PHYS331: Optics
Fall 2020: August 24–December 18
MWF 11:00 AM–11:50 AM, ~~W9 and~~ Zoom-ed
Zoom meeting: https://hawaii.zoom.us/j/99941087322
ID: 999 4108 7322 *Passcode:* 331678427 ("331optics")

Version 4: October 26, 2020 (subject to change)

Professor:	Dr. Kathy Cooksey; STB 220; kcooksey@hawaii.edu; 808-932-7195
Office Hours:	M 9–10 AM, MW 2–3 PM, F 10–11 AM, and by appt.; in-person or Zoom *Zoom meeting:* https://hawaii.zoom.us/j/93811629543 *ID:* 938 1162 9543 *Passcode:* 2665739 ("Cooksey")
Website:	Laulima PHYS-331-001 (HIL.14261.FA20)
Textbook:	*Introduction to Optics, 3rd. Ed.* by Pedrotti, Pedrotti, & Pedrotti (on reserve at Mookini Library)

Course Description: Intermediate optics. Topics include plane waves, multiple interfaces, polarization, light propagation in real material, Fourier optics, coherence theory, paraxial rays, diffraction and blackbody radiation.
Pre-requisites: PHYS272 and MATH243

Learning Objectives:

- Broad course goals:
  1. Understand when optics are well described as geometric (AKA paraxial, Gaussian) versus when accounting for the wave nature of light is necessary (AKA physical optics).
  2. Develop intuition for the behavior of a compound optic—composed of diverging and/or converging lenses and/or mirrors—and be able to predict whether there is a final image and if it is real or imaginary, inverted or upright, and magnified or not.
  3. Optics has a wide range of sub-fields (see the table of contents of *Introduction to Optics* by Pedrotti[3]). This course should lay a foundation from which the students may pursue many of the not-covered sub-fields.
  4. Practice and improve problem-solving skills, especially in how how an approach is motivated, how a solution is formatted, and how the answer is verified to be reasonable.
- Specific content goals:
  1. Ray tracing and computation of a geometric-optic system are two independent methods for determining what the system does. Thus they must be consistent and can be used to check the results of the other.
  2. Superposition is a common and important aspect of waves. It is the foundation for optical systems using diffraction and interference (e.g., Fourier optics, diffraction gratings).
  3. Application of computational/numerical techniques to understanding of optics and solving of problems.

Email, Textbook, and Website:

- UHH considers email and Laulima an official form of communication; students are responsible for receiving and returning information in a timely manner.
- The professor will email students at their `hawaii.edu` accounts only.

- Students must have: reliable internet access;[1] a Zoom account and the necessary A/V equipment[2] to participate remotely; and a scanner or equivalent capability[3] to produce a PDF from hand-written work.
- The required textbook is *Introduction to Optics, 3rd. Ed.* by Pedrotti, Pedrotti, & Pedrotti, also on reserve at the library. A more recent version may be used; the student is responsible for correlating the assigned reading to the updated textbook.
- The Laulima[4] course website is listed under PHYS-331-001 (HIL.14261.FA20). This site will be the hub for all course information.

Class Rules:

- Students are responsible for their own learning, which includes preparing for class, submitting work, asking questions, and seeking additional help. The professor can only teach; only the student can learn.
  - College is the last time someone will ask you to do something hard and help you do it. The majority of college students use instructors' office hours.
  - Office hours are good times to get individualized help from the expert (i.e., the instructor), and office hours are part of the instructor's job.
- Students must respect and support their peers' learning, which means helping each other with difficult concepts but not just giving the answer.
- Students need to convey (either in person, by email, through an intermediary, or somehow) to the professor questions, comments, and concerns about the course.
- The professor will be receptive to and respectful of the students' needs and interests and must generally follow the class rules as detailed for the students (also see next section).
- Group work is encouraged in class and for homework assignments. However, all submitted work must be the original work of the student with reference to any homework partners.
- All references (e.g., websites, books other than the official course textbook, etc.) used to complete assignments must be cited, including numbers, techniques, facts, etc.
- Solutions to problems must show sufficient supporting work to receive full points. A complete solution includes: proper problem setup (e.g., state assumptions, define knowns and unknowns as variables, draw and label a figure); sufficient work to follow substitutions and reductions (typically symbolically first, then numeric substitution); and assessment of solution (units but also order of magnitude). See the Problem-Solving Strategy section below.
- The professor will take attendance each class even though attendance is not part of the grade (see Grading below). Any student who misses a week of class without communicating with the professor will be made inactive on Laulima, meaning s/he cannot access course materials until meeting with the professor.
- A non-smart-phone calculator is required for every class. Students should practice with the calculator they will use for tests and the final exam.
- It is recommended to use a ruler and graph paper.

