetric matrices, Principal axis theorem. Normal, orthogonal and Hermitian matrices.

## MATH 2140 Modelling

(Fall term)

**Calendar description:** (Laboratory required) Introductory course on the design and analysis of mathematical models for real-life phenomena arising in the natural, engineering and social sciences. Not to be held with the former MATH 3820 or MATH 3821. Prerequisite: MATH 1230 (C+) or MATH 1690 (C+) or MATH 1500 (B) or MATH 1501 (B) or MATH 1510 (B) or MATH 1220 (C) or MATH 1300 (B) or MATH 1301 (B).

**Detailed program:**
• This is an introductory modelling course and does not have an ODE prerequisite. Simple ODE's are used in the course (explicit solutions, basic qualitative and numerical simulations using software (Octave/MatLab/Maple)).
• In terms of methods used:
– simple ODEs (scalar (linear/nonlinear) ODEs, notion of equilibrium and stability, Phase line analysis, bifurcation diagram, numerical simulations)
– simple difference equations (scalar, cobwebbing, for-loop algorithm)
– Markov chain (regular)
– Curve fitting (Least squares)
– Optimization (functions of one or two variables)

## MATH 2150 Multivariable Calculus

(Winter term)

**Calendar description:** (Laboratory required) The course is intended for students in mathematically rich disciplines. Parametric curves, arc length and curvature. Functions of several variables. Level curves. Partial derivatives, gradient, divergence and curl. Max/min problems. Double and triple integrals, line and surface integrals of functions and vector fields, and applications. Green's, Stokes, and divergence theorems. Not to be held with MATH 2130, MATH 2720, MATH 2721, or the former MATH 2750. Prerequisite: MATH 2080 (C) or the former MATH 2202 (C).

**Detailed program:**
• Quadric surfaces
• Parametric curves, vector functions and space curves;
• Derivatives and integrals of vector functions, arc length and curvature, tangential and normal acceleration, osculating plane;
• Partial derivatives, differentiability, tangent planes, and linear approximations chain rule, directional derivatives and gradients, maximum and minimum values Lagrangian multiplier method;
• Double integrals, double integrals in polar coordinates, applications, triple integrals, triple integrals in spherical and cylindrical coordinates;
• Vector fields, line integrals of functions and vector fields, fundamental theorem of calculus for line integrals, Green's theorem;
• Parametrized surfaces, surface integrals of functions, surface integrals of vector fields, curl and divergence, divergence theorem, Stokes' theorem.

## MATH 2160 Numerical Analysis 1

(Fall term)

**Calendar description:** (Laboratory required) Elementary techniques of numerical solution of mathematical problems: solution of equations, linear systems of equations, nonlinear equations; finite and divided differences, interpolation; numerical differentiation and integration. Not to be held with MATH 2120, the former MATH 2600, or MATH 2601. Prerequisites: [MATH 1232 (C) or MATH 1690 (C) or MATH 1700 (B) or MATH 1701 (B) or MATH 1710 (B)] and [MATH 1220 (C) or MATH 1300 (B) or MATH 1301 (B)].

**Detailed program:**
• Computer arithmetic and floating-point numbers, relative and absolute errors. Roundoff-errors and their propagation.
• Polynomial interpolation: Lagrange interpolation, finite and divided differences, natural and clamped cubic spline interpolation.
• Numerical differentiation and integration: Richardson's extrapolation, trapezoid and Simpson's rules, Newton-Cotes formulas, composite numerical integration, improper integrals.
• Least squares approximation, orthogonal polynomials approximation (Legendre and Chebyshev), and trigonometric polynomial approximation.
• Direct methods for solving linear systems: Gaussian elimination, pivoting methods, matrix factorization and special types of matrices.
• Iterative methods for solving linear systems: Jacobi and Gauss-Seidel iterative methods, relaxation methods, error bounds.
• Numerical solutions for nonlinear equations: bisection method, fixed point method, Newton's method, secant method. Error analysis.

## MATH 2170 Number Theory 1

(Winter term)

**Calendar description:** (Laboratory required) Prime numbers, unique factorization, linear congruences, Chinese remainder theorem, multiplicative functions, primitive roots and quadratic reciprocity. Not to be held with the former MATH 2500 or MATH 2501. Pre- or corequisite: MATH 2020 or [(the former MATH 2352 (C) or the former MATH 2300 (B) or MATH 2301 (B)) and consent of instructor].

**Note:** MATH 2090 will be accepted as prerequisite in place of MATH 2020.

**Detailed program:**
- Review of proof by induction
- Divisibility
- Primes, prime power decomposition
- Linear Diophantine equations $ax+by=c$.
- Properties of Congruences
  - addition mod n
  - multiplication mod n
  - congruence as an equivalence relation
- Solutions of linear congruences $ax=b \pmod{n}$
- Fermat's Little Theorem
- Wilson's Theorem
- Multiplicative functions
  - $\tau(n)$, $\sigma(n)$, $\varphi(n)$
- Perfect numbers and Mersenne primes
- Euler's Theorem
- RSA Encryption
- Primitive roots
- Quadratic congruences
- Quadratic reciprocity
- Additional problems explaining these concepts will be done in the tutorials
- Time permitting, additional topics may be covered, like
  - Sums of two squares
  - Pythagorean triples
  - Sums of four squares

## MATH 2180 Real Analysis 1

(Winter term)

**Calendar description:** (Laboratory required) Introduction to metric spaces including connectedness, compactness and continuity; topics in infinite series of numbers, and sequences and series of functions. Not to be held with the former MATH 3230. Prerequisite: MATH 2080 (C) or the former MATH 2202 (C).

