Department of Physics & Astronomy
Science B 605
403 220-5385
phasoffice@phas.ucalgary.ca

UNIVERSITY OF CALGARY
FACULTY OF SCIENCE

COURSE OUTLINE

1. **Course:** PHYS 501, Relativity - Winter 2024

Lecture 01 : MWF 14:00 - 14:50 in TISTUDIODE

Instructor	Email	Phone	Office	Hours
Dr Jared Stang	jared.stang@ucalgary.ca	403 220-8073	SB 527A	Tuesdays 12-1 pm, location TBD

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

All physics and course logistical questions are best asked in person (in office hours and just before/after class). Please contact Jared directly for any personal matters, and allow 5 business days for an email response.

There will be space to work at Jared's office hours---drop by to work on your homework or ask any questions.

To account for any necessary transition to remote learning for the current semester, courses with in-person lectures, labs, or tutorials may be shifted to remote delivery for a certain period of time. In addition, adjustments may be made to the modality and format of assessments and deadlines, as well as to other course components and/or requirements, so that all coursework tasks are in line with the necessary and evolving health precautions for all involved (students and staff).

In Person Delivery Details:

Class time: Class will consist of a combination of mini-lectures and group problem solving activities.

Reading assignments: Weekly (sometimes twice) reading will be assigned; these readings are designed to help you focus on the most important pieces within each section of Hartle, providing a base for class time and homework to build on. Due Mondays and some Fridays at 13:00.

Textbook: Several copies of the textbook will be available for short-term loan in the UCalgary and PASA libraries.

Homework assignments: Homework assignments will provide both practice with and extensions to the course material. Students are encouraged to work together and use whatever resources they like to complete the homework. However, as is scientific practice, all collaboration and resources should be cited and, when possible, resources should be shared with the PHYS 501 community via the course message board. Students should articulate their own understanding of the problems in their own words on submitted assignments. Homework is to be submitted online as a PDF file. The nominal homework deadline is 17:00 (aim for that and have the evening off), but submissions will be accepted until the end of the day without penalty.

Midterms: Two-phase midterms consist of a take-home solo phase and an in-person group phase. These will assess and support students in their understanding. The solo phase will be assigned at the end of one class in the midterm week (due at the start of the next class), and the group phase will take place during the next class.

Final exam: The final exam will consist of a take-home solo phase and an in-person group phase. The in-person phase will be scheduled during the normal exam period.

Problem grading: Unless otherwise noted, each part of each assignment, midterm, and exam problem will be weighted equally and graded on a scale from 0-3 as follows:

Score	Description
0	Completely missing or largely incomplete, incorrect, or incomprehensible
1	The solution is missing two or more key arguments or steps, and demonstrates a weak overall understanding of the problem topics.
2	A mostly correct and well-presented solution, but missing a key argument or step or having a significant gap in communication. Demonstrates good overall understanding of the problem topics.
3	Meets expectations for a well-communicated and correct solution, allowing for minor calculation errors. Includes discussion articulating your reasoning and conclusions.
3*	A completely correct and complete solution, including written discussion articulating your reasoning and conclusions and with care and attention paid to organization, formatting, grammar, and legibility.

Note: A 3 gives full points on any problem; a 3 is used to acknowledge very good solutions and communication.*

Course schedule: This schedule is subject to change as the semester progresses.

