Physics P4931B/P9930B

Course Information *January to April, 2021*

General Course Information

- **Course title:** "Relativity"

Instructor: Prof. W.K. Hocking: more details appear further down.

This is a combined course, including acceptable second third, and fourth year undergraduates, and potentially some graduate students. Graduate students will be graded independently of undergraduates, and may be asked to do extra material.

- **Course Delivery:**

Due to COVID-19, the course is a mixture of on-line lectures and in-class attendance. This is referred to as a "blended" course.

The course will comprise an equivalent load of 36 lecture-hours (well, strictly 36 × 50-minute sets) A significant part of this will be in the form of on-line videos.

Lecture notes will be posted in OWL - these will be a complete set. Please recognize that the copyright for the notes belongs with me (WKH). Lectures will be available BOTH in a pdf format and a video format.

Attendance at face-to-face in-person lectures is optional, but highly recommended.

We will meet in **person at the following time**.

Tuesday 1.30 pm – 3.20 pm, Room WSC-55. All other interactions will be by virtual communication. The purpose of this meeting-slot are multiple, and are described in more detail below. The time spent in this meeting is not planned to cover the whole 110 minutes - as a rule I will use 60-90 minutes, and stay on for further questions and interaction if needed.

On-line lectures will be so-called "asynchronous lectures". This means I will post prepared videos on OWL, typically of length 20-35 minutes, and students will need to **ensure that they set aside time to view these**. The videos will be taken down 10 days after initial posting, so please be sure to remember to retrieve them! I expect an **equivalent** of about 20 hours of lectures will be in such an on-line format (though each on-line lecture will be shorter than an hour, so there may be probably about 30 or so of them). Another 12-16 or so are to be given at the **Tuesday meeting** (exact number of these will depend on student progress). However, the **Tuesday lectures** will also be recorded, for students who may need to miss that time-slot at times.

Students will be expected to follow a viewing schedule which will be posted on OWL. This schedule will specify dates by which each video-lecture must be viewed, so that you will be able to do assignments and tutorials.

Office hours: After discussion with students about timetables, 2 one-hour slots will be allocated per week when I will open a zoom meeting and students can "meet" with me and discuss issues with lectures, or discuss items between each other. Students will be encouraged to send 'topics for discussion" prior to these meetings, so we can use the time most efficiently. Attendance is not mandatory, and students should preferentially attend only one of these times (if at all): the purpose of multiple slots is to allow more flexibility in student options.

Tuesday meeting: more details.

The Tueday meeting will have multiple purposes

(i) Lectures will be given at times.

(ii) Opportunities will exist for students to ask for clarification on preceding notes

(iii) Tutorials may be given as appropriate. These will not be examinable, but covering the material at the tutorial should help you with assignments and exams.

(iv) One of the Tuesday time-slots will be used for the **midterm**.

As a general summary, the course will comprise 20 hours of asynchronous lectures, 12-16 lectures presented on Tuesdays (these will be recorded) and made available, 60-90 minutes of commitment on Tuesdays (recognizing that some of this time is coincident with the in-class lectures), some tutorial sessions on Tuesdays, and 3-4 assignments.

Course Description

The course aims to introduce students to the principles, philosophy and mechanics of both Special and General Relativity. Special Relativity will occupy about the first 24-26 lectures, and General Relativity will be taught in the last 10-12 lectures. Originally the course will concentrate on simple concepts, using basic calculus, but as it proceeds, the concepts of tensors (covariant, contravariant, mixed and pseudo tensors) will be introduced. These concepts will be crucial to applications of General Relativity.

More specifically, the course will start at a very basic level - about first-year standard for a stronger student. The main concepts of time and space dilation, and simultaneity, will be introduced at this time. By about lecture 6-8, we will start to ramp up the level of difficulty and will begin working with Minkowsi diagrams. There will be some repetition of the earlier work, but Minkowski diagrams will allow us to see the issues more clearly, and also allow us to move on to elementary studies of accelerating reference frames and the associated time dilation effects.

The course gets exponentially harder from here on, as we do tensor theory (both covariant and controvariant) and then work up to Riemann Geometry and then push on to the beginnings of General Relativity.

Pre-requisites Co-requisites and Anti-requisites

Unless you have either the requisites for this course or written special permission from your Dean to enroll in it, you may be removed from this course and it will be deleted from your record. This decision may not be appealed. You will receive no adjustment to your fees in the event that you are dropped from a course for failing to have the necessary prerequisites.

