UNIVERSITY OF CALGARY
FACULTY OF SCIENCE

Department of Physics & Astronomy
Science B 605
403 220-5385
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COURSE OUTLINE

1. **Course:** PHYS 501, Relativity - Winter 2021

   Lecture 01: MWF 14:00 - 14:50 - Online

Instructor	Email	Phone	Office	Hours
Dr. Sean Stotyn	sean.stotyn@ucalgary.ca	403 210-7594	SA 101B	By appointment

This course on a modern approach to Einstein's theory of Special Relativity will begin with Lorentz transformations in classical mechanics and relativistic energy and momentum. These will be applied to relativistic kinematics and relativistic electrodynamics. Throughout the course, a geometrical interpretation will be developed via space-time diagrams and causal structure. Moving beyond the restrictive formulation in terms of inertial frames, four-vectors and tensors will be introduced, leading finally to an introduction to General Relativity and the Schwarzschild black hole.

Online Delivery Details:

Some aspects of this course are being offered in real-time via scheduled meeting times. For those aspects you are required to be online at the same time.

To help ensure Zoom sessions are private, do not share the Zoom link or password with others, or on any social media platforms. Zoom links and passwords are only intended for students registered in the course. Zoom recordings and materials presented in Zoom, including any teaching materials, must not be shared, distributed or published without the instructor's permission.

The Monday worksheet classes indicated in the course schedule will be held synchronously on Zoom. All other lectures will be pre-recorded and uploaded to D2L for the students to access on their own time.

Course Site:

D2L: PHYS 501 L01-(Winter 2021)-Relativity

Note: Students must use their U of C account for all course correspondence.

2. **Requisites:**

See section 3.5.C in the Faculty of Science section of the online Calendar.

Prerequisite(s):
Physics 455; and Mathematics 375 or 376; and Mathematics 367 or 377.

3. **Grading:**

The University policy on grading and related matters is described in F.1 and F.2 of the online University Calendar.

In determining the overall grade in the course the following weights will be used:

Component(s)	Weighting %	Date
Assignments (x6)	28	
Worksheets (x9)	9	
Pre-worksheet Quizzes (x8)	8	
Midterms (x2)	25	Take-home (due February 12 and March 24)
Final Assessment	30	Take-home problem set (released Saturday, April 17 and due at 5:00 PM on Saturday, April 24)

Each piece of work (reports, assignments, quizzes, midterm exam(s) or final examination) submitted by the student will be assigned a grade. The student's grade for each component listed above will be combined with the indicated weights to produce an overall percentage for the course, which will be used to determine the course letter grade.

The conversion between a percentage grade and letter grade is as follows.

	A+	A	A-	B+	B	B-	C+	C	C-	D+	D
Minimum % Required	95 %	90 %	85 %	80%	75%	70 %	65 %	60%	55%	53 %	50 %

There will be two take-home midterms in this course:

1. Midterm 1 will be released on **Wednesday Feb 10,** due on **Friday Feb 12,** and will cover material up to and including Friday Feb 5
2. Midterm 2 will be released on **Monday March 22,** due on **Wednesday March 24,** and will cover material up to and including Monday Mar 15

As your term work items (assignments, worksheets, pre-worksheet quizzes, and exams) accumulate, the marks for students will be posted on D2L. The marks that appear on this website are the marks that will be used to determine each student's overall course grade. Check your marks frequently; missing or incorrectly posted term work marks should be reported to the course instructor as soon as they are noticed. You should be prepared to produce the original work to verify the requested correction.

4. **Missed Components Of Term Work:**

The university has suspended the requirement for students to provide evidence for absences. Please do not attend medical clinics for medical notes or Commissioners for Oaths for statutory declarations.

In the event that a student legitimately fails to submit any online assessment on time (e.g. due to illness etc...), please contact the course coordinator, or the course instructor if this course does not have a coordinator to arrange for a re-adjustment of a submission date. Absences not reported within 48 hours will not be accommodated. If an excused absence is approved, then the percentage weight of the legitimately missed assignment could also be pro-rated among the components of the course.

Missed assignments:

Please contact the course instructor if you have a legitimate reason for missing a deadline for an assignment. Sleeping in, forgetting about the deadline etc. is not considered a legitimate reason.

Missed activities:

If a student misses an activity (e.g., worksheet, D2L quiz, etc.), they should contact the course instructor. If the instructor feels that an accommodation is warranted, then one will be provided.

Missed midterm:

Students who miss a midterm due to ill health or other valid reasons must contact the course instructor as soon as possible, and the instructor will get back to the student with a suitable accommodation.