Week	Textbook sections	Learning goals	Assessments
1, Jan 8–12	2.1–2.6	◦ Understand how non-Euclidean geometries differ from the Euclidean geometry of the plane. ◦ Use the line element to specify a geometry, including calculating distances and areas. ◦ Apply a coordinate transformation to write the line element of a geometry in different coordinates.	
2, Jan 15–19	4.1–4.4	◦ Identify the invariant intervals of Galilean relativity and special relativity. ◦ Articulate the postulates of special relativity. ◦ Use the Lorentz transformations to find the spacetime location of events in different reference frames. ◦ Draw spacetime diagrams, including worldlines to represent objects or observers, events, and corresponding axes in a boosted frame. ◦ Calculate the spacetime interval between two events and classify the relation between the events as timelike, spacelike, or null. ◦ Define proper time both qualitatively and quantitatively.	
3, Jan 22–26	4.5, 4.6, 5.1	◦ Apply the Lorentz transformations to describe and compute the effects of changing frames, including: ▪ Time dilation ▪ Length contraction ▪ Relativity of simultaneity ▪ Addition of velocities ◦ Define a 4-vector, and write it in terms of it's basis vectors. ◦ Understand and apply the Einstein summation convention in 4-vector expressions. ◦ Transform a 4-vector using the Lorentz transformations. ◦ Use the Minkowski metric tensor to compute the inner product between two 4-vectors.	Homework 1 due Wed, Jan 24.
4, Jan 29–Feb 2	5.2, 5.3, 5.5, 5.6	◦ Define and calculate the 4-velocity for a timelike observer. ◦ Define and calculate the basis 4-vectors for a timelike observer. ◦ Project 4-vectors onto the basis vectors of a timelike observer to compute what the observer would measure. ◦ Understand that proper time cannot be used to parameterize null worldlines. ◦ Define the wave 4-vector. ◦ Derive the relativistic Doppler shift by projecting the wave 4-vector onto the basis vectors for a moving observer.	
5, Feb 5–9	3.5, 5.4, 6.2, 6.3 Chapter 19, Feynman Lectures Vol II	◦ Derive the equations of motion for a system using the action principle (by finding the Euler-Lagrange equations). ◦ Articulate special relativity as the extremization of proper time, and derive and work with the corresponding Euler-Lagrange equations. ◦ Write Newton's 1st law in a four-dimensional form. ◦ Articulate Einstein's *equivalence principle*.	Homework 2 due Wed Feb 7.
6, Feb 12–16	6.4–6.6	◦ Derive time dilation effects from a general line element. ◦ Recognize the weak-field line element for a spherically symmetric gravitational potential. ◦ Compute time dilation effects due to special and general relativity in the weak-field line element. ◦ Conceptualize time dilation effects for gravity as 'time runs slower at lower potential.' ◦ Connect the weak-field line element (the geometric description) to the usual Newtonian gravity framework.	Midterm 1: Solo phase Wed-Fri; group phase on Fri Feb 16.
Term break			
7, Feb 26–Mar 1	7.1–7.3, 7.5, 7.6, 20.1, 20.2	◦ Understand that coordinates are just labels used to describe a geometry. ◦ Construct the Jacobian corresponding to a coordinate transformation, and carry out the transformation for vectors, covectors, and metrics. ◦ Given a geometry, derive and characterize curves defining light cones. ◦ Compute spacetime distances and volumes using the metric.	
8, Mar 4–8	8.1–8.3	◦ Conceptually understand the Christoffel symbols as arising from changes in basis vectors. ◦ Extremize the proper time to find the geodesic equation and read off the Christoffel symbols. ◦ Identify the 'obvious' symmetries in a metric, from being independent of a coordinate, and write the corresponding Killing vectors and conserved quantities. ◦ Derive the gravitational redshift by constructing the wave 4-vector using the timelike Killing vector; use it to compute expected physical redshifts.	Homework 3 due Wed Mar 8.