[1] UH Hilo has increased Wi-Fi capacity to include all parking lots; see https://hilo.hawaii.edu/help/wifi/.

[2] Laptops are available for checkout at the UH Hilo library; see https://hilo.hawaii.edu/library/laptops.

[3] A smartphone and an app like CamScanner (https://www.camscanner.com/) can be used to produce legible PDFs.

[4] If you need Laulima help, click the Request Assistance link at any page on Laulima: http://www.hawaii.edu/simp/laulima-feedback.php. Or go to UH System Help Desk: https://www.hawaii.edu/its/help-desk/.

- *COVID-19 Online Instruction*—whole semester
  - Lectures will be live via Zoom. Students must have reliable internet access,[1] a Zoom account, and the necessary A/V equipment[2] to participate remotely (i.e., webcam, mic, and speakers or headphones).
  - Lectures will not be recorded. Students are encouraged to learn how to take quick screen shots (the online equivalent of taking a picture of the whiteboard).
  - If a student misses lecture, s/he should, in the following order: review the posted material; get the notes from a peer; and ask the professor any follow-up questions. (In addition to contacting the professor, see Grading section below.)
  - The professor wants to see the students so webcams must be on and students visible the majority of the time.
  - Students will be participating during lecture. To facilitate explanations, students should have spare paper and a dark pen or a whiteboard and marker on hand, so they can hold up equations or sketches to their webcam.

Good-to-Know about the Professor:

- She enjoys teaching and wants to be better at it, and she really cares about helping students be better. These aspects combined mean she is on the students' side; trust in that and knowledge that she is receptive to feedback will smooth over rough patches.
- She chooses teaching techniques based on physics-education research to support student learning as best as possible. This means she has one or more reasons for nearly every component of and action in a course. She'll gladly motivate these choices whenever necessary or asked.
  - The COVID-19 pandemic has led to the professor teaching online. She still endeavors to use best practices, even given the new constraints.
- Her primary goal is to help students improve *how* they learn with the logic that if students learn how to learn, they can master any content. The related goal is to focus on transferrable skills so that time and effort spent for the class yield benefits beyond the course and semester.
- Generally, she does not answer questions directly. A student making connections and constructing a solution her- or himself will ingrain the answer more effectively, and the professor facilitates the process by asking leading questions. Since the motivation is to help the students, they should embrace and engage with this process. (It is also a transferrable skill to discuss ideas and answer questions on the fly.)
- She designs quizzes, tests, and exams so that no one gets 100% and no one gets 0% because either score would not be useful in assessing what the students understand and how to help. The percentage reflects what the student knows of what s/he could have learned; the letter grade reflects what the student learned and how much s/he has improved.
  The rule-of-thumb is to score above the median (see Grading below). She has no interest in failing students who make good-faith effort in the class (e.g., good attendance, submit completed work, ask questions in and out of class).
- She thinks no single resource is comprehensive, so the expectation is that the student will have to work with the professor, her materials, the textbook, and the wealth of material available on the internet.
- The expectation is that a course requires 2–3 hr outside-of-class time per credit per week. Hence a 15-cr semester equals 30–45 hr per week (i.e., a full-time job).
- She generally responds to email 24-to-48 hours after receipt. If the matter is urgent, the student should call (office voicemail is automatically emailed) or stop by her office (her general weekly schedule is on her homepage: http://www2.hawaii.edu/~kcooksey).

General Course Outline (subject to change):

Students are expected to read the textbook chapter, section(s), and/or figures before class. The "lectures" will rely on students having given a good faith effort to understanding the material. It is assumed that the students will read the brief introduction to each chapter, no matter the number of sections actually assigned. If figures without corresponding section are assigned, students should read any necessary surrounding text to understand the figure.

