Physics 480: Gravity & Relativity

West Chester University
Spring 2018

Syllabus

Updated: January 19, 2018

Instructor

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Office hours

Day	Time
Tuesday	1:30–3:00 pm
Wednesday	10:30 am–12:30 pm
Thursday	1:30–3:00 pm

Additional office hours by appointment.

Course details

	Day	Time	Location
Class:	Tuesday, Thursday	11:00 am–12:15 pm	Schmucker Sci. N. 192
Homework due:	Friday	5:00 pm	Merion 125 or D2L
Final exam:	Tuesday, May 8	10:30 am–12:30 pm	Schmucker Sci. N. 192

Course description

This semester's *Physics 480: Special Topics* is an introductory course on Special and General Relativity. Special Relativity topics include the Postulates of Relativity, time dilation/length contraction, spacetime, relativistic mechanics, and relativistic phenomena. Discussion of General Relativity will include the equivalence principle, the metric description of curved spacetime, geodesics, spacetime symmetries, the Schwarzschild solution, solar system tests of GR, black holes, and gravitational waves.

Prerequisites

Satisfactory completion of PHY180 is required to enroll in this course. Some course material overlaps with that of *PHY240: Modern Physics* and *PHY300: Classical Mechanics*. Completion of these classes is advantageous but not required.

Time commitment

PHY480 is a 3-credit hour course presented at the intermediate (junior/senior) level. As such, this course requires 3-9 hours of reading, assignments, and studying outside of scheduled class time each week.

Student learning outcomes

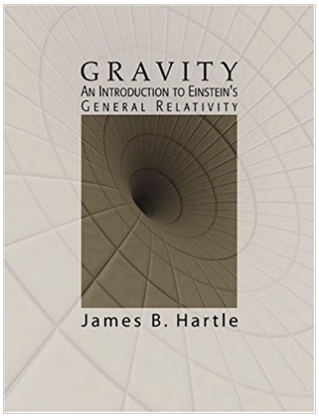
After successfully completing this course students will have mastery of several important concepts and calculational techniques in Relativity. In particular:

- Special Relativity: Students will be able to solve quantitative problems involving Lorentz transformations, relativistic kinematics, and the dynamics of relativistic point particles. Students will also be able to resolve conceptual "paradoxes" based upon the break-down of simultaneity, non-inertial observers, or relativistic conservation of momentum.
- Spacetime: Students will be able to use tools from geometry to describe spacetime, including the spacetime metric, index notation, spacetime vectors and 1-forms, coordinate transformations, and geodesics.
- Spacetime symmetries: Students will be able to describe spacetime symmetries both as symmetries of the metric ("isometries") and as symmetries of action principles. Students will be able to relate conserved quantities to their associated symmetries (Noether's theorem).
- Applications of GR: Student will be able to apply the tools and principles of General Relativity to physical systems including cosmology, the exterior of spherically-symmetric bodies, black holes, and gravitational waves.
- Experimental tests: Students will be able to describe in plain language several experimental tests of Special and General Relativity.

Lecture presentation, in-class discussion, textbook readings, and homework assignments will introduce and develop these learning outcomes. Outcomes will be assessed via exams.

Course materials

1. Textbook: The course textbook is *Gravity: An Introduction to Einstein's General Relativity*, by James B. Hartle. You are expected to have access to this text. New versions of the textbook are for sale at the WCU campus store for $114.75. You will find less expensive options on Amazon (e.g., http://a.co/aFqa2Tn), and elsewhere. You do not need to bring the textbook to class.



2. Calculator: For in-class exams and the final exam you will need a stand-alone calculator with no internet or communication abilities. You will want a calculator that can solve the quadratic formula, compute (hyper)trigonometric functions and powers, and operate in scientific notation. You may not use a mobile phone or computer.

