Course information

Math 22b focuses on multivariable calculus (functions of several variables, differentiation and integration in several variables, and vector calculus); it covers mostly the same topics as Math 21a but at a greater level of rigor. The course is primarily intended for students interested in the mathematical sciences. It is very strongly recommended to have previously taken Math 22a (or equivalent preparation).

Lectures: MWF 12:00-1:15pm, in Science Center Hall D

Instructor: Prof. Denis Auroux (auroux@math.harvard.edu)
Office hours: Fri 4/26 1:30-3pm, Tue 4/30 & Mon 5/6 12:00-1:30pm in SC 539

Course Assistants and Teaching Fellows (and their office hours):

- Raul Chavez (TF) (rchavez@math.harvard)
  - Saturdays 6:00-7:00pm and Sundays 2:00-3:00pm, Science Center 411
- Jianqiao Xia (TF) (jianqiaoxia@math.harvard)
  - Tuesdays 4:00-6:00pm, Science Center 111
- Khalil Ben-Gacem (kbengacem@college), Joshua Zhang (joshua_zhang@college)
  - Sundays 9:30-10:30am, Mather Dining Hall Private Room
  - (3/5) only 9:30-10:30 Leverett dhall
- Nicholas Lopez (nicholaslopez@college), Jacqueline Liu (jacquelineliu@college)
  - Mondays 9:00-10:00pm, Leverett DHall
- Karen Song (karensong@college), Alice Wu (awu1@college)
  - Saturdays, 10am-12 pm (The Inn (Adams Dhall))
- Kathleen Ho (kho@college), Victor Seco Roopnaraine (victorsecoroopnaraine@college)
  - Sundays 10:00-11:30am, Lowell House Pines Seminar Room (W-109)
  - (4/9 only Mather Dhall 7-8 PM)
- Jay Chooi (jeqin_chooi@college)
  - Fridays 3:45-5:00pm, Science Center 411 (last OH is 4/19)
- Alessandro Drake (adrake@college), Valerio Pepe (valeriopepe@college)
  - Sundays 8:00-10:00 pm, Dunster DHall

Textbook: Marsden and Tromba, *Vector Calculus,* 6th edition. (ISBN 978-1429215084)
Other multivariable calculus textbooks would also be suitable, but this is the book we will use as reference for notations, definitions, and problem sets.

Assessments

There will be **weekly homework assignments** (due every Wednesday by 12noon), **two in-class midterms (Wed Feb 14 and Wed April 3)**, and a 3-hour **final exam** during finals period **(Fri May 10, 2-5pm in SC Hall D).**

Practice midterms: 1A + solutions, 1B + solutions, 2A + solutions, 2B + solutions, Practice final + solutions, Extra practice + solutions

The weekly **problem sets** are a key aspect of this course. They are crucial to learning the material well, so you should attempt then on your own, and budget the time needed to work through them (while also making use of available resources when stuck: working with classmates, attending office hours, etc.). One homework score will be dropped for everyone, so you may miss one assignment without penalty, but you are still responsible for working through the material.

Approximate weighting: 35% homework, 15% first midterm, 20% second midterm, 30% final.

Academic integrity policy:

- You are encouraged to discuss and collaborate with each other on the homework assignments; the use of external resources is acceptable. However, make sure that you are able to work through the problems yourself. Additionally, you must write up your answers *in your own words* and in a manner that reflects your own understanding, and you must credit any sources or resources that were used. This is not only a matter of academic integrity, but also crucial for properly learning the material and skills that this course aims to cover.

For exams, collaboration or consultation of external sources is not allowed.

Testing accommodations: If you need accommodation or assistance for a documented disability, please

get in touch with the Disability Access Office as soon as possible so that they can arrange accommodations for you. If you have a DAO testing accommodation or a conflict with the scheduled time for a midterm, you will fill out an Out-of-Sequence Exam (OSE) request one week before the scheduled exam to arrange an earlier time to take the exam. Athletic practices and rehearsals don't qualify as approved conflicts.

Homework

Homework assignments will be posted here as PDF files. Go to Gradescope to submit your solutions. They will be due by Wednesday at 12 noon, and should be submitted on Gradescope. (Handwritten is completely fine, please upload a readable scan).

Many of these assignments will be on the longer side; it is essential that you budget the time needed to work through them in several installments during the week and not leave them all for a last-minute marathon session.

Late homework policy: You are allowed only **one** late homework (by at most 48 hours) for personal reasons (outside of approved extensions due to health issues, which should be requested ahead of the deadline). Moreover, your lowest homework score will be dropped, so you can skip one assignment without a penalty (but are still responsible for knowing the material and how to solve problems). Avoid doing this too early in the semester, as things will only get busier later on.

Collaboration policy: Besides getting help at office hours, you are encouraged to discuss the homework problems with other students, and you are allowed to consult external sources. However, the homework that you hand in should reflect *your own* understanding of the material and be written in your own words. You are NOT allowed to just copy solutions from other students or other sources (including generative AI). This is not only a matter of academic integrity, but also crucial for properly learning the material and skills that this course aims to cover.