**Detailed program:**
• Metric spaces: basic notions (distance function, open set, closed set, limit point), metric subspace, product space, convergent sequences, continuity of functions, uniform continuity, connectedness, compactness, Heine-Borel theorem, examples: inner product and normed vector spaces.
• Infinite series of numbers: absolute and conditional convergence, product of series, double sequences and series, rearrangements.
• Sequences and series of functions in metric spaces: uniform convergence, uniform convergence and differentiability, equicontinuity and Arzela-Ascoli for $C[0,1]$.

## MATH 3320 Algebra 2

(Fall term)

**Calendar description:** Basic structure theory of groups, integral domains and field extensions. Not to be held with the former MATH 3350. Prerequisite: MATH 2020 (C) or [(the former MATH 2352 (C) or the former MATH 2300 (B) or MATH 2301 (B)) and consent of instructor].

**Note:** MATH 3300 (C) is needed in place of (the former MATH 2352 (C) or the former MATH 2300 (B) or MATH 2301 (B)). In other words, if coming from old curriculum, no permission will be given without MATH 3300.

**Detailed program:**
• Groups: isomorphism theorems; Sylow Theorems; abelian groups; solvable groups; simple groups.
• Rings: polynomial rings: irreducible polynomials; factorizations; Eisenstein criterion; principal ideal domains; euclidean domains; unique factorization domains.
• Fields: finite, algebraic, and transcendental extensions; finite fields; splitting fields; euclidean construction.

## MATH 3322 Algebra 3

(Winter term)

**Calendar description:** A continuation of topics in Algebra 1 and Algebra 2. More structure theory of groups, general ring theory, fields and field extensions, Galois theory. Prerequisite: MATH 3320 (C) or [the former MATH 3350 (C) and consent of instructor].

**Detailed program:**

- 1. Group theory:
  - a) Constructions of groups: direct product (internal and external).
  - b) Free groups, presentations
  - c) Nilpotent groups
  - d) Composition series. Jordan-Holder theorem.
- 2. Ring theory:
  - a) Non-commutative rings, ideals and homomorphisms.
  - b) Noetherian and artinian rings. Hilbert Basis theorem
- 3. Field theory:
  - a) Algebraically closed fields
  - b) Theory of field extensions: separable polynomials, splitting fields, normal extensions, roots of unity. Algebraic and transcendental extensions.
  - c) Galois theory
  - d) Extensions by radicals. The general equation of degree $n$.

## MATH 3330 Computational Algebra

(Winter term)

**Calendar description:** An introduction to the use of computers for symbolic mathematical computation, involving solving nonlinear systems and differential equations. A suitable software package will be used to explore applications. Prerequisite: MATH 2090 (C) or the former MATH 3300 (C) or the former MATH 3350 (C) or consent of instructor.

**Note:** the former MATH 2300 or MATH 2352 are acceptable prerequisites in place of the former MATH 3300 (C) or the former MATH 3350 (C).

**Detailed program:**
• This course is an introduction to the use of computers for symbolic mathematical computation, commonly called computer algebra used now worldwide by millions of people to help with mathematical tasks in application areas such as engineering or finance.
• The types of mathematical computations of interest include polynomial arithmetic, Gröbner bases, factoring polynomials, solving systems of polynomial equations, Fourier Transform and interpolation, and analytic integration of functions.
• The course is designed to expose students to
– the concepts from modern algebra which are applied to the development of algorithms for symbolic computation;
– mathematics software used for symbolic computation;
– and various applications of symbolic computation in differential equation, geometry, cryptography, computer aided design, control systems and statistics.

## MATH 3340 Complex Analysis 1

(Winter term)

**Calendar description:** Analytic functions, Cauchy's theorem and integral formula, series representation of analytic functions, calculus of residues, Rouche's theorem and the principle of the argument. Not to be held with the former MATH 3710. Prerequisites: [MATH 2180 (C) or the former MATH 3230 (C)] and [MATH 2150 (C) or MATH 2720 (B) or MATH 2721 (B) or the former MATH 2750 (C)].

**Notes:** Students are advised to take MATH 3472 at the same time.

**Detailed program:**
• The geometry of the complex plane, analytic functions;
• Contour integrals, Cauchy's theorem, Cauchy's integral formula, maximum modulus theorem, harmonic functions;
• Series representation of analytic functions (convergence, power series, Taylor's theorem, Laurent series and classification of singularities;
• Residue calculus (Residue theorem, evaluation of definite integrals using residues;
• Rouche's theorem and Principle of the Argument theorem, open mapping theorem;

## MATH 3360 Combinatorics 2

(Fall term)

**Calendar description:** Advanced topics in combinatorics, including generating functions, elementary design theory, recurrences, chains and antichains, Polya counting. The course is intended for students in mathematically rich disciplines. Not to be held with the former MATH 4400. Prerequisite: MATH 2030 (C) or the former MATH 3400 (C).

**Detailed program:**
• Generating functions: Sampling without replacement, integer solutions of equations, partitions of integers, exponential generating functions, counting permutations, distinguishable balls into indistinguishable cells.
• Introduction to designs: Kirkman's school girl problem, including resolvable STS, the problem of 36 officers, Euler's conjecture on the existence of orthogonal pairs of latin squares, Fisher's inequality, finite projective planes, Bruck-Ryser theorem.
• Recurrences: Recurrences involving convolutions, Catalan numbers (including counting lattice paths, triangulations).
• Other topics: Rook polynomials, magic squares, Eulerian numbers, linear extensions, chains, antichains, Dilworth's theorem, LYM inequality, combinatorics on words, basic combinatorial matrix theory, Polya counting, van der Waerden's theorem for arithmetic progressions.

## MATH 3370 Graph Theory 2

(Odd Winter term, every other year: Winter 2017, Winter 2019, ...)

