PHY 151/201: Space, Time and Motion
Wisconsin Lutheran College
Course Syllabus Spring 2020

Introduction

What does it mean for an object to be in motion? More specifically, what is the cause of motion? How can it be measured, or quantified? Is it possible to think something is in motion when it is truly standing still? And is there a maximum speed of that any object can move?

In this course, we will engage in a careful study of *dynamics*—the science of the causes of motion and rest—paying particular attention to the ideas of space and time. We will focus on reading selections from Galileo's *Dialogues*, Pascal's *Physical Treatises*, Newton's *Principia* and Einstein's *Relativity*. Weekly laboratory sessions complement our classroom discussions.

Course times and locations

- PHY 151: General Physics 1 (Algebra-based) will meet in Generac S032 on Monday, Wednesday and Friday from 10:30 - 11:20
- PHY 201: Physics 1 (Calculus-based) will *also* meet on Thursday in Generac S032 from 11:30 - 12:20.
- Weekly laboratory sections will meet in Generac S115 on Tuesday, Thursday and Friday from 12:30-3:20.

Course instructors

Kerry K. Kuehn, Ph.D.,
Professor, Dept. of Physics,
Lecturer and Tuesday Laboratory section
Office: Generac Hall Room S133

www.kerrykkuehn.com,
kerry.kuehn@wlc.edu,

Joel Davis, Ph.D., Associate Professor,
Dept. of Chemistry
Thursday laboratory

Aaron Schindler, M.Sc.,
Instructor, Dept. of Physics
Friday laboratory section

Grade components

Classroom discussion	10%	Laboratory exercises	15%
Homework exercises	15%	Midterm exam	20%
Laboratory presentation	10%	Final exam	30%

Grading scale

A	100-93%	B	87-80%	C	74-67%	D	61-54%
AB	92-88%	BC	79-75%	CD	66-62%	F	53-0%

Physics course objectives

- *improve scientific reading comprehension:* students will engage in the careful reading, analysis and discussion of the most important scientific texts and ideas
- *articulate scientific ideas:* students will learn to speak and write on scientific topics using correct grammar, rational argumentation, and convincing style
- *solve problems:* students will learn to work out clear, correct, and creative solutions to both written and laboratory exercises
- *analyze and understand nature:* students will learn to grasp and to intuitively understand the workings of nature; this objective implies more than merely memorizing strategies and formulae used to solve technical problems
- *discern truth from error:* physics students will aim not merely to learn scientific ideas, but to evaluate and judge them, and to recognize their philosophical and even theological implications
- *prepare for the future:* physics students will be ready for the next step—whether it is moving on to upper-level coursework at the undergraduate level, enrolling in graduate studies in physics, or applying for a job in industry that requires understanding physics methods and concepts

Required Textbook

Kerry K. Kuehn, A Student's Guide through the Great Physics Texts, Volume II: Space, Time and Motion . Springer (2015). ISBN 978-1-4939-1365-7

Examinations

There will be two examinations in this class: one midterm and one final. To best prepare for the exams, you should

(1) read all of the *assigned reading* selections completely—(at *least* once),

(2) use the *study guide* after each reading—(to be sure you understand key points in the readings),
(3) participate in *classroom discussions*—(use our classroom discussion to figure out what you don't understand in the readings)
(4) work through the *homework exercises*—(*before* resorting to the posted solutions),
(5) *study the solutions* to the exercises—(to be sure you don't make the same mistakes twice),
(6) learn the *vocabulary words*—(to help with reading comprehension and overall literacy),
(7) review the *laboratory exercises*—(some exam questions may be based on what you did in lab), and
(8) regularly *visit me* during office hours to discuss physics—(I am a very nice person)

Reading and discussing the great texts

In this course, we will read and discuss some of the classic scientific texts dealing with the motion of bodies—whether they be rocks falling through fluids or planets hurtling through outer space. The scientific texts we will read are considered classics because they address timeless questions in a particularly honest and convincing manner. This does not mean that everything they say is true—in fact many classic scientific texts contradict one another—but it is by the careful analysis of the most reputable observations and opinions that one may begin to discern truth from error.