5. **Scheduled Out-of-Class Activities:**

There are no scheduled out of class activities for this course.

6. **Course Materials:**

Required Textbook(s):

James B. Hartle, *Gravity: An Introduction to Einstein's General Relativity*. Addison Wesley.

In order to successfully engage in their learning experiences at the University of Calgary, students taking online, remote and blended courses are required to have reliable access to the following technology:

- A computer with a supported operating system, as well as the latest security, and malware updates;
- A current and updated web browser;
- Webcam/Camera (built-in or external);
- Microphone and speaker (built-in or external), or headset with microphone;
- Current antivirus and/or firewall software enabled;
- Stable internet connection.

For more information please refer to the UofC ELearning online website.

7. **Examination Policy:**

   All examinations in the course will be open-book, open-resource, take-home exams. Students are free to consult their course notes, textbook, internet sources, etc. However, communication with others during any of the exams is strictly forbidden.

   Students should also read the Calendar, Section G, on Examinations.

8. **Approved Mandatory And Optional Course Supplemental Fees:**

   There are no mandatory or optional course supplemental fees for this course.

9. **Writing Across The Curriculum Statement:**

   For all components of the course, in any written work, the quality of the student's writing (language, spelling, grammar, presentation etc.) can be a factor in the evaluation of the work. See also Section E.2 of the University Calendar.

10. **Human Studies Statement:**

    Students will not participate as subjects or researchers in human studies.

    See also Section E.5 of the University Calendar.

11. **Reappraisal Of Grades:**

    A student wishing a reappraisal, should first attempt to review the graded work with the Course coordinator/instructor or department offering the course. Students with sufficient academic grounds may request a reappraisal. Non-academic grounds are not relevant for grade reappraisals. Students should be aware that the grade being reappraised may be raised, lowered or remain the same. See Section I.3 of the University Calendar.

    a. **Term Work:** The student should present their rationale as effectively and as fully as possible to the Course coordinator/instructor within **ten business days** of either being notified about the mark, or of the item's return to the class. If the student is not satisfied with the outcome, the student shall submit the Reappraisal of Graded Term work form to the department in which the course is offered within 2 business days of receiving the decision from the instructor. The Department will arrange for a reappraisal of the work within the next ten business days. The reappraisal will only be considered if the student provides a detailed rationale that outlines where and for what reason an error is suspected. See sections I.1 and I.2 of the University Calendar

    b. **Final Exam:**The student shall submit the request to Enrolment Services. See Section I.3 of the University Calendar.

12. **Other Important Information For Students:**

    a. **Mental Health** The University of Calgary recognizes the pivotal role that student mental health plays in physical health, social connectedness and academic success, and aspires to create a caring and supportive campus community where individuals can freely talk about mental health and receive supports when needed. We encourage you to explore the mental health resources available throughout the university community, such as counselling, self-help resources, peer support or skills-building available through the SU Wellness Centre (Room 370, MacEwan Student Centre, Mental Health Services Website) and the Campus Mental Health Strategy website (Mental Health).

    b. **SU Wellness Services:** For more information, see www.ucalgary.ca/wellnesscentre or call 403-210-9355.

    c. **Sexual Violence:** The Sexual Violence Support Advocate, Carla Bertsch, can provide confidential support and information regarding sexual violence to all members of the university community. Carla can be reached by email (svsa@ucalgary.ca) or phone at 403-220-2208. The complete University of Calgary policy on sexual violence can be viewed at (https://www.ucalgary.ca/policies/files/policies/sexual-violence-policy.pdf)

    d. **Misconduct:** Academic integrity is the foundation of the development and acquisition of knowledge and is based on values of honesty, trust, responsibility, and respect. We expect members of our community to act with integrity. Research integrity, ethics, and principles of conduct are key to academic integrity. Members of our campus community are required to abide by our institutional Code of Conduct and promote academic integrity in upholding the University of Calgary's reputation of excellence. Some examples of academic misconduct include but are not limited to: posting course material to online platforms or file sharing without the course instructor's consent; submitting or presenting work as if it were the student's own work; submitting or presenting work in one course which has also been submitted in another course without the instructor's permission; borrowing experimental values from others without the instructor's approval;

falsification/fabrication of experimental values in a report. Please read the following to inform yourself more on academic integrity:

Student Handbook on Academic Integrity
Student Academic Misconduct Policy and Procedure
Research Integrity Policy

Additional information is available on the Student Success Centre Academic Integrity page

e. **Academic Accommodation Policy:** Students needing an accommodation because of a disability or medical condition should contact Student Accessibility Services in accordance with the procedure for accommodations for students with disabilities available at procedure-for-accommodations-for-students-with-disabilities.pdf.