**Calendar description:** Advanced topics in graph theory, including matchings and coverings, optimization, factors, flows, extremal graph theory, basic Ramsey theory, connectivity, and spectral graph theory. Selected applications in science and operations research are studied. The course is intended for students in mathematically rich disciplines. Not to be held with COMP 4340. Prerequisite: MATH 2070 (C) or the former MATH 2400 (B) or permission of instructor.

**Detailed program:** For many of the following topics, real-world applications and algorithms are given.
• Brief review of elementary graph theory and basic definitions, including degree sequences, trees, minimum spanning trees (Prim's and Kruskal's algorithms), Eulerian trails (Fleury's algorithm), Hamiltonian cycles and applications, planar graphs, Euler's formula, the Four Colour Theorem, tournaments, strongly connected graphs, adjacency matrices.
• Graceful labellings of trees, Dijkstra's algorithm, breadth-first-search algorithms, and graph decompositions.
• Matchings and factors: Hall's marriage theorem, stable matchings, Gale-Shapley algorithm, Tutte's theorem, Konig-Egervary theorem, stable matchings, Menger's theorems, Dilworth's theorem, and Petersen's 1-factor theorem.
• Flows and networks: Ford-Fulkerson algorithm, integer flows, max-flow min-cut theorem, scheduling.
• Vertex colourings, chromatic polynomial, Brook's theorem, Erdos-Faber-Lovasz conjecture, list colourings, edge colourings, Vizing's theorem, line graphs.
• Extremal graph theory: including cages, circumference, Erdos-Gallai theorem, Mantel's theorem, Turan's theorem, extremal bipartite graphs.
• Perfect graphs, chordal graphs, comparability graphs, interval graphs.
• Basic graph Ramsey theory, Erdos-Szekeres recursion, small Ramsey numbers, Payley graphs.
• Introduction to algebraic (spectral) graph theory: eigenvalues, eigenvectors, expanders, strongly regular graphs.
• Optional topics (depending on time and student interest) may include: random graphs, threshold functions, large random models, the web and social network graphs, topological graph theory, random walks on graphs, Huffman's algorithm for prefix-free codes.

## MATH 3380 Introduction to Projective Planes

(Fall term)

**Calendar description:** Affine planes and projective planes, cross ratio, complex projective plane (the great unifier), Desargues' theorem, projective planes over division rings, Pappus' theorem and commutativity, the fundamental theorem for projectivities on a line, introduction of coordinates in a projective plane. Not to be held with the former MATH 2552 or the former MATH 3430. Prerequisite: MATH 2020 (C) or the former MATH 3300 (C) or the former MATH 3350 (C) or consent of instructor.

**Detailed program:**

- Affine Planes and Projective Planes, Homogeneous coordinates
- Desargues' Theorem, Pappus' Theorem, Projective Planes over Fields (iff Papus)
- Complex Projective Plane (the great unifier)
- Mobius transformations and the cross-ratio
- Examples of finite projective planes
- Projective Planes over Division Rings (iff Desargues)
- An example of a non-Desarguesian projective plane
- Characterization of the Euclidean Plane (e.g. as a projective plane with a metric determined by two "circular points" *I* and *J*)(i.e. where circles are different from other conics)
- Optional Topics (to be chosen depending upon students' interest)
  - Wedderburn's Theorem (Finite Desargues implies Pappus)
  - Fundamental Theorem for Projectivities on a Line
  - Planar ternary rings (algebraic analogs of projective planes)
  - Group law on conics (as a prelude to the famous group law on elliptic curves).

## MATH 3390 Introduction to Topology

(Fall term)

**Calendar description:** Topological spaces, continuity, connectedness, compactness, separation properties. Not to be held with the former MATH 3240. Prerequisite: MATH 2180 (C) or the former MATH 3230 (C) or consent of instructor.

**Detailed program:**
• Topological spaces: basic topological spaces, metric spaces, basic notions, bases, local bases, and subbases;
• Countability axioms: separability, first countability, second countability;
• Special maps: continuous, open, closed, and quotient maps. Homeomorphisms;
• New spaces from old spaces: subspaces, product spaces, and quotient spaces;
• Connectedness: connectedness, path connectedness, local connectedness, local path connectedness; components, and path components;
• Compactness: compact spaces, Lindelöf spaces, countably compact spaces, Tychonoff Theorem. Local compactness, and one-point compactification.
• Separation axioms: T0, T1, T2 (Hausdorff), regularity, T3, complete regularity;
• T3 1/2 (Tychonoff), normality, T4, and the relationships among them. Urysohn's Lemma, and Tietze's Extension Theorem;

## MATH 3410 Introduction to Mathematical Logic

(Even Fall term, every other year: Fall 2016, Fall 2018, ...)

**Calendar description:** Propositional and first-order logic. Recursion theory. Not to be held with the former MATH 4250. Prerequisite: MATH 2020 (C) or the former MATH 2202 (C) or the former MATH 2352 (C) or consent of instructor.

**Detailed program:**

- 1. Propositional logic.
  - Syntax, recursive definition of formulas and proof by induction on complexity. Disjunctive normal form. Semantics, truth tables.
  - Formal methods: a detailed treatment of at least one formal proof method for propositional logic (tableaux, propositional calculus, natural deduction, etc.) Completeness of the method, at least for finite sets of formulas.
- 2. Predicate logic.
  - Syntax and semantics of first order logic. Relation to propositional logic. Semantic consequence, validity. Structures and isomorphism. Extensions and substructures. Expansions of languages, expansions by constants, definitions.
- 3. Elements of Recursion Theory.
  - "Effective" or "algorithmic" functions and relations. Decidability. Primitive recursive and recursive functions and relations, recursively enumerable functions and relations.