You will not understand everything you read. Nobody does. The texts are challenging. Like great literature, these texts must be ``grown into", so to speak. So think of this course as a ``first dip" into the deep end of the pool. They are classic texts because—like fine wine—both the beginner and the advanced scholar can profit by studying them.

The time that we spend in the classroom will be devoted to discussion of the reading selections. As the discussion leader, I will typically ask questions regarding specific ideas which are found in the texts. For instance, I may ask, "What does the author mean by the term *weight*," or "Is it true that all matter has weight?" And if so, "How do you know?" The task will then be to try, as a group, to answer these questions.

It is critical that participants carefully read the assigned selections before engaging in discussion. This will help participants to make relevant comments and to cite textual evidence to support or contradict assertions made during the course of the discussion. In this way, many assertions will be revealed as problematic, in which case they must then be refined or rejected altogether. This is precisely the method used by scientists themselves in order to discover and evaluate competing ideas or theories.

Classroom discussion: étiquette and grading

During our discussion, you may speak with complete freedom. There is only one rule: *any comment or question you make must be made publicly so that all others can hear and respond*.

Each student will receive a discussion grade for the class which will range from 0% to 100%. To clarify how I approach classroom discussion grading, consider the following examples.

- **100%—** The student is actively engaged in the classroom discussion. His or her ability to raise interesting and relevant points from the text is evidence that they have studied the assigned text and put significant thought into analysis outside of class.
- **80%—** The student is somewhat engaged in the classroom discussion. He or she makes comments or raises questions during the discussion, but they have some trouble providing specific textual or rational support for their assertions.
- **60%—** The student is very occasionally engaged in the classroom discussion. They sit silently but politely. They may have read the assigned text, but have not thought enough about it to formulate any coherent thoughts. They uncritically accept whatever is said by the author, the instructor and the other students in the class.
- **0%—** The student comes to class, but instead of presenting his or her views to the class publicly, they whisper them to their friends. The instructor and other students find this distracting and a bit rude.

From an instructor's perspective, discussion is admittedly the most difficult grade to assign, as it is unavoidably somewhat subjective. Nonetheless, learning to verbally articulating scientific ideas in a public setting is an important skill and one of the secondary learning objectives of this course.

Most students are initially apprehensive about engaging in public discussion. This is natural. If you find yourself to be one of these it is important to realize that you do not need to make an elaborate point in order to engage in classroom discussion. Often, a short question can provide a simple avenue. For example, ``I am unclear what the author means by the term *centripetal*. Can someone please clarify?" Write down questions like these in the margins while reading the text. Start like this. Pretty soon, you may find yourself joining gamely in classroom discussion.

Homework exercises

Almost every day of lecture, one or two homework exercises will be given. For example, on Friday of the first week of class (see calendar, below) there are two assigned homework exercises: Scaling of a Sphere (Ex. 1.1) and Kleiber's law (Ex. 1.2). These problems should be worked out prior to the next class period. *Each exercise should be written out legibly on a separate sheet of paper with the exercise number and your name neatly printed at the top*. Three or four times during the course of the semester—on randomly selected days—I will collect one of the assigned homework exercises at the beginning of class, grade it, and return it to you. Homework exercises will be graded according to the following rubric:

- **100%—**answer is correct (or mostly correct), the method of arriving at the solution is clearly and thoughtfully explained
- **80%—**answer is not correct, but the method of arriving at the solution is clearly and thoughtfully explained
- **60%—**answer is not correct, little explanation is provided or the explanation is illegible
- **0%—**homework was not submitted, or a solution was submitted with no rationale or explanation.

You must complete the homework exercises prior to arriving at class: *late homework will not be accepted.*

Laboratory exercises, notebook and grading (to be discussed in lab)

Many reputable opinions regarding how nature works are wrong. In many cases, this is because these opinions do not conform to the way nature actually behaves. How can one determine how nature actually behaves? During our weekly laboratory session, we will cary out experimental investigations which attempt to reveal how nature works under controlled conditions. You will be provided with equipment and some general questions or suggestions related to the assigned reading for the week. It will be your responsibility to devise experimental techniques and procedures so as to clarify your understanding of nature.