Students needing an accommodation in relation to their coursework or to fulfill requirements for a graduate degree, based on a protected ground other than disability, should communicate this need, preferably in writing, to the Associate Head of the Department of Physics & Astronomy, Dr. David Feder by email phas.ahugrd@ucalgary.ca or phone 403-220-8127. Religious accommodation requests relating to class, test or exam scheduling or absences must be submitted no later than **14 days** prior to the date in question. See Section E.4 of the University Calendar.

f. **Freedom of Information and Privacy:** This course is conducted in accordance with the Freedom of Information and Protection of Privacy Act (FOIPP). Students should identify themselves on all written work by placing their name on the front page and their ID number on each subsequent page. For more information, see Legal Services website.

g. **Student Union Information:** VP Academic, Phone: 403-220-3911 Email: suvpaca@ucalgary.ca. SU Faculty Rep., Phone: 403-220-3913 Email: sciencerep@su.ucalgary.ca. Student Ombudsman, Email: ombuds@ucalgary.ca.

h. **Surveys:** At the University of Calgary, feedback through the Universal Student Ratings of Instruction (USRI) survey and the Faculty of Science Teaching Feedback form provides valuable information to help with evaluating instruction, enhancing learning and teaching, and selecting courses. Your responses make a difference - please participate in these surveys.

i. **Copyright of Course Materials:** All course materials (including those posted on the course D2L site, a course website, or used in any teaching activity such as (but not limited to) examinations, quizzes, assignments, laboratory manuals, lecture slides or lecture materials and other course notes) are protected by law. These materials are for the sole use of students registered in this course and must not be redistributed. Sharing these materials with anyone else would be a breach of the terms and conditions governing student access to D2L, as well as a violation of the copyright in these materials, and may be pursued as a case of student academic or non-academic misconduct, in addition to any other remedies available at law.

Assignments:

There will be 6 homework assignments that will be due roughly every two weeks. Each one will be composed of a handful of challenging questions designed to expand the skills we develop in lecture. Files are to be submitted to the appropriate dropbox on D2L as a single PDF file. If you are using your phone to take pictures of your work, then please download a pdf converter app. For example, I use CamScanner for Android and it works well. Apple and Google phones have similar apps that are free to download.

Expectations: It is encouraged that students work together on homework assignments in order to get a richer understanding of the material. However, the work turned in must be the student's and not a duplicate of someone else's. All written work must be neat, organized, and legible; any portions not following this will not be graded.

Worksheets:

These are to be worked on in the synchronous Monday lectures and submitted to the appropriate dropbox on D2L by 5:00 PM that Wednesday. Their purpose is to increase student engagement and have the students better construct the knowledge being learned in a structured manner. This is a type of formative assessment and is therefore crucial to learning the material in greater depth. Grading of the worksheets will be based on completion to encourage you to give them an honest try without fear of penalty.

Expectations: It is essential that students work collaboratively during these synchronous worksheet classes, so breakout zoom rooms will be used. It is expected that when answering the worksheet problems, all steps be

appropriately reasoned through so that somebody else can easily follow the thought process. All written work must be neat, organized, and legible.

Pre-worksheet quizzes:

Students will be expected to come to the worksheet classes prepared and so will be assigned a short video to watch on the content of that week's worksheet, on which there will be a pre-worksheet quiz comprised of a handful of multiple choice questions. These quizzes will be on D2L under Assessments>Quizzes and they will be made available to students on Thursdays at 5:00 PM and they will be due on Mondays at 2:00 PM.

Midterm and Final Assessment Details:

Midterm 1 will be a take-home exam that will be released at 2:00 PM on Wednesday February 10 and is to be submitted by 2:00 PM on Friday February 12.

Midterm 2 will be a take-home exam that will be released at 2:00 PM on Monday March 22 and is to be submitted by 2:00 PM on Wednesday March 24.

The Final Assessment will be a cumulative take-home problem set that will be released at 5:00 PM on Saturday April 17 and is to be submitted by 5:00 PM on Saturday April 24.

In the midterms and final assessment, students are not permitted to communicate with each other about the exam questions and must submit their own work. Students may ask questions directly to the course instructor.

