RICE NATURAL SCIENCES
Physics and Astronomy

QUARKNET

Introductory Physics at Rice University

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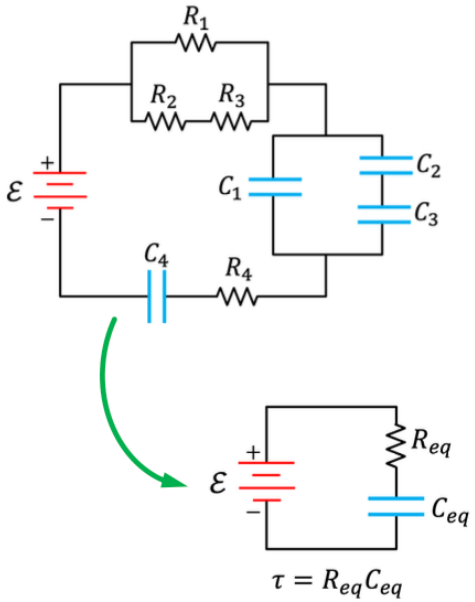

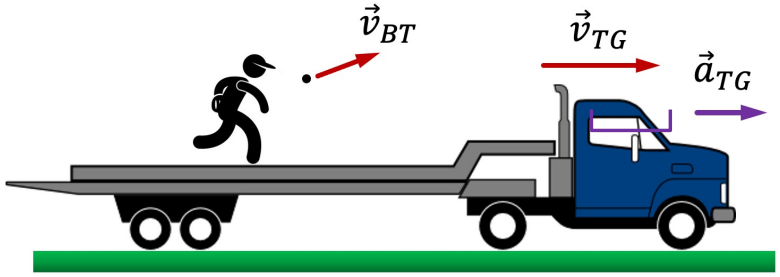

Frame 1: **T**ruck Frame 2: **G**round

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Physics and Astronomy

Introduction(s)

Dr. Robert Beaird
Associate Teaching Professor

My Roles and Responsibilities

- NTT Teaching Faculty
- Divisional Advisor – Natural Sciences
- RicePOP – Coordinator (1 of 4)
- Dept. Undergraduate Program Committee
- University Committee on Ex&S – Chair
- Baker College – Faculty Associate
- Rice Fencing Club – Faculty Sponsor

Dr. Melia Bonomo
Lecturer

Dr. Michael Cone
Assoc. Teaching Prof.

Dr. Julie Hoeink
Assist. Teaching Prof.

Dr. Jared Stenson
Assist. Teaching Prof.

Dr. Lam Yu
Assoc. Teaching Prof.

Pre-matriculation Credit

Q: Do I use my AP credit or retake the course?

A: It depends. What is your intended major?

Comfort level?

Competence?

AP Physics (C) Mechanics	PHYS 101- Mechanics with Lab (4 hrs)
AP Physics (C) E&M	PHYS 102- E&M with Lab (4 hrs)
AP Physics 1: Algebra Based	PHYS 141*- Concepts in Physics I (3hrs)
AP Physics 2: Algebra Based	PHYS 142*- Concepts in Physics II (3hrs)
Physics (HL)	PHYS 141*- Concepts in Physics I (3hrs) PHYS 142*- Concepts in Physics II (3hrs)