## MATH 3420 Numerical Analysis 2

(Winter term)

**Calendar description:** Numerical methods for eigenvalue problems, nonlinear systems, initial-value problems, boundary-value problems; finite difference methods for ordinary and partial differential equations; error analysis. Not to be held with the former MATH 3600 or MATH 3601. Prerequisites: [MATH 2090 (C) or the former MATH 2300 (B) or MATH 2301 (B) or the former MATH 2352 (C)] and [MATH 2150 (C) or MATH 2720 (B) or MATH 2721 (B) or the former MATH 2750 (C)] and [MATH 2160 (C) or the former MATH 2600 (C) or MATH 2601 (C)]. Pre- or corequisite: MATH 3440 or the former MATH 2800 or MATH 2801.

**Detailed program:**
• Numerical integration for multiple integrals. Gaussian quadratures.
• Numerical methods for eigenvalue problems.
• Numerical solutions for nonlinear systems. Error analysis.
• Numerical solution for initial value problems for ordinary differential equations: single step methods (Euler's method, Runge-Kutta methods), multi-step methods (Adams' methods, predictor-corrector methods). Local truncation error. Consistency, stability and convergence of numerical methods.
• Numerical solution for boundary value problems of ordinary differential equations: shooting methods for linear and nonlinear problems, finite difference methods for linear and nonlinear problems.
• Finite difference methods for PDEs. Error analysis.

## MATH 3440 Ordinary Differential Equations

(Fall term)

**Calendar description:** Theory and applications of ordinary differential equations; existence and uniqueness of solutions, linear systems, simple nonlinear systems. This course is theory-based and is intended for students in mathematically rich disciplines. Not to be held with the former MATH 3800. Prerequisite: MATH 2180 (C) or [(MATH 1300 (B) or MATH 1301 (B)) and (the former MATH 2730 (B) or MATH 2731 (B) or the former MATH 2750 (C))].

**Detailed program:**

- Introduction:
  - What are ODE and what are they used for?
  - Classification of ODE
  - Scalar case: separation of variables and variation of constants
- Basic general theory:
  - Lipschitz functions
  - Banach fixed point theorem
  - Picard's proof of existence and uniqueness
  - Continuation of solutions
  - Continuous dependence on initial conditions, on parameters
- Linear systems:
  - Existence and uniqueness
  - Vector space of solutions
  - Fundamental matrix solution
  - Wronskian
  - Abel's theorem
  - Variation of constants for nonhomogeneous linear systems
  - Homogenous systems with constant coefficients $e^{At}=\Phi(t)\Phi^{-1}(0)$
  - Laplace (light version)

## MATH 3460 Partial Differential Equations

(Winter term)

**Calendar description:** Method of characteristics for first order PDEs, wave, beam, heat and Laplace equations, derivation of PDEs, existence and uniqueness, energy estimates, well-posedness, maximum principles, separation of variables. Not to be held with the former MATH 3810. Prerequisites: [MATH 2150 (C) or the former MATH 2750 (C) or ((MATH 2720 (B) or MATH 2721 (B)) and (the former MATH 2730 (B) or MATH 2731 (B)))] and [MATH 3440 (C) or the former MATH 3800 (C)].

**Notes:** Students are advised to take MATH 3472 at the same time.

**Detailed program:**
• Introduction, elementary solution techniques, Method of characteristics for first order linear PDEs, singularities, classification of linear second order PDEs, reduction to canonical form, initial and boundary conditions, well-posed PDEs, Cauchy-Kovalevski Theorem (3 weeks)
• wave equation: derivation, solutions on infinite and semi-infinite intervals, domain of dependence, non-homogeneous terms in PDE and boundary conditions, existence and uniqueness, energy conservation, resonance (3 weeks)
• heat equation: derivation, maximum principle, existence and uniqueness, asymptotic behaviour (2 weeks)
• Fourier series and Sturm Liouville theory: eigenvalue expansion, convergence, completeness and orthogonality, Bessel and Legendre equations (2 weeks)
• separation of variables for the wave, heat and beam equations on finite intervals, Laplace equation on a rectangle and disk, non-homogeneous terms in PDE and boundary conditions, properties of harmonic functions, maximum principle (3 weeks)

## MATH 3470 Real Analysis 2

(Fall term)

**Calendar description:** Functions of bounded variation, Riemann-Stietjes integration and Lebesgue integration. Not to be held with the former MATH 3740 or the former MATH 3760. Prerequisites: [MATH 2150 (C) or MATH 2720 (B) or MATH 2721 (B) or the former MATH 2750 (C)] and [MATH 2180 (C) or the former MATH 3230 (C)].

**Detailed program:**
• Functions of bounded variation: monotonic functions, definition of total variation and properties, functions of bounded variation expressed as the difference of increasing functions, continuous functions of bounded variation, (curves and paths, arc length, change of parameter?) absolutely continuous functions;
• Riemann and Riemann-Stieltjes integral: definition and elementary properties, integration by parts, change of variable, step functions as integrators, reduction of Riemann- Stieltjes integral to a finite sum, fundamental theorems of integral calculus, uniform convergence and Riemann-Stieltjes integration, Lebesque criterion for the existence of Riemann integral;
• Lebesque integral on the real line: integral of a step function, monotonic sequences of step functions, upper functions, Lebesque integrable functions on general interval, basic properties of Lebesgue integral, Lebesque integration and sets of measure zero, monotone convergence theorems, dominated convergence theorem, convergence of improper Riemann integral, measurable functions, differentiation under the integral, interchanging the order of integration, $L^2(I)$ space, the Riesz-Fisher completeness theorem for $L^2(I)$;
• If time permits: measurable sets on the real line, Lebesgue integral over arbitrary sets on the real line.