Special permission is required from the department to take this course, and if you have been permitted to enroll, you will already have received such approval. The primary requirement will be a good working knowledge of calculus, and an open mind. The course will be structured in such a way that students unfamiliar with aspects of assumed knowledge for the course will receive sufficient direction that they may catch up on missing topics in their own time. However, the onus will be on the students to catch up on missing topics. There are no anti-requisites.

Instructor Information

- **Full name & title:** Professor Wayne K. Hocking, Physics & Astronomy Dept., UWO
email: whockingATuwo.ca

- **Office details:** Contact me at the "office meetings" on zoom (see above). For more personal issues, send me an email and we can arrange a private zoom meeting if appropriate. Please remember, however, that I also have other commitments, so such meetings should be used wisely.

Teaching Assistant

- Mark Baker

Texts, Readings, Materials

The main reference will be

Dirac, P.A.M., "General Theory of Relativity", Wiley & Sons, 1975 (69pp.),
ISBN 0-471-21575-9

*The text book is **not** mandatory. Most of the content of the course can be found on web OWL (or will be emailed to students) website as pdf files. Notes will be updated prior to each lecture when required.*

Additional Reading:

To be indicated in lectures as deemed appropriate.

EVALUATION:

Description of examinations

- One 2-hour midterm in mid-term

In view of COVID-19 uncertainties, the midterm is to be a ZOOM-based open book exam. You will be given time to do the exam, and some additional time (about 20 mins) to scan or photograph your exam and return it to the instructor. Exact date is yet to be set.

- A final 3-hour exam in April.

[Exam times will be posted when available. Students needing to make travel arrangements are advised to book travel dates outside of the examination period. *No makeup exams will be given to accommodate travel.*]

Assignments – approximately 3 to 4 to be given, distributed uniformly throughout the term. Dates to be announced. Assignments should be submitted electronically, either via OWL or directly to my email. Solutions may be either typed or handwritten, but handwritten ones need to be scanned and sent. It is the student's responsibility to ensure that the scanned copies are legible and contain no missing information.

Mark distribution

Marks will be weighted as approximately 1/3 of the course total for each of the problem assignments, the mid-term and the final exam. More specifically, weightings will be as follows.

- Problem assignments: 33%
- Midterm test: 33%
- Final exam: 34%

Make-up exams will be available for both the mid-term and the final exam, but these must be applied for in a formal manner (see the section " Academic Consideration for Student Absence and missed exams and assignments", which appears later in this document).

Please note: The Department of Physics and Astronomy, in rare cases, may adjust the final course marks in order to conform to Departmental policy.

Course Outline.

1. Galilean invariance and non-invariance
2. The Ether
3. The Michelson-Morley experiment
4. Violation of Galilean Invariance for electromagnetic systems
5. Constancy of the speed of light
6. Result of the constancy of the speed of light on temporal simultaneity
7. Simultaneity and time-dilation
8. Proper time
9. Length contraction
10. Proper Length
11. Lorentz transformations
12. An alternative derivation of the Lorentz transformations
13. Addition of velocities under Lorentz transformations
14. Measurement vs. observation
15. Momentum in Special Relativity
16. Energy in Special Relativity
17. Forces in Special Relativity
18. Work-Energy Theorem
19. What happens at the speed of light?
20. Zero-mass particles
21. $E=mc^2$.
22. Doppler shift
23. Aberrations
24. Minkowski Space
25. Minkowski Scaling
26. Time-like and Space-like intervals
27. World lines
28. Minkowski space using complex representation
29. Tensors
30. Tensors, Vectors and Matrices
31. Formal Tensor Theory
32. Mixed Tensors
33. Addition, multiplication of tensors: inner, outer products
34. Differentiation of tensors
35. Metric and Conjugate Metric tensors
36. Raising and lowering indices
37. Pseudo-tensors
38. Sample applications of tensor theory
39. Four vectors - 4-velocity, 4-acceleration, 4-momentum etc.
40. Conservation of 4-vectors
41. Equations of motion as 4-vectors
42. Model of a photon using 4-vectors
43. Relativistic Electrodynamics
44. Maxwell's equations in 4-space

45. Poynting tensor
46. Electromagnetic Stress tensor
47. Covariant electrodynamics
48. Electrodynamic energy-momentum tensor
49. Noether's theorem
50. Gauge invariance
51. Riemann geometry
52. General relativity
53. Einstein's field equations
54. Einstein-Hilbert action
55. Linearized gravity (spin-2)
56. Higher derivative gravity

** Due to Covid-19, we may terminate the course a little earlier if the need arises, but I'd like to get to at least item 53 if we can.