Assessment

This course follows the official WCU scale for grades:

Grade	Quality Points	Percentage	Interpretation
A	4.00	93–100	Excellent
A−	3.67	90–92	
B+	3.33	87–89	Superior
B	3.00	83–86	
B−	2.67	80–82	
C+	2.33	77–79	Average
C	2.00	73–76	
C−	1.67	70–72	
D+	1.33	67–69	Below Average
D	1.00	63–66	
D−	0.67	60–62	
F	0.00	<60	Failure

Refer to the WCU Undergraduate Catalog for description of NG (No Grade), W, Z, and other grades. Elements of the course will contribute to the course grade as follows:

Percent	Category
35%	Homework
40%	Exams ($2 \times 20\%$)
25%	Final exam

35% Homework: Weekly homework assignments are posted on D2L and are due at the time listed on page 1. Paper assignments are submitted to the PHY480 homework box in the Physics Library (Merion 125), while electronic assignments are submitted to the appropriate "dropbox" on D2L.

Homework is assessed for both completeness and accuracy. Homework may be "spot checked", i.e., not all aspects of an assignment may be examined. Homework should be prepared following the Homework guidelines described below.

Solutions to homework problems are posted on D2L after the assignment deadline. No work will be accepted after solutions are posted. See Policies on late or missed work below.

40% Exams: There will be 2 exams administered during the semester, each worth 20% of your course grade. These exams are tentatively scheduled for the dates listed on the Course Schedule. Exams may be in-class or take-home. In-class exams are "closed book": the only aids allowed are a stand-alone calculator and the course equation

sheet. Take-home exams are "open book:" students may use approved references, but may collaborate. Take-home exams will be offered for approximately 24 hours.

Exam scores may be scaled ("curved") to conform to a standard distribution of grades. Failure to take a exam results in a 0 score.

25% Final exam: The comprehensive final exam is scheduled for the time listed on page 1. The final exam is "closed book" in the same manner as in-class exams.

Final exam scores may be scaled ("curved") to conform to a standard distribution of grades. Failure to take the exam results in a 0 score.

Feedback and scores for homework and exams are provided on the documents themselves, which are returned about a week after they are submitted. Scores for homework and exams are posted on the D2L gradebook.

Although unlikely, I reserve the right to alter the assessment scheme in order to accommodate for unforeseen circumstances or to better serve the learning objectives of the course. In particular, the dates of exams may be changed within one week of the exam date (scheduled or actual).

Accommodation

If you require additional accommodation for any aspect of the course you must notify me in advance so that we can make arrangements. Depending on the accommodation, you may need to provide documentation.

- OSSD: If you have an ongoing medical condition which effects your ability to meet the course expectations then you should register with the Office of Services for Students with Disabilities (OSSD). **To receive accommodation you must submit your OSSD letter via D2L** (path: Assessments>Assignments>OSSD letters of accommodation).
- Acute medical conditions: If you have an acute medical condition which causes you to miss at least three consecutive school days then you may seek accommodation from the Office of the Assistant Dean of Students.
- Personal emergencies: Rarely, a personal emergency can arise which prevents a student from meeting course expectations. In such a rare circumstance I am happy to work with the student in order to make appropriate arrangements. I require documentation which verifies the emergency. If desired, the Office of the Assistant Dean of Students can act as a liaison and provide confidential verification of the emergency.

University-Sanctioned Events

If you are unable to perform an aspect of the course due to a University-Sanctioned Event you must notify me in advance so that we can make arrangements. **Official documentation verifying your participation in the event must be submitted via D2L** (path: Assessments>Assignments>Absence letters for University-Sanctioned Events).

Homework guidelines

The work you submit for homework assignments should be a **finished product**, not your initial scratch-work. Your work should follow these guidelines:

- Assignments should be hand-written on clean letter size paper with blue or black pen (colors are okay for drawing figures). If you make a mistake, simply cross it out – no white out or scribbling. Work that is typeset or written in pencil will not be accepted. Paper ripped from a spiral notebook will be burned without inspection.
- Include sufficient prose so that I can follow the logic behind your work.
- Use complete sentences.
- When appropriate, assess the accuracy of your work.
- Show all work. If you use software such as *Matlab* or *Mathematica*, include a printed copy of your notebook or script.
- List any partners you worked with while completing your homework.
- List any references you used, aside from the course materials.

The purpose of these guidelines is to help you with the process of critiquing your own work, including both your logic and your computations. Please do not give undue attention to the presentation of your homework.