Homework (in *italics*) are due at class time, as scheduled below. One problem will be graded in detail for half the points; the rest will be checked for completeness (e.g., attempt, assessment) for the other half. Problem sets are to be uploaded to Laulima:Drop Box as one or a few clear, organized, and clearly labeled PDF(s); a scanner or equivalent is necessary. Feedback will be given on the PDF(s); this includes about the quality of submission, which must be addressed before the next homework upload. The professor reserves the right to *not* grade unclear, disorganized, poorly labeled, or non-PDF solutions. There is a 24-hr late deadline, at a 25% penalty; the professor will grade mixed on-time+late submissions to maximize the student's points. Complete solutions will be posted after the late deadline.

> Note: grading of problem sets like homework is a compromise. The professor would normally have in-class quizzes on homework (one problem given verbatim, only Equation Sheet allowed). However, given the likely difficulties with a hybrid course and uncertainty induced by the pandemic, real-time professor-student interaction is precious, thus lecture will predominately be reserved for teaching—and, ideally, learning.

There are three two-part tests, during non-homework weeks; there will be have an "in-class"/ online conceptual portion for 30% (no calculator or Equation Sheet) and a take-home quantitative portion for 70%. The take-home portion will be posted on Laulima and due the same day, to be completed and submitted at the student's leisure. All content from a cutoff and earlier are fair game, including problems; the cutoff is determined by what assignments have been submitted and have solutions posted (hence the assignment(s) named in the square brackets by the scheduled teest below). This pattern is designed so that students have a chance to: (i) learn the material via lecture and assignments; (ii) practice the content via assignments; and (iii) receive feedback via graded work and/or posted solutions. Thus, there is a lag between material being the focus of lecture and when the material will be on a test. The cumulative final exam will have a format similar to the tests.

Date	Topic	Activity
M 24 Aug	L1. PHYS331 Overview	Pre-quiz (for credit only; completed on Laulima, by end of day)
W 26 Aug	L2. Nature of Light (Ch. 1, Fig. 3-19)	
F 28 Aug	L3. Geometric Optics I (§2-2–§2-3)	
M 31 Aug	L4. Geometric Optics II (§2-4–§2-5, Fig. 3-18, 10-3)	
W 2 Sep	L5. Geometric Optics III (§2-6–§2-7)	
F 4 Sep	L6. Geometric Optics IV (Fig. 3-34a)	
M 7 Sep	*Labor Day (no class)*	
W 9 Sep	L7. Geometric Optics V (§2-8)	
F 11 Sep	L8. Geometric Optics VI (§2-9)	
M 14 Sep	L9. Geometric Optics VII (Fig. 3-20, 3-22, 3-24)	
W 16 Sep	L10. Geometric Optics VIII (3-31–3-32, 3-34, 3-36)	*HW#1: Geometric Optics I (due 30 Sep)*
F 18 Sep		"Hands-on" optics: ray-boxes
M 21 Sep	L11. Geometric Optics IX (Fig. 3-25–3-28)	
W 23 Sep	L12. Geometric Optics X (§2-10–§2-12)	
F 25 Sep	L13. Geometric Optics XI (§3-1)	
M 28 Sep	L14. Geometric Optics XII (§3-2, §20-3–§20-7)	
W 30 Sep	L15. Geometric Optics XIII (§19-1, Fig. 19-2, §19-3–§19-5)	HW#1 due; *HW#2: Geometric Optics II (due 14 Oct)*
F 2 Oct	L16. Geometric Optics XIV (§3-5–§3-6)	
M 5 Oct	L17. Geometric Optics XV (§3-7)	"Hands-on" optics: refractor
W 7 Oct		Test #1: Geometric Optics I [HW#1]
F 9 Oct	L18. Matrix Method I (§18-1)	*Mid-term Course Eval. (Laulima Survey; closes F Oct 16)*
M 12 Oct	L19. Matrix Method II (https://www.mathsisfun.com/algebra/matrix-multiplying.html, §18-2–§18-4)	
W 14 Oct	L20. Matrix Method III (§18-5–§18-6)	HW#2 due; *HW#3: Geometric Optics III (due 28 Oct)*
F 16 Oct	L21. Matrix Method IV (§18-7–§18-8)	
M 19 Oct	L22. Matrix Method V	
W 21 Oct	L23. Matrix Method VI (§18-9–§18-10)	
F 23 Oct	L24. Matrix Method VII	
M 26 Oct		"Hands-on" optics: numerical method
W 28 Oct	L25. Physical Optics I (§4-1–§4-8)	HW#3 due; *HW#4: Matrix Method (due W Nov 11 though holiday)*
F 30 Oct	L26. Physical Optics II (§5-1–§5-2, §7-1–§7-2)	
M 2 Nov	L27. Physical Optics III (§5-3–§5-4)	
W 4 Nov		Test #2: Geometric Optics II [HW#2–3]
F 6 Nov	L28. Physical Optics IV (§9-1)	
M 9 Nov	L29. Physical Optics V (§9-2–§9-3, §9-5)	
W 11 Nov	*Veteran's Day (no class)*	HW#4 due; *HW#5: Physical Optics (due 25 Nov)*
F 13 Nov	L30. Physical Optics VI	
M 16 Nov	L31. Physical Optics VII (§21-1)	
W 18 Nov	L32. Physical Optics VIII	
F 20 Nov	L33. Physical Optics IX (§11-1–§11-2)	
M 23 Nov	L34. Physical Optics X (§11-3–§11.4)	
W 25 Nov	L35. Physical Optics XI (§11-5–§11-6)	HW#5 due; *HW#6: Review (due 9 Dec)*
F 27 Nov	*Thanksgiving break (no class)*	
M 30 Nov	L36. Physical Optics XII (§12-1–§12-2)	"Hands-on" optics: diffraction gratings
W 2 Dec	L37. Physical Optics XIII (§12-4)	
F 4 Dec		Test #3: Matrix Method & Physical Optics [HW#4–5]
M 7 Dec	L38. Course Synthesis	"Hands-on" optics: Review (STB205)
W 9 Dec		HW#6 due; Post-quiz (for credit only; completed on Laulima, by end of day)
W 16 Dec	Final Exam	9:40 AM–11:40 AM (trust but verify)