You must keep a record of your work during the laboratory sessions. *To this end, you will need to purchase a lab notebook which must be brought to lab on your first laboratory session.* Your lab notebook must be sturdy, must be at least 8.5 x 11 inches and must be quad-ruled (graph paper). You must allow the first few pages in your lab book to serve as a table of contents. The purpose of the lab book is to serve as a single source which contains all of the information relevant to your experiments. In particular, during each laboratory session, you should record the following information in your laboratory notebook:

- Your name and your laboratory partner's name, the date and a title for the experiment.
- A neat sketch of any experimental apparatus you use, along with labels (make and model).
- A clear description of your experimental procedure(s), including difficulties which you experienced in carrying out your experiments.
- Tables containing any data which you collect. You must never write data anywhere else: not on scrap paper, not on the back of your hand, nowhere. Also, you must write down an estimated uncertainty in any measurement which you perform. For instance, if you use a stop watch to time a falling ball, you should estimate the precision with which you were able to record the time. This is always slightly larger than the resolution of the device being used.

Your lab report must be written in blue or black ink. It must be written in chronological order. That is, you might first describe some of your procedure, then record some data, then describe some more of your procedure, then some more data , and finally do some analysis. The important thing is that you write clearly and that you spread out your writing so that the reader of your notebook can easily ascertain what you did, and reproduce it if necessary. If it contains computer printouts of data tables or plots, these must be trimmed to fit neatly on a page and secured with tape. Do not fold or stack your plots. All plots must occupy at least half of a laboratory book page (*i.e.* don't make tiny plots).

Before leaving the lab, your instructor will assign you a grade based on the neatness, clarity and completeness of your laboratory notebook. Each student will receive a weekly laboratory grade which will range from 0% to 100%. What follows are a few example students and the grade each received for one particular week.

- **100%—**The students conceived of an appropriate experimental program and have systematically executed it. When they ran into difficulties, they were able to arrive at a reasonable solution or work-around. Their data is of good quality, and their analysis involves a reasonable assessment of sources of systematic error.
- **80%—** The students conceived of an appropriate experimental program and have systematically executed it. Although they were able to complete his experiments, either their data was inconclusive, or their analysis involved a significant systematic error which for which they were unable to account.
- **60%—** The students conceived of an appropriate experimental program, but were unable to complete significant portions of the laboratory assignment.
- **0%** —The students completed little or none of the laboratory assignment.

Laboratory presentations

After collecting your data and performing some preliminary analysis, you will be prepared to share your experiments and your results with your classmates. Therefore, each week during the lab session, we will spend the first fifteen minutes discussing the previous week's laboratory exercise. Each individual will be assigned a week during the semester on which to do a formal presentation. The formal presentations must include:

- acknowledgement of the collaborators on your experiment
- description of the problem you were trying to solve, and how this relates to the week's lecture,
- a description of how you attempted to solve the problem, including a detailed description of your experimental apparatus and procedure,
- plots or tables of your data, along with a description of how you analyzed your data, and
- a summary of the significance of your laboratory work. It is not good enough to simply state your results without any analysis of their meaning. If your results are different than you had expected, then you must address this issue directly. This should include an analysis of any systematic errors. Be sure to distinguish between systematic and random errors.

The presentation should last no more than ten minutes, and will be followed by a short question and answer session. Be sure to bring visual aides that will allow others to get a clear look at you experimental setup and any data or plots you have prepared. The grade you receive will depend upon both the quality of your data and the extent to which you address the points mentioned in the previous section.

If you are not assigned to do a formal presentation, you should still look at your lab notebook to compare your method and results to those of the other groups. Our laboratory discussion sections will be aimed at understanding the meaning and significance of the experiments performed during lab sessions, and at discussing ways in which the experiments might have been performed so as to achieve the most meaningful results.

Final thoughts

I want to encourage you to come to me with any concerns you may have during the course of the semester, whether they be physics questions or difficulties with reading or discussion. This course is designed to challenge you, but not to "break" you. Reading the classics in any field is challenging, but very rewarding. I would very much like to help you succeed and to enjoy this class! My contact information is listed at the beginning of this syllabus, so please feel free to contact me!

Course calendar

See the next pages for a detailed schedule of the assigned readings, key concepts, laboratory exercises, homework assignments, and exams for the semester. Students enrolled in PHY 151 will attend lectures on Monday, Wednesday and Friday. Students enrolled in PHY 201 will, in addition, attend lecture on Thursday.