Course Policies

Disabilities Accommodation Policies

Students with disabilities work with Accessible Education (formerly SSD) which provides recommendations for accommodation based on medical documentation or psychological and cognitive testing. The Academic Accommodation for Students with Disabilities policy can be found at:
https://www.uwo.ca/univsec/pdf/academic_policies/appeals/Academic Accommodation_disabilities.pdf

Academic Consideration for Student Absence and missed exams and assignments.

Students will have up to two (2) opportunities during the regular academic year to use an on-line portal to self-report an absence during the semester, provided the following conditions are met: the absence is no more than 48 hours in duration, and the assessment for which consideration is being sought is worth 30% or less of the student's final grade. Students are expected to contact their instructors within 24 hours of the end of the period of the self-reported absence, unless noted on the syllabus. Students are not able to use the self-reporting option in the following circumstances:

- for exams scheduled by the Office of the Registrar (e.g., December and April exams)
- absence of a duration greater than 48 hours,
- assessments worth more than 30% of the student's final grade,
- if a student has already used the self-reporting portal twice during the academic year

If the conditions for a Self-Reported Absence are *not* met, students will need to provide a Student Medical Certificate if the absence is medical, or provide appropriate documentation if there are compassionate grounds for the absence in question. Students are encouraged to contact their Faculty academic counselling office to obtain more information about the relevant documentation.

In **this course**, assignments can be self-reported, but for the **two exams** (both of which are worth > 30%) you will need to provide a *Student Medical Certificate* or *appropriate documentation* (as outlined in the previous paragraph) and appeal as discussed above. Please also see the paragraph below about who you can and cannot contact.

Students should also note that *individual instructors are not permitted to receive documentation* directly from a student, whether in support of an application for consideration on medical grounds, or for other reasons. **All documentation required for absences that are not covered by the Self-Reported Absence Policy must be submitted to the Academic Counselling office of a student's Home Faculty.**

For policy on Academic Consideration for Student Absences - Undergraduate Students in First Entry Programs, see:
https://www.uwo.ca/univsec/pdf/academic_policies/appeals/Academic_Consideration_for_absences.pdf
and for the Student Medical Certificate (SMC), see:
http://www.uwo.ca/univsec/pdf/academic_policies/appeals/medicalform.pdf

Accommodations for Religious Holidays

Students should consult the University's list of recognized religious holidays, and should give reasonable notice in writing, prior to the holiday, to the Instructor and an Academic Counsellor if their course requirements will be affected by a religious observance. Additional information is given in the Western Multicultural Calendar:
https://multiculturalcalendar.com/ecal/index.php?s=c-univwo

You may also be eligible to write the Special Exam if you are in a "Multiple Exam Situation" (see http://www.registrar.uwo.ca/examinations/exam_schedule.html).

If a student fails to write a scheduled Special Examination, the date of the next Special Examination (if granted) normally will be the scheduled date for the final exam the next time this course is offered. The maximum course load for that term will be reduced by the credit of the course(s) for which the final examination has been deferred. See Academic Calendar for details (under Special Examinations).

Scholastic Offenses

Scholastic offences are taken seriously and students are directed to read the appropriate policy, specifically, the definition of what constitutes a Scholastic Offence, at the following Web site:
http://www.uwo.ca/univsec/pdf/academic_policies/appeals/scholastic_discipline_undergrad.pdf.

Below, several special offences are outlined. In case of conflict with the official description in the link given above, the link takes priority.

Cheating
Cheating refers, among other things, to access to exam and assignment solutions by illicit means, including theft from other students, copying from other students, illegal access to instructor notes, inappropriate extraction from the world-wide-web, and illegal coercion of teaching assistants and other staff. The definition of cheating is not restricted to these examples, and may be interpreted more broadly at the instructor's discretion. If two assignments are handed up that are identical, or close to identical, both with be given zero mark. Assignment answers should be distinctively individual.

Plagiarism
Students must write their essays and assignments in their own words. Whenever students take an idea, or a passage from another author, they must acknowledge their debt both by using quotation marks where appropriate and by proper referencing such as footnotes or citations. Plagiarism is a major academic offence (see Scholastic Offence Policy in the Western Academic Calendar - see the link given above under "scholastic offences".

Classroom Conduct
Disruptive behaviour will not be tolerated in class. Please respect the rights of your classmates to benefit from the lecture by limiting your conversations to those essential to the class. Students who persist in loud or rude behaviour will be asked to leave.

General Academic Policies and Covid-related issues.

The website for Registrarial Services is http://www.registrar.uwo.ca.