AP: 4 or 5 IB: 6 or 7

*D3 credit only

RICE NATURAL SCIENCES
Physics and Astronomy

Intro Physics Sequences

Three Levels of Rigor

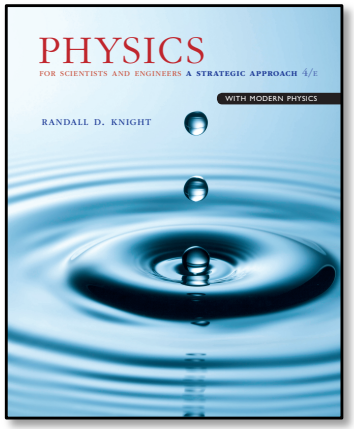


PHYS 125 & 126- *General Physics* & *General Physics II*

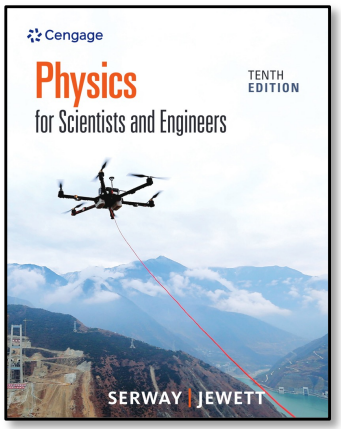
Course format: 2 plenary lectures, 1 discussion, 1 lab

Audience: bioscience & premedical majors
Homework: "in house" problems on Canvas
& handwritten Pledge Problems

Calculus-based… but punches are pulled a bit.



R.D. Knight



Serway & Jewett

PHYS 101 & 102- *Mechanics* & *Electricity and Magnetism*



Course format: 2 plenary lectures, 1 discussion, 1 lab

Audience: physical science & engineering majors
Homework: textbook's problems on WebAssign

Calculus-based… does not shy away from math.

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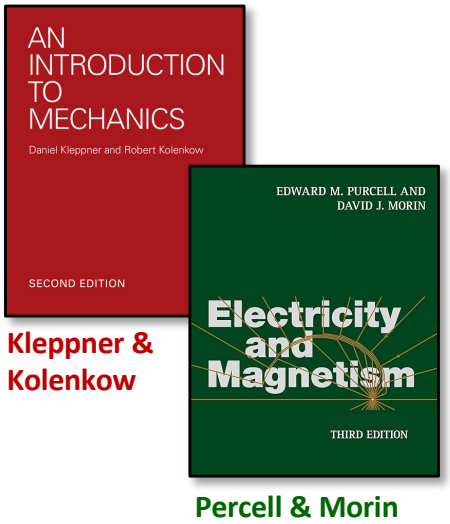
Intro Physics Sequences

Three Levels of Rigor



Kleppner & Kolenkow

Percell & Morin

PHYS 111 & 112- *Honors Mechanics* & *Honors E&M*

Course format: 3 plenary lectures, 1 lab

Audience: physical science & engineering majors
… with *strong* background in physics and calculus

Homework: textbook's problems, handwritten submission

Calculus-based… seriously math heavy.

("Honors" means "*advanced* treatment of intro topics".)

Drop-Back Provision

Add date: Week 2 Drop-back: Week 7

Risk-averse students can take more challenging courses than they are feel prepared for.

Overconfident students have an escape plan if they bite a little too much to begin with.

Example: A student who has AP credit for Mechanics wishes to take PHYS 111 to better understand the material.

After week 2, the student discovers that PHYS 111's workload is a bit too challenging or time-consuming.

The student can "drop back" to PHYS 101 with no penalty… or judgement.

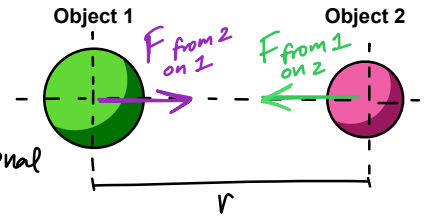
PHYS 125 Lecture

Orbital Dynamics

B. Law of Gravitation: Equation

- Two objects will exert a force of attraction on each other according to their masses and the distance between them
- These forces are a Newton's 3rd pair! $\vec{F}_{21} = -\vec{F}_{12}$

$$F_g = \frac{G m_1 m_2}{r^2}$$



where G is the universal gravitational constant, "Big G":

$$G = 6.6743 \times 10^{-11} \frac{N m^2}{kg^2}$$

distance from the center of each mass

RICE PHYS 125 - Week 5 10

Semi old-school:

- iPad used as an "overhead"
- Notes provided after class
- Mostly lecture
- Some active learning

Covered:

- Newton's Law
- Near Earth
- Circular orbits

Not Covered:

- Elliptical orbits
- Kepler's Laws
- Orbital Energetics

B. Law of Gravitation: Where does "little g" come from?

What is the gravitational force on an object of mass m sitting on the Earth's surface?

$$F_g = \frac{G m_1 m_2}{r^2} = \frac{G M_E m}{R_E^2}$$

if we just calculate out this part of the equation we get:

$$\frac{G M_E}{R_E^2} = \frac{\left(6.6743 \times 10^{-11} \frac{N m^2}{kg^2}\right)\left(5.972 \times 10^{24} kg\right)}{\left(6.378 \times 10^6 m\right)^2}$$

$$= 9.798 \frac{N}{kg} \approx 9.8 \frac{kg\,m}{kg\,s^2} = \boxed{9.8 \frac{m}{s^2} = g}$$

Newton unit $N = \frac{kg\,m}{s^2}$

That's why we've been using $F_g = mg$ on the Earth's surface!

mass of the earth: $M_E = 5.972 \times 10^{24}$ kg

radius of the earth: $R_E = 6.378 \times 10^6$ m

RICE PHYS 125 - Week 5 11

B. Orbits: An Extension of Centripetal Acceleration Concepts

An orbit can be modeled as circular motion with centripetal acceleration due to a net force (F_g) towards the center of the orbit.

FBD for satellite

$$F_g = \frac{G M_E m}{r^2}$$

from Earth on satellite

Newton's 2nd Law

$$\sum F_r = m a_r$$

sum of radial forces on satellite; mass of satellite; centripetal acceleration of satellite

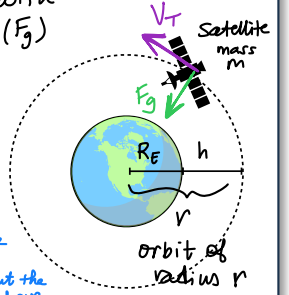
Recall $a_r = \frac{v_T^2}{r}$

$$F_g = m a_r$$

$$\frac{G M_E m}{r^2} = m \frac{v_T^2}{r}$$

$$\frac{G M_E}{r} = v_T^2$$

Here, for example we're poised to answer Q's about the radius, height above earth, or tangential velocity



RICE PHYS 125 - Week 5 19

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PHYS 125 Discussion

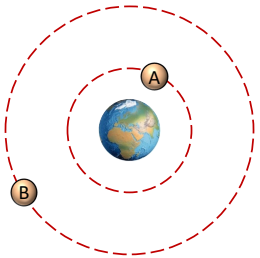
Orbital Dynamics

Discussion Question

Two satellites A and B of the same mass are going around Earth in concentric orbits. The distance of satellite B from Earth's center is twice that of satellite A.

What is the orbital speed of B, in terms of the orbital speed of A?

1. $v_B = v_A / 2$
2. $v_B = v_A / \sqrt{2}$
3. $v_B = v_A$
4. $v_B = \sqrt{2} v_A$
5. $v_B = 2 v_A$



Earth is not really flat. Fast enough projectiles can 'see' the curvature of Earth's surface.

A fast enough projectile will miss the ground!

(a) How fast would a cannonball have to be in order to orbit the Earth at sea level?

(b) How long would it take the cannonball to orbit the Earth at sea level?

Possibly Useful Numbers

$M_E = 5.98\times10^{24}$ kg $\quad R_E = 6.37\times10^{6}$ m

$G = 6.67\times10^{-11}$ Nm^2/kg^2

(a) Orbits: F_G is the centripetal force F_c.

$$F_G = \frac{GmM_E}{r^2} \qquad F_c = ma_c = \frac{mv^2}{r}$$

Use these to find the orbital speed v.

(b) Circular orbit is uniform circular motion.

$$v = r\omega \qquad \omega = \frac{2\pi}{T}$$

Use these to find the orbital period T.

Orbital speed and period depend only on mass of the planet and orbital radius!