Week 1 (Jan 20-24). No classes on Monday.		
	Key ideas	ratios of quantities; dimensional analysis; scaling;
	Lab	Water coherence (Ex. 2.4)
	Mon	

PHY 151/201: Space, Time and Motion
Wisconsin Lutheran College
Course Syllabus Spring 2020

	Wed	Welcome! Go over syllabus. Introduction to Galileo and his 1638 *Dialogues*.
		Assignment: Read *Scaling in Art and Nature* (ASG Ch. 1).
	Thurs	3Blue1Brown video on Why a sphere's surface area is four times its shadow from Dec. 2, 2018.
	Fri	Discuss ASG Ch. 1.
		Assignment: Scaling of a sphere (Ex. 1.1), Kleiber's law (Ex. 1.2); read The Coherence of Substances (ASG Ch. 2).
Week 2 (Jan 27-31)		
	Key ideas	Aristotle's wheel; atomism; density; buoyancy; Archimedes' principle;
	Lab	Archimedes' Principle (Ex. 3.4) and Falling Bodies (Ex. 3.5)
	Mon	Discuss ASG Ch. 2.
		Assignment: Water breaking (Ex. 2.1), Wire breaking (Ex. 2.2). Read Archimedes' Principle and Falling Bodies (ASG Ch. 3).
	Wed	Discuss ASG Ch. 3
		Assignment: Floating iceberg (Ex. 3.1), Sinking ball of wax (Ex. 3.3)
	Thursday	Rolling wheel kinematics. Polygon Paradox (Ex. 2.3)
	Fri	Discuss ASG Ch. 3
		Assignment: Falling gold balls (Ex. 3.2). Read Falling bodies and pendular motion (ASG. Ch. 4).
Week 3 (Feb. 3-7)		
	Key ideas	drag; pendular motion; frequency; tension; resonance; musical chords; dissonance;
	Lab	Harmony (Ex. 5.6)
	Mon	Discuss ASG. Ch. 4.
		Assignment: Ivory balls (Ex. 4.1), Comparing pendulums (Ex. 4.2), Lunar pendulum (Ex. 4.3). Read Pendular Motion and Harmony (ASG Ch. 5).
	Wed	Discuss ASG. Ch. 5.
		Assignment: Dissonance (Ex. 5.1), Suspended weight (Ex. 5.2), Violin strings (Ex. 5.3)
	Thurs	Systems of units. Natural frequency and dimensional analysis (Ex. 5.4)
	Fri	Discuss ASG Ch. 5. Introduce ASG Ch. 6.
		Assignment: Harmony essay (Ex. 5.6). Read The Law of the Lever (ASG. Ch. 6).
Week 4 (Feb. 10 -14)		
	Key ideas	equilibrium; fulcrum; law of the lever; torque/moment; center of gravity;
	Lab	Beam Breaking (Ex. 6.8), Stick breaking (Ex. 7.3)
	Mon	Discuss ASG. Ch. 6; focus on Galileo's proof of the law of the lever on pg. 73-74.
		Assignment: Seesaw equilibrium (Ex. 6.1), Achilles tendon (Ex. 6.2).
	Wed	Discuss ASG. Ch. 6.; focus on Prop. 1-6.