9, Mar 11–15	9.1–9.4	◦ Identify the 'obvious' symmetries of the Schwarzschild metric and associated Killing vectors. ◦ Use the conserved quantities to find the effective potential for test particles. ◦ Analyze the effective potential of the Schwarzschild geometry to characterize types of timelike orbits. ◦ Fully characterize stable circular timelike orbits in the Schwarzschild geometry at a given radial location and for a specific total mass M. ◦ Calculate the proper time, coordinate time, angular speed, and physical velocity for a stable circular timelike orbit in Schwarzschild. ◦ Derive and identify the characteristics of the innermost stable circular orbit. ◦ Derive and analyze the effective potential for null orbits in Schwarzschild.	
10, Mar 18–22	12.1–12.3	◦ Fully characterize radial plunge orbits in the Schwarzschild geometry. ◦ Rewrite the Schwarzschild geometry in Eddington-Finkelstein coordinates. ◦ Analyze the light-cone structure of a spacetime in Eddington-Finkelstein coordinates and sketch an Eddington-Finkelstein spacetime diagram. ◦ Identify the transformation of the Schwarzschild geometry to Kruskal-Szekeres coordinates. ◦ Draw the Kruskal diagram for the maximally extended Schwarzschild spacetime. ◦ Sketch and interpret worldlines, events, and light signals on the Kruskal diagram. ◦ Compute (T,X) locations of events on the Kruskal diagram by finding intercepts of worldlines, and translate back to Schwarzschild (t,r) coordinates. ◦ Interpret the meaning of the black hole spacetime metric inside the horizon.	Homework 4 due Wed Mar 20.
11, Mar 25–29 (Friday holiday)	16.1, 16.2, 16.4 or 18.1–18.4 or Electrodynamics and Relativity chapter in Griffiths' Introduction to Electrodynamics	Choose your topic: Gravitational waves or cosmological models or relativistic electrodynamics	Midterm 2: Solo phase Mon-Wed; group phase on Wed Mar 27.
12, Apr 1–5 (Monday holiday)	16.1, 16.2, 16.4 or 18.1–18.4 or Electrodynamics and Relativity chapter in Griffiths' Introduction to Electrodynamics	Choose your topic: Gravitational waves or cosmological models or relativistic electrodynamics	
13, Apr 8–9		◦ Describe the relationship between matter-energy and spacetime.	Homework 5 due Mon Apr 8.

Inclusivity in PHYS 501: PHYS 501 is a learning community that is welcoming of diverse backgrounds, experiences, and perspectives. This means that we strive for inclusivity in our classroom, virtual spaces, practices, and interactions. Mutual respect, civility, and the ability to listen to and observe others carefully are crucial; active, thoughtful, and respectful participation in all aspects of the course will make our time together as productive and engaging as possible. Please indicate if you have a preferred name that you'd like to be called. (You can update your preferred name in the "Personal Information" section of My UCalgary. See https://www.ucalgary.ca/registrar/student-centre/updating-personal-information.) You are also encouraged to help others use your correct pronouns by including them on your name tent. Discrimination or harassment of any form will not be tolerated. I welcome any suggestions for improving the learning environment.

If you have a particular need to facilitate your learning in this course, please contact Student Accessibility Services (details in section 12.e) as soon as possible to arrange accommodations.

Course learning incomes: Coming into the course, students should be able to:

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

Course Site:

D2L: PHYS 501 L01-(Winter 2024)-Relativity

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

Equity Diversity & Inclusion:

The University of Calgary is committed to creating an equitable, diverse and inclusive campus, and condemns harm and discrimination of any form. We value all persons regardless of their race, gender, ethnicity, age, LGBTQIA2S+ identity and expression, disability, religion, spirituality, and socioeconomic status. The Faculty of Science strives to extend these values in every aspect of our courses, research, and teachings to better promote academic excellence and foster belonging for all.

The Physics and Astronomy EDI Committee acknowledges there are persistent barriers that prevent such accessibility and hinder our progress towards EDI. Our representatives (faculty, postdocs, graduate and undergraduate students) are committed to addressing any concerns and work towards proactive solutions that enact necessary change within the department. To submit anonymous questions, comments or concerns regarding EDI related issues, please reach out to our Associate Head EDI, Claudia Gomes da Rocha (claudia.gomesdarocha@ucalgary.ca)

2. Requisites:

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

Prerequisite(s):
Physics 455 or Electrical Engineering 475.