Policies on late or missed work

If you suspect that you will not be able to meet a course deadline you should notify me in advance so that we can discuss possible resolutions. The policies on late and missed work are as follows:

- Homework: I collect homework from the homework box once per week, shortly after the homework deadline. Late work must be submitted directly to me as it will go unnoticed in the box. I grade homework one problem at a time, and one problem at a sitting. Thus, late work will not receive credit for problems already graded. No work is accepted after solutions are posted on D2L.

- Exams: Exams are not offered at alternate times, unless an exam conflicts with a University-Sanctioned Event (see University-Sanctioned Events above). Failure to take an in-class exam, or hand in a take-home exam prior to the deadline, results in a 0 score.
- Final exam: The final exam time and date are arranged by the Registrar and are beyond my control. The final exam is not offered at alternate times. Failure to take the final exam results in a 0 score.

Attendance policy

I expect you to attend all class meetings on time and ready to participate and learn. Obviously, if you are sick or unwell then you should not attend class. Federal law requires that I periodically take attendance. Students who miss more than 4 classes by the end of term will be reported as having poor attendance. This is of no consequence, unless you fail the course. Students who fail the course while having poor attendance will receive a "Z" grade. See the WCU Title IV Federal Financial Aid Compliance Policy.

If you miss a class it is your responsibility to make up the missed learning opportunity by reviewing the lecture notes, text, and other course materials. You are welcome to seek assistance in office hours, but I cannot reproduce an entire lecture outside of class. Missing class does not excuse you from completing other aspects of the course on time.

Your attendance is excused for a University-Sanctioned Event, provided you submit official documentation – see University-Sanctioned Events above.

Electronic device policy

The only personal electronic devices that may be used in class are tablet-style computers which use a stylus. Other electronic devices such as mobile phones, ipods, and laptop computers are not conducive to the kind of note-taking necessary for this course. Their use distracts the user and students around them. It's fine if you have these devices with you, but they must remain out of sight. If I see or hear these devices then I will ask you to leave the class.

Course schedule

The attached Course Schedule provides a tentative schedule which includes lecture material, assignments deadlines, and exam dates. This is the first time this course is being offered at WCU, and as such it is likely that this schedule will be updated throughout the semester in order to better meet our needs and accommodate unforeseen circumstances. An up-to-date Course Schedule is available on D2L (path: Content>Course documents).

The final exam time and date are arranged the by the Registrar's Office and can change. You should plan to be available the entire Final Exam Period (May 8-11, 2018).

D2L, email, and all that

- Course platform: All course documents are maintained on the course D2L site. I use the D2L announcement tool to make class-wide announcements. You are responsible for regularly checking the course D2L site. I may not announce in class changes to course content on D2L. As with all technology, D2L can have glitches and service outages. For this reason, check D2L frequently.

- Email: I use email for individual correspondence and for time-sensitive class-wide communications. You are responsible for regularly accessing, reading, and responding to course communications sent to your university email account. Except in the event of a technical failure or an emergency, I will only use university email (mine and yours) to correspond.

- Communication: All electronic communication should be written with appropriate language and etiquette. Please consult the guides here and here.

- Discussing grades: Due to limitations set by federal law (FERPA), I will not discuss grades over email. I am happy to discuss your progress in the course in person during office hours or by appointment.

Additional resources

There are many excellent textbooks on relativity. While our course textbook serves as the primary reference for this class, the following textbooks are also useful:

- *Modern Physics*, by Krane: This is the textbook for PHY240. Chapter 2 of this text will be useful for the first two weeks of term when we discuss the basics of Special Relativity.

- *Exploring Black Holes*, by Taylor & Wheeler: This book describes many of the GR tools we use in class. It also gives an excellent introduction to the Schwarzschild spacetime. Like all of the books by Taylor and Wheeler, it is very "chatty", for better or for worse.

- *A First Course in General Relativity*, by Shutz: This is probably the best book to learn more about General Relativity. Material is presented at a level above our course but below a graduate course.

- *Gravitation*, by Misner, Thorne, & Wheeler: To borrow a phrase, this book "insists upon itself". Nevertheless, if you can withstand the repetition, the awkward notation, and the hand-waviness, this is a great book from which to learn GR.