Grading:

- The grade depends on the following categories: completing pre/post-quizzes (5%); homework (35%); tests (40%); and final exam (20%).
  - Homework and the quantitative portions of the tests and final exam are to be uploaded to Laulima:Drop Box (or where instructed) as one or a few clear, organized, and clearly labeled PDF(s); a scanner or equivalent is necessary. The professor reserves the right to *not* grade unclear, disorganized, poorly labeled, or non-PDF solutions.
  - The lowest homework grade will be dropped. There is a hard 24-hr late deadline, at a 25% penalty.
  - If a student notices an inconsistency in the professor's grading, s/he should ask; it might be a mistake or it might be a subtle point. Students are encouraged to ask questions about grading.
- Attendance is recorded but not part of the grade.
  - If a student must miss a class for a reasonable reason, s/he should email the professor before the start of class time.
  - If a student were unable to email in advance due to extreme circumstances, s/he should contact the professor as soon as possible. Such instances will be judged on a case-by-case basis.
    - In such (and similar) situations, the student is strongly encouraged to contact Student Services (info below). Student Services are liaisons between students and instructors, when Life adversely impacts Academics. If Student Services advocates on a student's behalf, the professor will work to accommodate any missed content and points.
  - If a student must miss a test or the final exam for a reasonable reason, please discuss the options with the professor as soon as possible.
    - Homework is never excused because the deadlines are known in advance and there is a late deadline.
    - If a student were excused from a test or exam, the graded work will not be included in her/his final grade.
    - If a student were excused from all points in a given category, the percentage of the other categories will be increased to fill the void.
- Cheating is not tolerated. Any question of cheating will be tested with an oral exam, to see whether the student(s) involved understand the material. Cheating will result in a zero for the item in question and a report to the University. It may result in immediate failure of the course.
- The final letter grade will be given based on the class statistics (e.g., the 25^{th}, 50^{th}/median, 75^{th} percentiles). The goal is to score higher than the median on all graded work. The expectation is that final grades higher than the median will pass with at least a C and that the 25^{th} to 50^{th} percentiles will likely earn something in the C range.
  - The professor will give projected final letter grades after each test so the students know where they stand.