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:

Course Component	Weight	Due Date (duration for exams)	Modality for exams	Location for exams
Homework assignments[1]	30%	Ongoing		
Reading assignments[2]	10%	Ongoing		
Midterms[3]	30%	Ongoing		
Registrar Scheduled Final Exam[4]	30%	Will be available when the final exam schedule is released by the Registrar	in person	Will be available when the final exam schedule is released by the Registrar

[1] Five homework assignments, usually due Wednesdays 5pm.
[2] Reading assignments due 1h before class Mondays and many Fridays.
[3] Two midterms, with take-home solo phase (worth 13% each) followed by in-person group phase (worth 2% each).
[4] A take-home solo exam (worth 25%) will be followed by the in-person group phase (worth 5%). The group phase of the exam will be during the registrar-scheduled exam time slot.

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 %

This course will have a Registrar Scheduled Final exam that will be delivered in-person and on campus. The Final Examination

Schedule will be published by the Registrar's Office approximately one month after the start of the term. The final exam for this course will be designed to be completed within 2 hours.

The University of Calgary offers a flexible grade option, Credit Granted (CG) to support student's breadth of learning and student wellness. Faculty units may have additional requirements or restrictions for the use of the CG grade at the faculty, degree or program level. To see the full list of Faculty of Science courses where CG is not eligible, please visit the following website: https://science.ucalgary.ca/current-students/undergraduate/program-advising/flexible-grading-option-cg-grade

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

In the event that a student legitimately fails to submit any online or in-person assessment on time (e.g. due to illness, domestic affliction, 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, or possible exemption and reweighing of components. Absences not reported within 48 hours will not be accommodated. Students may be asked to provide supporting documentation (Section M.1) for an excused absence, See FAQ.

If an excused absence is approved, options for how the missed assessment is dealt with is at the discretion of the coordinator or course instructor. Some options such as an exemption and pro-rating among the components of the course may not be a viable option based on the design of this course.

Missed reading assignments: The lowest two reading assignment scores (including zeros) will be dropped.

Missed homework assignments: At the start of the term, you are allotted four "free pass" days. You may use these days to hand in your homework late with no penalty. You can use all four days on one assignment (e.g., to hand it in four days late) or you may spread them out (e.g., use one day on Assignment 3, two days on Assignment 4, ...).

Missed midterm: Students who miss a midterm due to ill health or other valid reasons must contact the course instructor as soon as possible (within 48h of the start of the take-home midterm), and the instructor will work with the student to determine a suitable accommodation.

The above policies are meant to provide flexibility for the majority of situations where course work might be missed. In general, no further accommodations will be considered.

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*: Cambridge University Press.

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, the course textbook, other books, D2L, or internet sources, but directly web-searching the text of a problem constitutes academic misconduct. Any sources used must be referenced. Communication with others about the exam during the take-home period 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 a s 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 their website 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 here.

d. **Student Ombuds Office:** A safe place for all students of the University of Calgary to discuss student related issues, interpersonal conflict, academic and non-academic concerns, and many other problems.

e. **Student Union Information:** SU contact, Email your SU Science Reps: science1@su.ucalgary.ca, science2@su.ucalgary.ca, science3@su.ucalgary.ca,

f. **Academic Accommodation Policy:**

It is the student’s responsibility to request academic accommodations according to the University policies and procedures listed below. The student accommodation policy can be found at: https://www.ucalgary.ca/legal-services/sites/default/files/teams/1/Policies-Student-Accommodation-Policy.pdf

Students needing an accommodation because of a disability or medical condition should communicate this need to Student Accessibility Services in accordance with the Procedure for Accommodations for Students with Disabilities: https://www.ucalgary.ca/legal-services/sites/default/files/teams/1/Policies-Accommodation-for-Students-with-Disabilities-Procedure.pdf.

Students needing an accommodation in relation to their coursework or to fulfil requirements for a graduate degree, based on a Protected Ground other than Disability, should communicate this need, by filling out the Request for Academic Accommodation Form and sending it to Dr. David Feder by email phas.ahugrd@ucalgary.ca preferably 10 business days before the due date of an assessment or scheduled absence.

g. **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
Faculty of Science Academic Misconduct Process
Research Integrity Policy

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

h. **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.

i. **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.

j. **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.

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 04 2024 11:10

Department Approval