		Assignment: Aligning a support rafter (Ex. 6.4), Transverse fracture (Ex. 6.5). Read Beams, Bones and Giants (ASG. Ch. 7).
	Thurs	Lecture on static equilibrium; force and torque diagrams
	Fri	Discuss ASG. Ch. 7. Work through Limestone Pillar (Ex. 7.1),
		Assignment: Forestry (Ex. 6.6), Stick breaking (Ex. 7.2).
Week 5 (Feb. 17-21)		
	Key ideas	uniform motion; uniformly accelerated motion; kinematics;
	Lab	Rolling balls (Ex. 9.5)
	Mon	Discuss ASG. Ch. 7.
		Assignment: Read Naturally accelerated motion (ASG. Ch. 8)
	Wed	Discuss ASG. Ch. 8.
		Assignment: Truth and error (Ex. 8.1); Motion sketching (Ex. 8.2)
	Thurs	Equation of motion for falling bodies (Ex. 8.3)
	Fri	Discuss ASG. Ch. 8.
		Assignment: Read The Mean Speed Theorem (ASG. Ch. 9)
Week 6 (Feb. 24-28)		
	Key ideas	Zeno's paradox, and other arguments against Galileo's theory of uniform acceleration;
	Lab	Ramp laboratory (Ex. 10.2)
	Mon	Discuss ASG Ch. 9.
		Assignment: Falling cannonball (Ex. 9.1), Ball toss (Ex. 9.2)
	Wed	Discuss ASG Ch. 9. Work through Castaway kinematics (Ex. 9.3)
		Assignment: Read Equilibrium, Force and Acceleration (ASG. Ch. 10)
	Thurs	Descartes' theory of falling bodies (Ex. 9.4). Geometry proof (Ex. 11.1).
	Fri	Discuss ASG Ch. 10; work through Inclined Plane (Ex. 10.1)
		Assignment: read From Conic Sections to Projectile Motion (ASG Ch. 11).
Week 7 (Mar. 2-6)		
	Key ideas	equilibrium; the epitaph of Stevinus; force & acceleration; projectile motion;
	Lab	Artillery laboratory (Ex. 11.4)
	Mon	Discuss ASG Ch. 11
		Assignment: Archery (Ex. 11.2). Skim (don't read) The Speed and Force of a Projectile (ASG Ch. 12).
	Wed	Discuss ASG Ch. 12. Work thru Castaway physics (Ex. 12.1).
		Study for Exam 1, which covers up through Chapter 10.

	Thurs	Lecture on laminar and turbulent drag; Reynolds number (Ex. 11.3)
	Fri	**Exam 1**
		Assignment: during spring break, read Reason, Authority and Science (ASG Ch. 13) and write down short answers to Study Questions 13.1, 13.2, and 13.4
Week 8 (Mar. 9-13) Spring Break. No classes.		
Week 9 (Mar. 16-20)		
	Key ideas	fluid equilibrium; hydrostatic paradox; Pascal's principle;
	Lab	U-tube (Ex. 14.4), Torricellis' law (Ex. 14.5). PHY 201 students must do challenge calculation.
	Mon	Discuss ASG Ch. 13. Introduce hydrostatic paradox from Ch. 14.
		Assignment: Read Pascal's Principle (ASG Ch. 14)
	Wed	Discuss ASG Ch. 14; focus on three explanations of Pascal's principle.
		Assignment: Fluid weight (Ex. 14.1). Read Submerged bodies (ASG Ch. 15).
	Thurs	Fluid equilibrium and center of gravity (Ex. 14.2)
	Fri	Discuss ASG Ch. 15. Work through Hydrostatic Pressure and Buoyancy (Ex. 15.1),
		Assignment: Floating ice cube (Ex. 15.2).
Week 10 (Mar. 23-27)		
	Key ideas	hydrostatic pressure; weight of air; siphons; arguments for and against the vacuum;
	Lab	Bell jar laboratory (Ex. 16.6); Canoe conundrum (Ex. 15.3)
	Mon	Discuss ASG Ch. 15.
		Assignment: Read Syringes, Siphons and Suckling Infants (ASG Ch. 16)
	Wed	Discuss ASG Ch. 16. Work through Valved Siphon (Ex. 16.4).
		Assignment: Suction Cup (Ex. 16.1). Read Life Under a Sea of Air (ASG Ch. 17) and Does Nature Abhor a Vacuum (ASG Ch. 18)
	Thurs	Rising bubble (Ex. 16.2); Newton's beads (Ex. 16.5)
	Fri	Discuss ASG Ch. 17 & 18
		Assignment: Read Mass, Momentum and Force (ASG Ch. 19)
Week 11 (Mar. 30 - Apr. 3)		
	Key ideas	inertia; mass; force; Newton's 3 laws of motion; Newton's bucket; absolute and relative motion
	Lab	Force and rotation (Ex. 20.3)
	Mon	Discuss ASG Ch. 19
		Assignment: Centripetal force (Ex. 19.2). Read Absolute and Relative Motion (ASG Ch. 20)
	Wed	Discuss ASG Ch. 20. Focus on Newtons' spinning bucket.
		Assignment: Relative linear motion (Ex. 20.1). Read Newton's Laws of Motion (ASG Ch. 21)