Problem-Solving Strategy (AKA "The Format"): This is the recommended approach (and, possibly, format) for solutions to quantitative problems. It is not necessarily applicable to conceptual problems (though may be useful).

Student's Name
Collaborator(s):

PHYS331 Homework#*X*

1. Problem title or very brief description

   Physics Category
   - Identify the broad category under which the problem falls because this reduces the set of concepts and equations that will be useful.
   - The broadest categories reflect the course modules (e.g., "Fermat's Principle" or"ray tracing") but being more specific can be useful (e.g., "Fermat's Principle (time derivative)", "ray tracing (diverging optic)").

   Definitions
   - Define the variables to represent the known/given quantities (with units) and the unknown/target quantities.
   - Use informative symbols for the variables; subscripts are useful.
   - Often a diagram is a useful way to define the known and unknown variables.

   Algebraic Derivation
   - Write the basic equations on which the solution is based, in terms of the defined variables. There should be as many equations as unknowns.
   - Algebraically manipulate the equations to reduce and simplify.

   Numeric Substitution
   - If the problem requires a numeric answer, substitute into the reduced equation (while tracking units explicitly) and compute the result.

   Assessment
   - Check the units come out correctly (even if it's a non-numeric answer).
   - If it's a numeric answer, check the order-of-magnitude, else justify the derived equation scales reasonably with each variable.
   - Clearly justify that the final answer is reasonable. Units and order-of-magnitude/scaling are two "sanity checks" but also demonstrate understanding of expectation based on physics.
     - If result is not expected, discuss whether this is the point (e.g., learning, new intuition) or if it seems incorrect.
     - If the latter, then attempt to explain what is wrong (and earn back points).

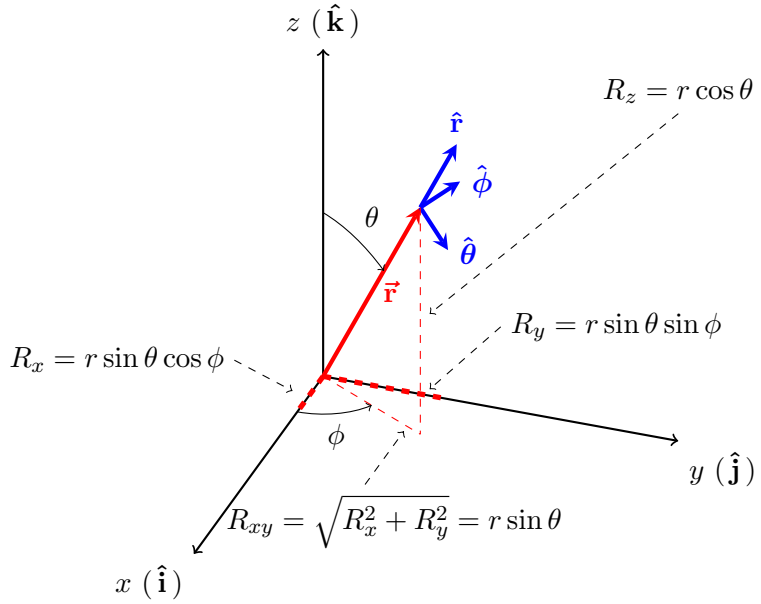
2. Problem title or very brief description

   Physics Category
   Definitions
   Algebraic Derivation
   Numeric Substitution
   Assessment