In accordance with policy, http://www.uwo.ca/its/identity/activatenonstudent.html, the centrally administered e-mail account provided to students will be considered the individual's official university e-mail address. It is the responsibility of the account holder to ensure that e-mail received from the University at his/her official university address is attended to in a timely manner.

Contingency plan for an in-person class pivoting to 100% online learning
In the event of a COVID-19 resurgence during the course that necessitates the course delivery moving away from face-to-face interaction, all remaining course content will be delivered entirely online, either synchronously (i.e., at the times indicated in the timetable) or asynchronously (e.g., posted on OWL for students to view at their convenience). The grading scheme will **not** change. Any remaining assessments will also be conducted online as determined by the course instructor.

All of the remote learning sessions for this course will be recorded. The data captured during these recordings may include your image, voice recordings, chat logs and personal identifiers (name displayed on the screen). The recordings will be used for educational purposes related to this course, including evaluations. The recordings may be disclosed to other individuals participating in the course for their private or group study purposes. Please contact the instructor if you have any concerns related to session recordings.

Participants in this course are not permitted to record the sessions, except where recording is an approved accommodation, or the participant has the prior written permission of the instructor.

Tests and examinations in this course may be conducted using remote proctoring services, such as (but not limited to) Proctortrack or Zoom. In any one exam, one of these software packages will be chosen and all remote students must abide by the decision to

use only this software. It will not be possible to use multiple types of software in any one exam.

By taking this course, you are consenting to the use of this software and acknowledge that you will be required to provide **personal information** (including some biometric data) and the session will be **recorded**. More information about this remote proctoring service is available in the Online Proctoring Guidelines at the following link:
https://www.uwo.ca/univsec/pdf/onlineproctorguidelines.pdf

Completion of this course will require you to have a reliable internet connection and a device that meets the technical requirements for this service. Information about the technical requirements are available at the following links:
proctortrak: https://www.proctortrack.com/tech-requirements/
Zoom: https://support.zoom.us/hc/en-us

If Zoom (or equivalent) is used for examinations, you will be required to keep your camera on for the entire session, hold up your student card for identification purposes, and share your screen with the invigilator if asked to do so at any time during the exam. The exam session will **not** be recorded.*

* Please note that Zoom servers are located outside Canada. If you would prefer to use only your first name or a nickname to login to Zoom, please provide this information to the instructor in advance of the test or examination.

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Complaints and Suggestions

If you have a concern about something, please let us know. We rely on your feedback. Please contact initially the person most directly concerned; this will usually be your instructor. If that is not satisfactory, or if there is something more general bothering you, talk it over with the Physics & Astronomy Department Chair or the Associate Chair of Undergraduate Studies (for contact information see http://www.physics.uwo.ca).

Contacting the Instructor
See prior section titled "**Instructor Information".**

*We will not **read or respond** to emails from addresses that do not end in "@uwo.ca".*

Other advice for successful performance:

You must work out the problem assignments to succeed in this course. Merely attending lecture and reading the textbook will not do it! If you encounter difficulties in doing the problems, ask your TAs or me for help. Copying assignments of others is likely to be to your own detriment. By all means work with others on assignments if you want to, but if you simply copy the answers, and do not understand what you have written, it will undoubtedly disadvantage you when exams come around. Be sure to use your own words when writing assignments. Remember- if two assignments are handed up that are identical, or close to identical, both with be given zero mark. Assignments should be distinctively individual.

Support Services

Please visit the Science & Basic Medical Sciences Academic Counselling webpage for information on add/drop courses, academic considerations for absences, appeals, exam conflicts, and many other academic related matters: https://www.uwo.ca/sci/counselling/

Please contact the course instructor if you require lecture or printed material in an alternate format or if any other arrangements can make this course more accessible to you. You may also wish to contact Student Accessibility Services (SAS) at (519) 661-2147 if you have any questions regarding accommodations.

Western University is committed to a thriving campus as we deliver our courses in the mixed model of both virtual and face-to-face formats. We encourage you to check out the Digital Student Experience website to manage your academics and well-being: https://www.uwo.ca/se/digital/.

Learning-skills counsellors at the Student Development Centre (http://www.sdc.uwo.ca) are ready to help you improve your learning skills. They offer presentations on strategies for improving time management, multiple-choice exam preparation/writing, textbook reading, and more. Individual support is offered throughout the Fall/Winter terms in the drop-in Learning Help Centre, and year-round through individual counselling.

Students who are in emotional/mental distress should refer to Mental Health@Western (http://www.health.uwo.ca/mental_health) for a complete list of options about how to obtain help.

Additional student-run support services are offered by the USC,
http://westernusc.ca/services.