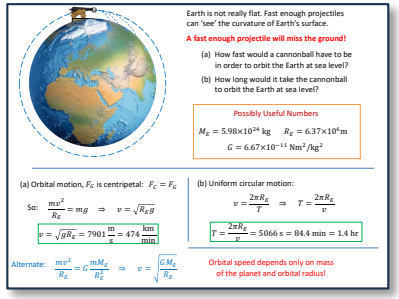
$$v = \sqrt{\frac{GM_E}{r}} \qquad T = 2\pi\sqrt{\frac{r^3}{GM_E}}$$

Discussion Questions

- Multiple choice
- "Think, pair, share"
- Student "volunteer" at the board

Free Response Problems

- Posed & scaffolded
- Think, pair, share
- Volunteer at the board
- Solution provided online



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Supplemental!

PHYS 125 Discussion

Orbital Dynamics

In-class and homework is not enough!

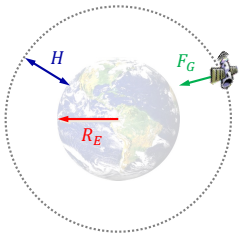
- Some bog-standard problems.
- Some challenging problems.
- Premeds are surprisingly proactive about working the supplemental material!

An Earth satellite moves in a circular orbit $H = 640$ km above the earth's surface with a period $T = 98.0$ min.

What is a_c the centripetal acceleration of the satellite?

$M_E = 5.98\times10^{24}$ kg $R_E = 6.37\times10^{6}$ m

$G = 6.67\times10^{-11}$ Nm^2/kg^2



Orbits: F_G is the centripetal force F_c.

$$F_G = \frac{GmM_E}{r^2} \qquad F_c = ma_c$$

Circular orbit is uniform circular motion.

$$v = r\omega \qquad \omega = \frac{2\pi}{T} \qquad a_c = \frac{v^2}{r}$$

Use these to find an expression for altitude a_c in terms of G, M_E and T.

Then run the numbers and calculate!

Altitude: H =?!

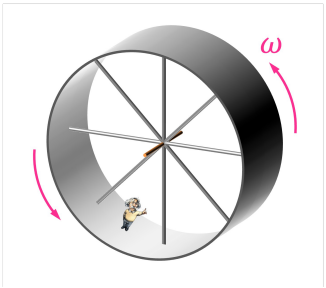
Orbital radius: $r = R_E + H$

Period: $T = 24$ hr

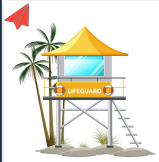
Discussion Question

Einstein is standing on the "floor" of a rotating space station that is spinning counter clockwise with angular speed ω, as shown below. If Einstein drops a ball from rest (relative to himself) from a height h above the floor, where will the ball land?

1. At his feet.
2. Behind him.
3. Ahead of him.
4. Depends on the value of ω.



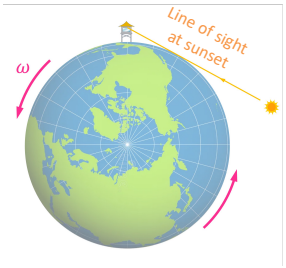
Note: this is a challenging question, and a bit beyond the scope of the course.



You are sitting at the base of a lifeguard tower at the equator. Your friend, is sitting at the top of the tower ($h = 6.0$ m). At sundown, your friend sees the sun disappear behind the horizon 19 s after you do. You decide to use this information to estimate the earth's radius.

(a) Through what angle θ has the earth rotated during the 19 s?

(b) What is the approximate radius of the earth?



(a) Uniform circular motion means constant ω:

$$\omega = \frac{\Delta\theta}{\Delta t}$$

Your time: $\Delta t_{you} = 19$ s

One day: $\Delta t_{day} = 24$ hr

(b) The sun sets when the sun drops below the horizon… and is no longer in your field of view.

Use the figure to construct a right triangle that will relate Earth's radius R_E, the tower height H, and the angle θ you found in (a).