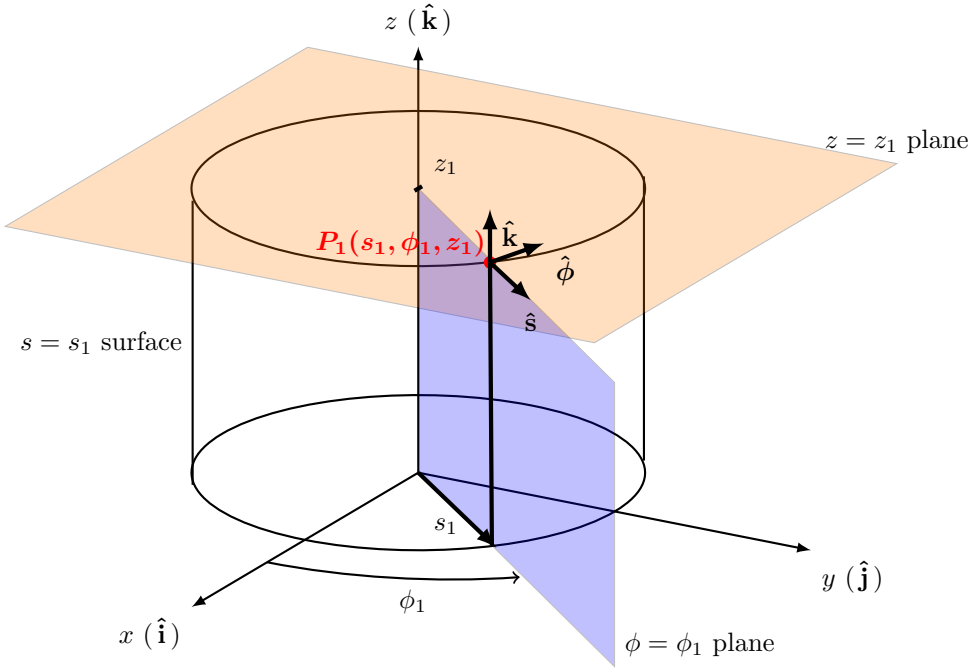
3. *...wash, rinse, repeat*

Content Not on Equation Sheet: Below are a combination of fundamental concepts in physics that must be learned (which is more than memorized) and relationships that can be derived from fundamental concepts and given equations. This is not a comprehensive list.

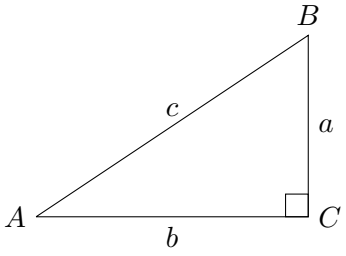
- Coordinate systems and conventions but if: (i) axes are orthogonal (i.e., at right angles) and (ii) a clear figure is used, the results should be self-consistent (so largely correct).
  - Spherical coordinates (r, θ, ϕ) on Cartesian coordinate (x, y, z) system:



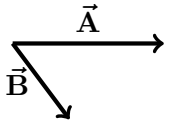
  - Cylindrical coordinates (s, ϕ, z) on Cartesian coordinate (x, y, z) system (in 2D, known as polar coordinates (s, ϕ) with respect to (x, y)):



- Units
  - Ångström: $1\,\text{Å} = 10^{-10}\,\text{m}$
  - Joule: $1\,\text{J} = 1\,\text{kg}\,\text{m}^2\,\text{s}^{-2}$
  - Power (luminosity): $1\,\text{W}$ (watt) $= 1\,\text{J}\,\text{s}^{-1}$
  - Ampere: $1\,\text{A} = 1\,\text{C}\,\text{s}^{-1}$
  - Volt: $1\,\text{V} = 1\,\text{kg}\,\text{m}^2\,\text{A}^{-1}\,\text{s}^{-3}$
  - Angular measurements:
    - Degree: $1^\circ = \dfrac{1}{360}$ of a circle $= \dfrac{2\pi}{360}\,\text{rad}$ (radian)
    - Arcminute ($'$): $1' = \dfrac{1}{60}^\circ$
    - Arcsecond ($''$): $1'' = \dfrac{1}{60}'$
- Geometry:
  - Angle between two points (in radian) is $\theta = \dfrac{s}{r}$ where s is distance subtended at distance r.
  - Solid angle between two points (in steradians) is $\Omega = \dfrac{A}{r^2}$, where A is area subtended at distance r.
  - Circumference of circle: $d = 2\pi r$
  - Area of circle: $A = \pi r^2$
  - Surface area of sphere: $A = 4\pi r^2$
  - Volume of sphere: $V = \dfrac{4\pi}{3} r^3$
  - Volume of a cylinder: $V = \pi r^2 h$
- Trigonometry (see figure):
  - Interior angles of a triangle sum to 180° or $\pi\,\text{rad}$
  - $\sin(\angle A) = \dfrac{1}{\csc(\angle A)} = \cos(\angle B) = \dfrac{a}{c}$
  - $\cos(\angle A) = \dfrac{1}{\sec(\angle A)} = \sin(\angle B) = \dfrac{b}{c}$
  - $\tan(\angle A) = \dfrac{1}{\cot(\angle A)} = \cot(\angle B) = \dfrac{a}{b}$ (discontinuous function)
  - $\cos^2\theta + \sin^2\theta = 1$ (Pythagorean theorem) and $\sec^2\theta = 1 + \tan^2\theta$
  - $\sec^2\theta = 1 + \tan^2\theta$