Academic integrity

Students are expected to follow all WCU rules and guidelines on academic integrity as described in the WCU Undergraduate Catalog. Here are a few relevant issues for this class:

- Homework box: This course uses a homework box located in Merion 125 to submit assignments. Obviously, you are not to open the box or in any way access the work of your peers which has been placed in the box.
- Online platform: D2L is an extension of the classroom and as such all WCU rules regarding student behavior apply on these platforms. Do not violate the copyrights of these sources or misrepresent your identity on D2L.
- Collaboration: Students are encouraged to study together and collaborate on assignments. However, you should go through the process of solving each homework problem yourself. List collaborators on your homework. Submitting solutions which you have not yourself obtained is fraud.
- Online resources: Students are welcome to use online resources to help them complete assignments. List references used (aside from course materials) on your homework. However, "resources" does not include specific solutions to assigned problems, whether found online or elsewhere. **Submitting solutions which you have not yourself obtained is fraud.**

Students who violate WCU rules of academic integrity will receive a failing grade (F) in the course and an Academic Integrity Violation Report. These actions will adversely affect your academic career and could result in expulsion from the University.

Intellectual property

The instructor utilizes copyrighted materials under the Freedom and Innovation Revitalizing the United States Entrepreneurship Act of 2007 (Fair Use Act). Apart from such copyrighted materials, all other intellectual property associated with this course is owned and copyrighted by the instructor, including, but not limited to, lectures, course discussions, course notes, slides, assessment instruments such as exams, and supplementary materials posted or provided to students authored by the instructor. No recording, copying, storage in a retrieval system, or dissemination in any form by any means of the intellectual property of the instructor, in whole or in part, is permitted without prior written permission of the instructor. When such permission is granted, it must specify the utilization of the intellectual property and all such permissions and waivers shall terminate on the last day of the semester in which this course is held.

UNIVERSITY STATEMENTS

Updated: June 2016

The following required statements are common to undergraduate course syllabi. Further information regarding university-wide academic policies may be found in the WCU Undergraduate Catalog as well as your respective major department handbook.

Academic & personal integrity

It is the responsibility of each student to adhere to the university's standards for academic integrity. Violations of academic integrity include any act that violates the rights of another student in academic work, that involves misrepresentation of your own work, or that disrupts the instruction of the course. Other violations include (but are not limited to): cheating on assignments or examinations; plagiarizing, which means copying any part of another's work and/or using ideas of another and presenting them as one's own without giving proper credit to the source; selling, purchasing, or exchanging of term papers; falsifying of information; and using your own work from one class to fulfill the assignment for another class without significant modification. Proof of academic misconduct can result in the automatic failure and removal from this course. For questions regarding Academic Integrity, the No-Grade Policy, Sexual Harassment, or the Student Code of Conduct, students are encouraged to refer to the Physics Department Undergraduate Handbook, the WCU Undergraduate Catalog, the Ram's Eye View, and the University website at www.wcupa.edu.

Students with disabilities

If you have a disability that requires accommodations under the Americans with Disabilities Act (ADA), please present your letter of accommodations and meet with me as soon as possible so that I can support your success in an informed manner. Accommodations cannot be granted retroactively. If you would like to know more about West Chester University's Office of Services for Students with Disabilities (OSSD), please contace the OSSD which is located at 223 Lawrence Center. The OSSD hours of Operation are Monday – Friday, 8:30 a.m. – 4:30 p.m. Their phone number is 610-436-2564, their fax number is 610-436-2600, their email address is ossd@wcupa.edu, and their website is at www.wcupa.edu/ussss/ossd.

Excused absences policy for University-sanctioned events

Students are advised to carefully read and comply with the excused absences policy for university-sanctioned events contained in the WCU Undergraduate Catalog. In particular, please note that the "responsibility for meeting academic requirements rests with the student," that this policy does not excuse students from completing required academic work, and that professors can require a "fair alternative" to attendance on those days that students must be absent from class in order to participate in a University-Sanctioned Event.

Reporting incidents of sexual violence

West Chester University and its faculty are committed to assuring a safe and productive educational environment for all students. In order to meet this commitment and to comply with Title IX of the Education Amendments of 1972 and guidance from the Office for Civil Rights, the University requires faculty members to report incidents of sexual violence shared by students to the University's Title IX Coordinator, Ms. Lynn Klingensmith. The only exceptions to the faculty member's reporting obligation are when incidents of sexual violence are communicated by a student during a classroom discussion, in a writing assignment for a class, or as part of a University-approved research project. Faculty members are obligated to report sexual violence or any other abuse of a student who was, or is, a child (a person under 18 years of age) when the abuse allegedly occurred to the person designated in the University protection of minors policy. Information regarding the reporting of sexual violence and the resources that are available to victims of sexual violence is set forth at the webpage for the Office of Social Equity at http://www.wcupa.edu/_admin/social.equity/.