## MATH 3472 Real Analysis 3

(Winter term)

**Calendar description:** Fourier series and Fourier transforms; orthogonal systems and $L^2$ theory, convergence and approximation. Multivariable calculus of maps from $R^n$ to $R^m$, general chain rule and general notion of derivative, implicit function and inverse function theorems. Not to be held with the former MATH 3740 or the former MATH 3760. Prerequisite: MATH 3470 (C).

**Detailed program:**
Multivariable differential calculus, directional and total derivatives, Jacobian matrix, chain rule, mean-value theorem for differentiable functions, sufficient conditions for differentiability, equality of mixed partial derivatives, Taylor's formula;Implicit functions: functions with nonzero Jacobian, the inverse function theorem, the implicit function theorem.
Fourier series and Fourier integrals: orthogonal systems of functions, theorem on best approximations, Fourier series of a function relative to an orthonormal system, properties of the Fourier coefficients, Riesz-Fischer theorem for an orthonormal system, the convergence and representation problems for trigonometric series, Riemann-Lebesque lemma, the Dirichlet integrals, Integral representation for partial sums of Fourier series, Riemann's localization theorem, sufficient conditions for convergence of a Fourier series at a particular point, Cesaro summability, Fejer's theorem and consequences, Fourier integral theorem integral transforms;

## MATH 3480 Set Theory

(Odd Fall term, every other year, Fall 2015, Fall 2017, ...)

**Calendar description:** Axiomatic set theory. Cardinality, well-ordered sets, ordinal numbers, cardinal numbers. Axiom of Choice. Ordinal and cardinal arithmetic. Transfinite induction and recursion. Not to be held with the former MATH 3220. Prerequisite: MATH 2020 (C) or the former MATH 2202 (C) or consent of instructor.

**Detailed program:**
• 1. Basic axioms. Set algebra. Ordered pairs, relations, functions, equivalences and partitions, orderings.
• 2. Natural numbers. Axiom of Infinity. Properties of the natural numbers.The recursion theorem. Arithmetic.
• 3. Operations and relations on a set. Mathematical structures.
• 4. Cardinality. Finite, countable and uncountable sets. Linear orderings.
• 5. Cardinal numbers, cardinal arithmetic, the cardinality of the continuum.
• 6. Well ordered sets, ordinal numbers. The Axiom of Replacement. Transfinite induction and recursion. Ordinal arithmetic. Initial ordinals, alephs, arithmetic of alephs.
• 7. The Axiom of Choice and (some of) its equivalents. The use of the Axiom of Choice in mathematics. Foundational questions. The arithmetic of cardinal numbers using AC. Infinite sums and products.
• 8. Regular and singular cardinals. Cardinal exponentiation.
• 9. Well founded relations and sets, the Axiom of Foundation.

## MATH 4240 Advanced Group Theory

(Even Fall term, every other year: Fall 2016, Fall 2018, ...)

**Calendar description:** Representation theory of finite groups, presentations of finite and infinite groups, or other topics. Prerequisite: MATH 3322 (C) or the former MATH 3350 (C) or consent of instructor.

**Detailed program:**
• Part A. Representation theory of finite groups
• Basic Definitions and First Examples
• Maschke's Theorem and Complete Reducibility
• Character Theory and the Orthogonality Relations
• Morphisms of Representations
• The Orthogonality Relations
• Characters and Class Functions
• The Regular Representation
• Representations of Abelian Groups
• Part B. Presentations and infinite group theory
• Construction of groups from generators and relators
• Dehn's fundamental problems
• Free groups
• Tietze transformations
• Presentation of subgroups (Reidemeister-Schreier method) and factor groups
• Free products
• Free products with amalgamation
• Other topics in group theory may be selected.

## MATH 4260 Abstract Measure Theory

(Fall term)

**Calendar description:** Lebesgue and abstract measures, measurable functions, convergence theorems, absolutely continuous functions, measure spaces, the Radon-Nikodym theorem, Fubini's and Tonnelli's theorems. Not to be held with the former MATH 4750. Prerequisite: MATH 3472 (C) or the former MATH 3740 (B+) or the former MATH 3760 (C).

**Detailed program:**
• Lebesgue Measure: definition and properties of Lebesgue outer measure and Lebesque measure, non-measurable sets, Lebesgue measurable functions, Littlewood's three principles Lebesgue Integral: definition and properties, Fatou's Lemma, Monotone convergence theorem, Dominated convergence theorem;Differentiation and Integration: Differentiation of monotone functions, Differentiation of an integral;
• Measure spaces, Measurable functions, integration, Fatou's lemma, monotone convergence theorem, Lebesgue dominated convergence theorem; Signed measures, Hahn decomposition theorem, Radon Nikodym theorem (statement only), Lebesue decomposition theorem;Measure and outer measure, Caratheodory theorem, theorems of Fubini and Tonneli;

## MATH 4270 Algebraic Topology

(Winter term)

**Calendar description:** This course will serve as an introduction to elements of homotopy or homology theory. Not to be held with the former MATH 4230. Prerequisites: [MATH 3322 (C) or the former MATH 3300 (C)] and [MATH 3390 (C) or the former MATH 3240 (C)], or consent of instructor.