- Vectors:
  - Direction convention: $\vec{\mathbf{r}}_{12}$ points from 1 to 2
  - Unit vector $\hat{\mathbf{r}} = \dfrac{\vec{\mathbf{r}}}{r}$
  - Right-hand rule: There are three ways to apply the right-hand rule to $\vec{\mathbf{A}} \times \vec{\mathbf{B}}$ and figure out the cross-product direction:



    - * *Finger Curl Rule:* Point your right fingers in the direction of $\vec{\mathbf{A}}$, curl them towards the direction of $\vec{\mathbf{B}}$ (through the smallest angle), the right thumb points into the page.
    - * *Palm Rule:* Point your right thumb along $\vec{\mathbf{A}}$ and right fingers along $\vec{\mathbf{B}}$, then the palm faces into the page.
    - * *"Gang Sign":* Point your right index finger in direction of $\vec{\mathbf{A}}$, your middle finger in the direction of $\vec{\mathbf{B}}$, and your thumb (at a right angle to index and middle fingers) points into the page.

- Miscellaneous mathematics:
  - Logarithm Rules, where b is the base (e.g. base-10 is $\log_{10}()$, or often $\log()$; natural logarithm is base e, so $\log_e()$, often $\ln()$):
    - * $\log_b(xy) = \log_b x + \log_b y$
    - * $\log_b\left(\frac{x}{y}\right) = \log_b x - \log_b y$
    - * $\log_b(x^y) = y \log_b x$
    - * $b^{\log_b x} = x$
  - Common and relevant Taylor series (mostly demonstrate the small-angle approximation):
    - * $\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + ... = \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)!}\theta^{2n+1}$
    - * $\cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \frac{\theta^6}{6!} + ... = \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)!}\theta^{2n}$
    - * $\tan\theta = \theta + \frac{\theta^3}{3} + \frac{2\theta^5}{15} + \frac{17\theta^7}{315} + ...$, for $|\theta| < \frac{\pi}{2}$
- Miscellaneous fundamental physics:
  - Wavelength-frequency relation: $v = \lambda\nu$
  - Photon energy: $E = h\nu$, where h is the Planck constant.
  - Mass-energy equivalence: $E = mc^2$
  - Power (or luminosity if emitted): $P = \frac{dE}{dt}$.
  - Electric or Coulomb force (force on Q_1 due to Q_2): $\vec{\mathbf{F}}_{12}(r) = -\frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}\,\hat{\mathbf{r}}_{12}$
  - Electric field due to Q_2: $\vec{\mathbf{E}}_2 = \frac{\vec{\mathbf{F}}_{12}}{Q_1}$
- Geometric Optics:
  - Fermat's principle: $v = \frac{c}{n_\lambda}$
  - Speed of EM wave in medium: $v = \frac{1}{\sqrt{\varepsilon\mu}}$
  - Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$
  - Law of reflection: angle of incidence equals angle of reflection
  - Sign conventions
    - * Cartesian sign convention (not used in this course; changes fundamental equations)
    - * Radius of curvature is positive if the center is to the right of the vertex and negative if the center is to the left
    - * Optics with positive focal lengths are converging optics. Optics with negative focal lengths are diverging optics.