Course Schedule:

The following is a rough outline of the topics covered, the readings that are expected, and important due dates:

Date	Chapter sections	Topics covered	Due Dates
Jan. 11	N/A	Introduction to the course, Incomes Worksheet	
Jan. 13	4.1–4.2	Invariance of EM waves, Lorentz transformations, postulates of relativity	
Jan. 15	4.3	Space-time, space-time diagrams, light cones, causality	
Jan. 18	4.4–4.5	Proper time, Lorentz boosts, simultaneity of events	
Jan. 20	4.5–4.6	Length contraction, relativistic addition of velocities	
Jan. 22	N/A	4-vectors, the metric tensor, scalar products, Lorentz symmetry	
Jan. 25	5.1	Worksheet 1	
Jan. 27	5.2	4-velocity, observer basis vectors, local measurements	Assignment 1
Jan. 29	N/A	Null worldliness, wave 4-vector, observer-dependence + Doppler shift	
Feb. 1	5.5, 5.6	Worksheet 2	
Feb. 3	5.6	4-potential, transformation of electromagnetic fields	
Feb. 5	N/A	Variational principle for time-like and null particles, geodesics	
Feb. 8	3.5, 5.4, 5.5	Worksheet 3	
Feb. 10	N/A	**MIDTERM 1 RELEASED - NO CLASS**	Assignment 2
Feb. 12	5.3	4-acceleration, 4-force, 4-momentum, relativistic energy-momentum	Midterm 1
Feb. 15-19	N/A	**READING BREAK: NO CLASSES SCHEDULED**	
Feb. 22	6.2–6.4	Equivalence principle, gravitational time dilation	
Feb. 24	6.5, 6.6	Gravitational weak field, Newtonian gravity in curved space-time terms	
Feb. 26	N/A	Coordinates, metric, summation convention, light cones, worldlines	
Mar. 1	7.1–7.3, 7.5	Worksheet 4	
Mar. 3	7.6, 7.8, 20.1, 20.2	Space-time volumes, dual vectors, inverse metric	Assignment 3
Mar. 5	N/A	Parallel transport of vectors, covariant derivative, Christoffel symbols	
Mar. 8	20.4, 8.1	Worksheet 5	
Mar. 10	8.2, 8.3	Symmetries, Killing vectors, time-like and null geodesics	
Mar. 12	N/A	Schwarzschild geometry, gravitational red/blue shift, FRW metric	
Mar. 15	9.1, 9.2	Worksheet 6	
Mar. 17	N/A	**MIDTERM 2 RELEASED - NO CLASS**	Assignment 4
Mar. 19	9.3	Time-like orbits, conserved quantities, effective potential	Midterm 2
Mar. 22	9.3	Stable time-like circular orbits, ISCO	
Mar. 24	9.4	Null orbits, photon sphere, impact parameter, null effective potential	

Mar. 26	N/A	Schwarzschild black hole, Eddington-Finkelstein coordinates	
Mar. 29	12.1	Worksheet 7	
Mar. 31	12.3	Kruskal-Szekeres extension, Penrose diagram	Assignment 5
Apr. 2	N/A	**GOOD FRIDAY: UNIVERSITY CLOSED**	
Apr. 5	12.3	**EASTER MONDAY: UNIVERSITY CLOSED**	
Apr. 7	12.2	Worksheet 8	
Apr. 9	N/A	More on the Kruskal-Szekeres extension	
Apr. 12	N/A	Gravitational collapse to a black hole	
Apr. 14	N/A	Review	Assignment 6

Course Learning Incomes

Coming into the course, students should be able to:

1. Construct the laws of Newtonian physics in inertial frames in cartesian, cylindrical, and spherical coordinates.
2. Utilize available symmetry to make a given problem tractable.
3. Perform basic vector calculus (Green’s theorem, Stokes’ theorem, etc.) using unit vector notation.
4. Express electrodynamics in terms of fields that exert forces on charged particles.
5. Use the Euler-Lagrange equations to find equations of motion (this will also be reviewed in the course).

Course Outcomes:

- Describe the Lorentz transformation laws of space-time and apply them to resolve apparent paradoxes.
- Describe how energy and momentum of null and time-like particles transform between inertial frames.
- Use the symmetries of space-time to construct the 4-velocity of a generic time-like observer, and the wave 4-vector of a null particle.
- Interpret and draw conclusions about causal structure from space-time diagrams.
- Identify the key properties of black holes, including event horizons, singularities, and (un)stable orbits.

Electronically Approved - Jan 11 2021 10:31

Department Approval

Electronically Approved - Jan 11 2021 13:57

Associate Dean's Approval