**Note:** MATH 3320 (C) will be accepted in place of MATH 3322 (C).

**Detailed program:**
• The topics in *italics* are to be covered if time permits.
• Homotopy. Retracts and deformational retracts.
• The fundamental group. Simply connected spaces. Fundamental group of a circle. *Higher homotopy groups.*
• Group presentations. Free groups. *Tietze transformations.* Free products of groups. Free products with amalgamation.
• Seifert-van Kampen theorem and consequences.
• Covering spaces. Lifting maps. Universal covers. Covering transformations. Fundamental groups and covering spaces.
• Applications: (a) Brouwer Fixed Point Theorem (b) Fundamental Theorem of Algebra (c) Borsuk-Ulam Theorem
• Classification of Manifolds **or** Singular Homology
• Isotopy, Knot Groups, Link Groups **or** Mayer-Vietoris Sequences
• Covering Spaces and Group Theory **or** Examples in Basic Homology

## MATH 4280 Basic Functional Analysis

(Winter term)

**Calendar description:** Banach spaces, Hahn-Banach, open mapping and closed graph theorems, principle of uniform boundedness, linear operators and functionals, dual space, $L_p$ and $L_q$ spaces, weak and weak* topologies, Hilbert spaces and compact operators on a Hilbert space. Not to be held with the former MATH 4750. Prerequisites: [MATH 3472 (C) or the former MATH 3740 (B+) or the former MATH 3760 (C)] and [MATH 3390 (C) or the former MATH 3240 (C)], or consent of instructor.

**Detailed program:**
• Normed Spaces: definition of normed and Banach spaces, completeness, subspaces, quotient spaces;
• Linear operators and functionals: equivalent conditions for continuity of linear operators, bounded linear functionals;
• $L_p$ spaces, Riesz representation theorem;
• Dual space, reflexive Banach spaces, weak and weak-star topology, Alaoglu's theorem;
• Hahn-Banach extension theorem and its consequences, open mapping theorem,closed graph theorem, principle of uniform boundedness;
• Hilbert spaces: elementary properties and examples, orthogonality, Riesz representation theorem, orthonormal sets of vectors and bases, isomorphic Hilbert spaces and Fourier transform for the circle, proof of Radon Nikodym theorem;
• Compact and Hilbert-Schmidt operators on Hilbert spaces (time permitting);

## MATH 4290 Complex Analysis 2

(Fall term)

**Calendar description:** Conformal mappings, normal families, harmonic and subharmonic functions, Perron's family, Dirichlet problem and Green's function. Not to be held with the former MATH 4710. Prerequisites: [MATH 3340 (C) or the former MATH 3700 (B+) or the former MATH 3710 (C)] and [MATH 3390 (C) or the former MATH 3240 (C)].

**Detailed program:**
• Conformal mappings and linear fractional transformations;
• Spaces of analytic functions: normal families, Arzela-Ascoli theorem, Montel's theorem, Riemann mapping theorem, spaces of meromorphic functions;
• Harmonic functions: mean Value Property for harmonic functions, maximum modulus theorems for harmonic functions, harmonic functions on a disk, solution of the Dirichlet problem on a disk, Harnack's inequality and Harnack's Theorem;
• Subharmonic and superharmonic functions: maximum principle, connections to harmonic functions, Perron's family, the Dirichlet problem on general domains, Green's function.

## MATH 4300 Combinatorial Geometry

(Even Winter term, every other year, Winter 2016, Winter 2018, ...)

**Calendar description:** Topics in combinatorial geometry, including arrangements of convex bodies, introduction to polytopes, problems in discrete geometry, repeated distances, and geometric graphs. Prerequisite: MATH 3360 (C) or the former MATH 3400 (C) or consent of instructor.

**Detailed program:**
• Discrete geometries: finite affine, projective, and hyperbolic configurations, combinatorics of finite geometries, duality, the Sylvester-Gallai theorem, double counting incidences.
• Convexity and arrangements of convex bodies:, theorems of Helly, Caratheodory, Radon, polytopes (cyclic, neighbourly), Steinitz's theorem, Minkowski's theorem.
• Hyperplanes, regions determined by lines and hyperplane.
• Other topics including: Euclidean Ramsey theory, Voronoi diagrams, VC-dimension, distinct distances, repeated distances, chromatic number, geometric graphs, geometric discrepancy.

## MATH 4320 Dynamical Systems

(Even Fall term, every other year: Fall 2016, Fall 2018, ...)

**Calendar description:** Techniques for the qualitative analysis of nonlinear systems of ordinary differential equations and discrete-time systems. Not to be held with the former MATH 4800. Prerequisite: MATH 3440 (C) or the former MATH 3800 (C).

**Detailed program:**

- General considerations (3 weeks):
  - Stability in the sense of Lyapunov
  - Reminder on linear systems (continuous- and discrete-time)
  - Phase plane analysis / Cobwebbing
- Linearization (3 weeks):
  - Stable and centre manifold theorems
  - Applications to local asymptotic stability
- Bifurcation analysis (3 weeks):
  - Saddle, pitchfork, blue sky, period doubling and Hopf bifurcations
  - Poincare maps
- Global theory (3 weeks):
  - Lyapunov functions
  - Planar systems (Poincaré-Bendixson and Dulac theorems, maybe a course on Hilbert's 16th problem)

## MATH 4330 Fundamentals of Approximation Theory

(Odd Fall term, every other year: Fall 2015, Fall 2017, ...)

**Calendar description:** Theoretical aspects of approximation theory: density, existence, uniqueness; direct and inverse theorems for polynomial approximation. Prerequisites: [MATH 2080 (C) or the former MATH 2202 (C)] and [MATH 2160 (C) or the former MATH 2600 (C) or MATH 2601 (C)], or consent of instructor.

**Detailed program:**
• Density, existence, uniqueness.
– Kolmogorov theorem. Chebyshev polynomials. Haar (Chebyshev) systems. Theorems of Weierstrass, Korovkin, Stone, Muntz, Mergelyan.
• Polynomial approximation.
– Polynomial partition of unity. Moduli of continuity. Direct theorem for approximation by polynomials. Moduli of smoothness. Whitney inequality. Bernstein polynomials. Trigonometric polynomial kernels: Dirichlet, Fejer, Jackson, Stechkin. Stechkin's theorem (without a proof).Bernstein inequality for trigonometric polynomials. Inverse theorem for approximationby trigonometric approximation. Bernstein inequality for algebraic polynomials.Markov inequality. Influence of endpoints in polynomial approximation.Inverse theorem for approximation by algebraic polynomials. Lipschitz spaces.