	Thurs	Absolute rotational motion (Ex. 20.2)
	Fri	Discuss ASG Ch. 21
		Assignment: Momentum and force (Ex. 21.1). Action-reaction pairs (Ex. 21.3). Read Conservation of Momentum (ASG Ch. 22)
Week 12 (Apr. 6 - 10) Easter break; no classes Thursday or Friday		
	Key ideas	conservation of momentum; center of gravity motion; free body diagrams;
	Lab	Force and rotation (Ex. 20.3) if you haven't finished it yet.
	Mon	Discuss ASG Ch. 22
		Assignment: Force Addition and Newton's Second Law (EX. 22.1). Ball stuck in a Wedge (Ex. 22.2).
	Wed	Discuss ASG Ch. 22
		Assignment: Colliding Blocks (Ex. 22.4). Conservation of Momentum Proof (Ex. 22.6). Read The Third Law and the Power of Machines (ASG Ch. 23)
	Thurs	No class
	Fri	No class
Week 13 (Apr. 13 - 17) Easter break; no classes on Monday		
	Key ideas	conservation of energy; elastic and inelastic collisions; centripetal force and acceleration
	Lab	Collision (Ex 22.7)
	Mon	No class
	Wed	Discuss ASG Ch. 23. Colliding Steel Pendulums (Ex. 23.3). Kinetic Energy (Ex. 23.5)
		Assignment: Free Body Diagrams and Projectiles (Ex. 23.1). Free Body Diagrams and Pendulums (Ex. 23.2). Read Centripetal forces and acceleration (ASG Ch. 24)
	Thurs	3Blue1Brown video on Conservation of Energy and Momentum and the Computation of Pi: Part 1 and Part 2. from Jan 13 and Jan 20, 2019.
	Fri	Discuss ASG Ch. 24
		Assignment: Inferring force laws (Ex. 24.1). Whirling Beads (Ex. 24.2). Read Newton's Rules of Reasoning (ASG Ch. 25)
Week 14 (Apr. 20 - 24)		
	Key ideas	induction and deduction; principle of parsimony; Kepler's laws of planetary motion; gravitation
	Lab	Centripetal force (Ex. 24.4)
	Mon	Discuss ASG Ch. 25
		Assignment: Read Planetary Motion (ASG Ch. 26)
	Wed	Discuss ASG Ch. 26

		Assignment: Phases of Venus (Ex. 26.2). Read Universal Gravitation (ASG Ch. 27)
	Thurs	Escape velocity (Ex. 27.5)
	Fri	Discuss ASG Ch. 27
		Assignment: Acceleration and the Force of Gravity (Ex. 27.1). Read Hypothesis and Natural Theology (ASG Ch. 28)
Week 15 (Apr. 27 - May 1)		
	Key ideas	scientific method; natural theology; principle of relativity; inertial coordinates; speed of light
	Lab	Relativity laboratory (Ex. 29.2)
	Mon	Discuss ASG Ch. 28
		Assignment: Read The Principle of Relativity (ASG Ch. 29)
	Wed	Discuss ASG Ch. 29
		Assignment: Inertial coordinates (Ex. 29.1); Read The Absolute Speed of Light (ASG Ch. 30)
	Thurs	
	Fri	Discuss ASG Ch. 30. Relativistic time dilation (Ex. 30.2);
		Assignment: Simultaneity (Ex. 30.1);
Week 16 (May 4 - 8)		
	Key ideas	relativistic time dilation; length contraction;
	Lab	Speed of light laboratory (Ex. 31.7)
	Mon	Discuss ASG Ch. 30; Relativistic length contraction (Ex.30.3)
		Assignment: More Astronauts (Ex. 30.4);
	Wed	Relativistic Velocity Addition (Ex. 31.2). Galactic travel (Ex. 31.6)
	Thurs	Nuclear Fusion Reaction (Ex. 32.1). Relativistic Energy (Ex. 32.2)
	Fri	Review. Q&A
Week 17 (May11 - 15). Final exams.		