Emergency preparedness

All students are encouraged to sign up for the University's free WCU ALERT service, which delivers official WCU emergency text messages directly to your cell phone. For more information, visit www.wcupa.edu/wcualert. To report an emergency, call the Department of Public Safety at 610-436-3311.

Electronic mail policy

It is expected that faculty, staff, and students activate and maintain regular access to University provided e-mail accounts. Official university communications, including those from your instructor, will be sent through your university e-mail account. You are responsible for accessing that mail to be sure to obtain official University communications. Failure to access will not exempt individuals from the responsibilities associated with this course.

Course Schedule

Updated: January 19, 2018

Date	Day	Topic	Reading by week
WEEK	**1**		
01/23	T	Course intro; The road to Relativity	Hartle §3.1, 3.2, 4.1, 4.2
01/25	R	Space and time, apart	Krane §2.1-2.4
01/26	F	**Due: Homework 0**	
WEEK	**2**		
01/30	T	Space and time, together	Hartle §4.3-4.4
02/01	R	Spacetime	Krane §2.6
02/02	F	**Due: Homework 1**	
WEEK	**3**		
02/06	T	Lorentz transformations	Hartle §4.5
02/08	R	SR mechanics 1	Krane §2.5
02/09	F	**Due: Homework 2**	Hartle §5.1, 5.2
WEEK	**4**		
02/13	T	SR mechanics 2	Hartle §5.3, 5.5, 5.6
02/15	R	SR mechanics 3	Krane §2.7
02/16	F	**Due: Homework 3**	
WEEK	**5**		
02/20	T	Gravity 1	Hartle §3.3, 3.4
02/22	R	Gravity 2	Hartle §6.1-6.3, 6.5, 6.6
02/23	F	**Due: Homework 4**	
WEEK	**6**		
02/27	T	Metric 1	Hartle §7.1-7.3
03/01	R	**EXAM 1: Special Relativity**	
03/02	F	–	
WEEK	**7**		
03/06	T	Metric 2	Hartle §2.3-2.7
03/08	R	Metric 3	Hartle §7.4-7.6, 7.8
03/09	F	**Due: Homework 5**	
WEEK	**8**		
03/13	T		
03/15	R	**SPRING BREAK!**	
03/16	F		

Date	Day	Topic	Reading by week
WEEK	**9**		
03/20	T	Geodesics 1	Hartle §3.5, 5.4, 8.1
03/22	R	Geodesics 2	Zwiebach §4.5, 5.1-5.3
03/23	F	**Due: Homework 6**	
WEEK	**10**		
03/27	T	Geodesics 3	Hartle §8.2, 9.1
03/29	R	Schwarzschild 1	
03/30	F	**Due: Homework 7**	
WEEK	**11**		
04/03	T	Schwarzschild 2	Hartle §9.2-9.4
04/05	R	**EXAM 2: Tools of GR**	
04/06	F	–	
WEEK	**12**		
04/10	T	Schwarzschild 3	Hartle Ch. 10, §11.1
04/10	R	Schwarzschild 4	
04/13	F	**Due: Homework 8**	
WEEK	**13**		
04/17	T	Black holes 1	Hartle §12.1-12.3
04/19	R	Black holes 2	
04/20	F	**Due: Homework 9**	
WEEK	**14**		
04/24	T	Black holes 3	Hartle §16.1, 16.3
04/26	R	Gravitational waves 1	Carroll §7.4
04/27	F	**Due: Homework 10**	
WEEK	**15**		
05/01	T	Gravitational waves 2	Hartle §16.2, 16.4, 16.5
05/03	R	Gravitational waves 3	
05/04	F	**Due: Homework 11**	
WEEK	**16**		
05/08	T	**FINAL EXAM: 10:30 am–12:30 pm**	
05/10	R		
05/11	F		