## MATH 4340 Introduction to Algebraic Geometry

(Odd Winter term, every other year: Winter 2017, Winter 2019, ...)

**Calendar description:** This course will introduce students to the basics of affine and projective varieties through a combination of basic theoretical tools and elementary examples. Prerequisite: MATH 3322 (C) or the former MATH 3350 (C) or consent of instructor.

**Detailed program:**
• Projective spaces and projective coordinates
• Plane curves: their degree and class. Nodal and cuspidal singularities. Bitangents and inflexional tangents. Plucker formulae. The genus formula.
• Commutative rings and their ideals. Hilbert basis theorem and the Nullstellensatz.
• General Projective Varieties. Irreducibility and Dimension. Tangent spaces and singularities of algebraic varieties.
• Elliptic Curves and the Geometric Group Law. Rational and integral points on elliptic curves.
• Grassmann varieties. Plucker coordinates and Plucker equations.
• Introduction and first examples of moduli spaces.

## MATH 4360 Introduction to Differential Geometry

(Even Winter term, every other year: Winter 2016, Winter 2018, ...)

**Calendar description:** Manifolds and submanifolds; vector and tensor fields, Lie brackets and derivatives. Also at least one of the following: exterior differential calculus and Stokes' theorem, introduction to Riemannian geometry, symplectic geometry and hamiltonian mechanics. Not to be held with the former MATH 4730. Prerequisites: [MATH 3472 (C) or the former MATH 3740 (B) or the former MATH 3760 (C)] and [MATH 3390 (C) or the former MATH 3240 (C)].

**Detailed program:**

- Manifolds: definitions, examples, differentiable maps, submanifolds, curves, tangents, coordinate vector fields, differentials, vector fields.
- Vector analysis: vector fields, transformation laws, flows and Lie derivatives, Lie bracket, Frobenius theorem.
- I would also add one (and only one) of the following topics, which can be left to the preference of students.
  - Exterior differential forms and Cartan's differential calculus. General Stokes theorem.
  - Symplectic geometry and hamiltonian mechanics.
  - Riemannian geometry.

## MATH 4370 Linear Algebra and Matrix Analysis

(Fall term)

**Calendar description:** Vector and matrix norms, matrix factorizations, eigenvalues and eigenvectors, theory of non-negative matrices. Applications to differential equations, math biology, numerical analysis, digital image processing, data mining, GPS, Markov chains, graph theory, etc will be given in this course. Not to be held with the former MATH 4310. Prerequisite: MATH 2090 (C) or the former MATH 2300 (B) or MATH 2301 (B) or the former MATH 2352 (C).

**Detailed program:**
• Vector and matrix norms
• Matrix factorizations (LU, QR, Schur, SVD) and pseudoinverse
• projections, least squares
• eigenvalues and eigenvectors (Gerschgorin theorem, variational characterization of eigenvalues, quadratic forms, normal and symmetric positive definite matrices)
• Jordan form, function of matrices
• Perron-Frobenius theory
• Many applications (differential equations, math biology, numerical analysis, digitial image processing, data mining, GPS, Markov chains, graph theory, etc) will be given in this course.

## MATH 4380 Mathematical Biology

(Odd Winter term, every other year: Winter 2017, Winter 2019, ...)

**Calendar description:** Formulation, analysis and simulation of suitable models in mathematical biology. Applications will be chosen from fields such as population dynamics, epidemiology, ecology, immunology and cellular dynamics. Not to be held with the former MATH 3530. Prerequisite: MATH 4320 (C) or the former MATH 3800 (C) or consent of instructor.

**Detailed program:**
• Ecological models (cooperation, competition)
• Dynamics of infectious diseases
• Structured models (discrete and continuous models)
• Reaction kinetics (enzyme kinetics, Michaelis-Menten, Cooperative reactions, Autocatalysis, Activation and Inhibition) (deterministic and stochastic approaches)
• Reaction diffusion, taxis models (microcospic derivation of diffusion (random walk -> diffusion equation), derivation of conservation laws)

## MATH 4390 Numerical Approximation Theory

(Even Fall term, every other year: Fall 2016, Fall 2018, ...)

**Calendar description:** Computational aspects of approximation by interpolatory polynomials, convolutions, artificial neural networks, splines and wavelets. Prerequisites: [MATH 2150 (C) or MATH 2720 (B) or MATH 2721 (B) or the former MATH 2750 (C)] and [MATH 2160 (C) or the former MATH 2600 (C) or MATH 2601 (C)], or consent of instructor.

**Detailed program:**
• Optimization of the Lagrange operator. Chebyshev nodes.
• Multivariable polynomials. Linear independence, dimension of the space of multivariable polynomials, possibility of interpolation.
• Tensor-product interpolation. Interpolation by translates of a single function.
• Approximation by convolution. Good kernels.
• Artificial neural networks. Greedy algorithm.
• Optimal reconstruction of functions.
• Cardinal B-splines and the sinc function. Box splines.
• Wavelets. Haar function. Two-scale relation. Multiresolution. Cascade algorithm.