- **Homework 1** (due Wednesday 1/31) and solutions
- **Homework 2** (due Wednesday 2/7) and solutions
- **Homework 3** (due Wednesday 2/14) and solutions
- **Homework 4** (due Wednesday 2/28) and solutions
- **Homework 5** (due Wednesday 3/6) and solutions
- **Homework 6** (due Wednesday 3/20) and solutions
- **Homework 7** (due Wednesday 3/27) and solutions
- **Homework 8** (due Wednesday 4/3) and solutions
- **Homework 9** (due Wednesday 4/10) and solutions
- **Homework 10** (due Wednesday 4/17) and solutions
- **Homework 11** (due Wednesday 4/24) and solutions

Lecture topics

Here is a list of topics and approximate timetable. We may end up deviating slightly from the planned topics or timetable.

Date	Lecture Topic
1. Mon 1/22	Geometry in $\mathbf{R}^n$, vectors, dot product (Â§1.1, 1.2, 1.5) (Notes, Worksheet and solutions, Flashcards)
2. Wed 1/24	Determinant and cross product (Â§1.3) (Notes, Worksheet and sols.)
3. Fri 1/26	Lines and planes; visualizing functions (Â§1.3, 2.1) (Notes, Worksheet and solutions)
4. Mon 1/29	Functions, limits and continuity (Â§2.1, 2.2) (Notes, Worksheet, sols.)
5. Wed 1/31	Partial derivatives, differentiability (Â§2.3) (Notes, Worksheet, sols.)
6. Fri 2/2	Differentials, tangent approximation (Â§2.3) (Notes, Worksheet, sols.)
7. Mon 2/5	Paths and curves, velocity, acceleration (Â§2.4, 4.1) (Notes, Worksheet, solutions)
8. Wed 2/7	The chain rule (Â§2.5) (Notes, Worksheet, solutions)
9. Fri 2/9	Gradients and directional derivatives (Â§2.6) (Notes, Worksheet, sols.)

10. Mon 2/12	Review for midterm 1 (Notes; Practice 1A and solutions, Practice 1B and solutions)
11. Wed 2/14	**MIDTERM 1** (solutions)
12. Fri 2/16	Higher derivatives, Taylor's theorem (Â§3.1,3.2) (Notes, Worksheet, solutions)
13. Wed 2/21	Taylor's theorem and local extrema (Â§3.2,3.3) (Notes, Worksheet, solutions)
14. Fri 2/23	Local and global extrema (Â§3.3) (Notes, Worksheet, solutions)
15. Mon 2/26	Constrained extrema: Lagrange (Â§3.4) (Notes, Worksheet, sols.)
16. Wed 2/28	Implicit function theorem (Â§3.5) (Notes, Worksheet, solutions)
17. Fri 3/1	Double integrals over rectangles (Â§5.1, 5.2) (Notes, Worksheet, sols.)
18. Mon 3/4	Double integrals over general domains (Â§5.3, 5.4) (Notes, Worksheet, solutions)
19. Wed 3/6	Triple integrals (Â§5.5) (Notes, Worksheet, solutions)
20. Fri 3/8	Change of variables (Â§6.1, 6.2) (Notes, Worksheet, solutions)
	â€” (Spring break) â€”
21. Mon 3/18	Polar, cylindrical, spherical coordinates (Â§1.4) (Notes, Worksheet, sol.)
22. Wed 3/20	Integrals in polar, cylindrical, spherical coordinates (Â§6.2) (Notes, Worksheet, solutions)
23. Fri 3/22	Applications of double and triple integrals (Â§6.2, 6.3) (Notes, Worksheet, solutions)
24. Mon 3/25	Vector fields; grad and curl; arc length (Â§4.2-4.4) (Notes, Worksheet, solutions)
25. Wed 3/27	Path and line integrals (Â§7.1, 7.2) (Notes, Worksheet, solutions)
26. Fri 3/29	Fundamental theorem for line integrals; conservative fields (Â§7.2, 8.3) (Notes, Worksheet, solutions)
27. Mon 4/1	Review for midterm 2 (Notes; Practice 2A and solutions; Practice 2B and solutions)
28. Wed 4/3	**MIDTERM 2** (solutions)
29. Fri 4/5	Green's theorem (Â§8.1) (Notes, Worksheet, solutions)
30. Mon 4/8	Curl and div, Green's theorem revisited (Â§4.4, 8.1) (Notes, Worksheet, solutions)
31. Wed 4/10	Surfaces, surface area (Â§7.3, 7.4, 7.5) (Notes, Worksheet, sols.)
32. Fri 4/12	Surface integrals and flux (Â§7.6) (Notes, Worksheet, solutions)
33. Mon 4/15	Divergence theorem (Â§8.4) (Notes, Worksheet, solutions)
34. Wed 4/17	Stokes' theorem (Â§8.2) (Notes, Worksheet, solutions)
35. Fri 4/19	More on Green, Stokes and divergence (Â§8.1-8.5) (Notes)
36. Mon 4/22	Physical applications; final review part 1 (Notes)
37. Wed 4/24	Final review part 2 (Notes; Practice final, solutions; extra practice, solutions)
Fri 5/10	**FINAL EXAM (2-5pm in SC Hall D)**