    - Real objects and images have positive distances. Negative objects and images have negative distances.
    - Positive angles for rays pointing upwards. Negative angles for rays pointing downwards.
- Principal rays (i.e., ray tracing)
    - In parallel to optical axis, out through focal point (or out as if from focal point).
    - In through focal point (or as if from focal point), out parallel.
    - Into vertex, undeviated.
- Focal length of spherical mirror: $f = -\dfrac{R}{2}$
- Mirror equation and thin-lens equation: $\dfrac{1}{s} + \dfrac{1}{s'} = \dfrac{1}{f}$
- Magnification is ratio of image's height or angle to object's.
- Total magnification: $M = \prod_i m_i$
- Diopter $= \dfrac{1\,\mathrm{m}}{f}$, where f is focal length.
- Refracting power: $P = V + V'$, where vergence $V = \dfrac{1}{s}$ and $V' = \dfrac{1}{s'}$.
- Angular magnification of simple telescope: $m = \dfrac{\alpha'}{\alpha} = -\dfrac{f_{\mathrm{occ}}}{f_{\mathrm{eye}}}$

Campus-wide Information

UH Hilo COVID-19 Pandemic Information: https://hilo.hawaii.edu/covid19/
Disability Support: Any student with a documented disability who would like to request accommodation should contact the University Disability Services Office—Hale Kauanoe A Wing Lounge; 932-7623 (V), 932-7002 (TTY), uds@hawaii.edu—as early in the semester as possible.
Advising: Advising is a very important resource designed to help students complete the requirements of the University and their individual majors. Students should consult with their advisor at least once a semester to decide on courses, check progress towards graduation, and discuss career options and other educational opportunities provided by UH Hilo. Advising is a shared responsibility, but students have final responsibility for meeting degree requirements.
Kilohana Academic Success Center: The KASC provides academic support opportunities for all UH Hilo students that foster their development into independent, self-motivated learners. Students who visit Kilohana have access to subject-specific and academic skills tutoring from UHH students selected for their academic achievement and dedication to helping others succeed. Kilohana is located on the lower level of the Mookini Library and on the web at http://hilo.hawaii.edu/kilohana/.
Human Rights: The University of Hawai'i at Hilo prohibits discrimination in its education programs based on race, national origin, color, creed, religion, sex, age, disability, veteran status, sexual orientation, gender identity or associational preference. If at any time during class you feel uncomfortable about what is being talked about, or feel that your human rights have been violated, please feel free to leave the room. However, the professor asks that you confer with her as soon as possible about what happened so that appropriate action can be taken if necessary to avoid future problems. If you are uncomfortable speaking with the professor about your concern, please contact Kalei Rapoza (kaleihii@hawaii.edu), Interim EEO/AA Director, at 932-7626.
UH Hilo Title IX Policy: The University of Hawaii is committed to providing a learning, working and living environment that promotes personal integrity, civility, and mutual respect and is free of all forms of sex discrimination and gender-based violence, including sexual assault, sexual harassment, gender-based harassment, domestic violence, dating violence, and stalking. If you or someone you know is experiencing any of these, the University has staff and resources on your campus to support and assist you. Staff can also direct you to resources that are in the community. Here are some of your options:

> If you wish to remain anonymous, speak with someone confidentially, or would like to receive information and support in a confidential setting, contact: • UH Hilo Counseling Services: SSC, room E-203, 932-7465; • UH Hilo Medical Services: Campus Center, room 212, 932-7369; and/or • Hawai'i Island YWCA, 935-0677.
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> If you wish to report an incident of sex discrimination or gender-based violence including sexual assault, sexual harassment, gender-based harassment, domestic violence, dating violence, or stalking as well as receive information and support,† contact: • Libby Bailey, Title IX Coordinator, 932-7818, libby.bailey@hawaii.edu; • Jennifer Stotter, Director of the Office of Equal Opportunity & Deputy Title IX Coordinator, 932-7641, jstotter@hawaii.edu; and/or • Kalei Rapoza, Interim Director of Human Resources, 932-7626, kaleihii@hawaii.edu.
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> †Please note that you do not have to file a report with the University to receive institutional support or assistance.

As a member of the University faculty, the professor is required to immediately report any incidence of sex discrimination or gender-based violence to the campus Title IX Coordinator. Although the Title IX Coordinator and professor cannot guarantee confidentiality, the student will still have options about how the case will be handled. The goal is to make sure the student is aware of the range of options available and has access to the necessary resources and support. For more information regarding sex discrimination and gender-based violence, the University's Title IX resources and the University's Policy, Interim EP 1.204, go to: http://www.hawaii.edu/titleix.
Student Conduct: Students are expected to follow the University of Hawai'i at Hilo Student Code of Conduct available at the following URL: http://www.uhh.hawaii.edu/catalog/student-conduct-code.html.