## MATH 4440 Numerical Analysis of Partial Differential Equations

(Winter term)

**Calendar description:** Finite difference method, mathematical theory of Elliptic PDEs, finite element method, iterative solution of linear systems, spectral methods. Emphasis will be on the error analysis (stability, consistency and convergence) of the various methods. Prerequisites: [MATH 3420 (C) or the former MATH 3600 (C) or MATH 3601 (C)] and [MATH 3460 (C) or the former MATH 3810 (C)] and [MATH 3470 (C) or the former MATH 3740 (B) or the former MATH 3760 (C)], or consent of instructor. It is recommended that MATH 4370 be taken prior to or at the same time.

**Note:** spectral methods will NOT be covered.

**Detailed program:**

• Finite difference methods (3 weeks)

– Consistency, stability and convergence, second and fourth order schemes for the Laplacian operator, Dirichlet and Neumann problems, polar coordinates and domains with curved boundaries, discretization of the biharmonic operator, upwind schemes for advection-dominated PDEs, tools for stability analysis (summation by parts, discrete Poincare-Friedrichs inequality, discrete maximum principle, discrete Green's function)

• Mathematical theory of PDEs (2 weeks)

– Basic introduction by examples, distributions, Sobolev spaces, Sobolev embedding, traces, Poincare inequalities, Green's identities, weak solutions, Lax Milgram Lemma, elliptic PDE theory

• Finite elements (4 weeks)

– Galerkin formulation, inverse estimates, $H^1$ and $L^2$ error estimates, higher-order elements, numerical integration, mostly for the Poisson equation but also the Stokes problem and linear elasticity

• Numerical linear algebra (2 weeks)

– Condition number, classical and modern iterative methods, analysis of convergence rates, preconditioning

• Spectral methods (2 weeks)

– Truncation and interpolation error estimates for trigonometric, Legendre and Chebyshev polynomials, spectral convergence, Fourier spectral methods, spectral collocation, Dirichlet, Neumann and fourth order problems

## MATH 4450 Number Theory 2

(Winter term)

**Calendar description:** Algebraic number theory, arithmetic geometry and analytic number theory, Diophantine equations, examples such as arithmetic of elliptic curves and Dirichlet *L*-functions. Not to be held with the former MATH 3450. Prerequisites: [MATH 2020 (C) and MATH 2170 (C)] or [(the former MATH 2500 (C) or MATH 2501 (C)) and the former MATH 2202 (C) and the former MATH 2750 (C)], or consent of instructor.

**Detailed program:**
• Arithmetic functions
• Multiplicative functions
• Mobius function $\mu(n)$, Dirichlet convolution, the Riemann zeta-function
• Quadratic reciprocity, Gauss lemma, Jacobi symbol
• Quadratic forms
• Pythagorean triples
• Sums of four squares, sums of powers
• Diophantine approximations, quadratic forms
• Diophantine equations:
  – Pell's equation ($x^2-Dy^2=1$)
  – Mordell's equation ($y^2=x^3+17$)
  – Fermat's equation ($x^4+y^4=1$)
  – Catalan's equation ($x^p-y^q=1$)
• Taxicab numbers.
• Additional Topics (depending upon available faculty expertise and students' interests) may be selected from congruent numbers, elliptic curves, Mordell's theorem, how FLT was finally proved, cryptography and integer factorization, prime number theorem, Dirichlet series and Bruck-Ryser-Chowla theorem.

## MATH 4460 Partial Differential Equations 2

(Odd Fall term, every other year: Fall 2015, Fall 2017, ...)

**Calendar description:** Green's function, Poisson, heat, Schrodinger and wave equations in two and three spatial dimensions, variational characterization of eigenvalues, Fourier and Laplace transforms, introduction to functional analytic techniques in PDEs. Not to be held with the former MATH 4810. Prerequisites: [MATH 3460 (C) or the former MATH 3810] and [MATH 3470 (C) or the former MATH 3740 (B) or the former MATH 3760 (C)], or consent of instructor.

**Detailed program:**
• Green's function, Green's identities, maximum principle, Dirichlet's principle, method of images, method of eigenfunction expansion (2 weeks)
• Poisson, heat, Schrodinger and wave equations in two and three spatial dimensions, non-homogeneous terms in PDE and boundary conditions, Huygen's principle, Hydrogen atom (5 weeks)
• Variational characterization of eigenvalues of the Laplacian, asymptotics of the eigenvalues (1 week)
• Fourier and Laplace transforms, distributions (2 weeks)
• Introduction to Sobolev spaces, existence and uniqueness theory of weak solutions to elliptic PDEs via the Lax-Milgram lemma (3 weeks)

## MATH 4470 Rings and Modules

(Odd Fall term, every other year: Fall 2015, Fall 2017, ...)

**Calendar description:** The general theory of (non-commutative) rings, modules and algebras. Prerequisite: MATH 3322 (C) or the former MATH 3350 or consent of instructor.

**Detailed program:**
• 1. Modules over a ring. Modules as generalizations of vector spaces, of abelian groups, of ideals. Modules as representations of a ring.
• 2. Diagrams and exact sequences. The Hom group. The lattice of submodules, basic lattice-theoretic concepts. Sums and products of modules.
• 3. Free modules and generators. Finitely generated and finitely presented modules. Noetherian and artinian modules and rings.
• 4. Constructions of rings: matrix rings, skew polynomial rings, and related constructions.
• 5. The category of modules. Categories and functors. Duality, natural transformations. Product, coproduct, pushout, pullback. Exact functors. Direct and inverse limits and their construction in the category of modules.
• 6. Tensor product of modules.
• 7. Semisimple modules and rings.
– And topics selected from:
• 8. Projective modules, dual basis theorem. Hereditary rings, hereditary artinian rings.
• 9. Injective modules. Essential extensions, injective envelope. Uniform modules, indecomposable injectives. Injective modules over a noetherian ring.
• 10. Algebras. Artin-Wedderburn theorems. Radical. Tensor product.