Solve for R_E in terms of H and θ … and *then* sub in the numbers and calculate!

Comparison of Depth

Orbital Dynamics

PHYS 125 (and PHYS 101)

- Newton's 2nd and Gravitation
- Circular orbits

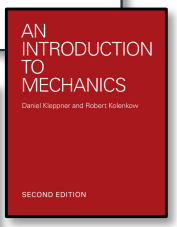
PHYS 111

- Newtonian Gravity (Ch. 3)
- Central force motion (Ch. 10)

3.3 Gravity
Gravity, the most familiar of the fundamental forces, played an honored role in the development of mechanics; Newton discovered the law of universal gravitation in 1666, the same year that he formulated his laws of

respectively, separated by distance r. Let $\mathbf{F}_{b,a}$ be the force exerted on particle b by particle a. Our verbal description of the magnitude of the gravitational force can be expressed mathematically as

$$|\mathbf{F}_{b,a}| = \frac{GM_aM_b}{r^2}.$$



13.3 Newton's Law of Gravity

Newton proposed that *every* object in the universe attracts *every other* object with a force that is

1. Inversely proportional to the square of the distance between the objects.
2. Directly proportional to the product of the masses of the two objects.

To make these ideas more specific, FIGURE 13.4 shows masses m_1 and m_2 separated by distance r. Each mass exerts an attractive force on the other, a force that we call the **gravitational force.** These two forces form an action/reaction pair, so $\vec{F}_{1\text{ on }2}$ is equal and opposite to $\vec{F}_{2\text{ on }1}$. The magnitude of the forces is given by Newton's law of gravity.

Newton's law of gravity If two objects with masses m_1 and m_2 are a distance r apart, the objects exert attractive forces on each other of magnitude

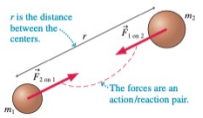
$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{Gm_1m_2}{r^2} \qquad (13.2)$$

The forces are directed along the straight line joining the two objects.

The constant G, called the **gravitational constant,** is a proportionality constant necessary to relate the masses, measured in kilograms, to the force, measured in newtons. In the SI system of units, G has the value

$$G = 6.67 \times 10^{-11}\ \text{N m}^2/\text{kg}^2$$

FIGURE 13.4 The gravitational forces on masses m_1 and m_2.



13.6 Satellite Orbits and Energies

Solving Newton's second law to find the trajectory of a mass moving under the influence of gravity is mathematically beyond this textbook. It turns out that the solution is a set of elliptical orbits, which is Kepler's first law. Kepler had no *reason* why orbits should be ellipses rather than some other shape. Newton was able to show that ellipses are a *consequence* of his theory of gravity.

The mathematics of ellipses is rather difficult, so we will restrict most of our analysis to the limiting case in which an ellipse becomes a circle. Most planetary orbits differ only very slightly from being circular. The earth's orbit, for example has a (semiminor axis/semimajor axis) ratio of 0.99986—very close to a true circle!

FIGURE 13.16 shows a massive body M, such as the earth or the sun, with a lighter body m orbiting it. The lighter body is called a **satellite,** even though it may be a planet orbiting the sun. For circular motion, where the gravitational force provides the centripetal acceleration v^2/r, Newton's second law for the satellite is

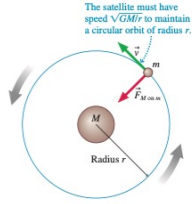
$$F_{M\text{ on }m} = \frac{GMm}{r^2} = ma_r = \frac{mv^2}{r} \qquad (13.21)$$

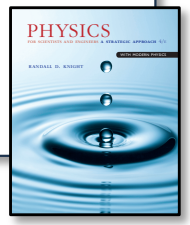
Thus the speed of a satellite in a circular orbit is

$$v = \sqrt{\frac{GM}{r}} \qquad (13.22)$$

A satellite must have this specific speed in order to have a circular orbit of radius r about the larger mass M. If the velocity differs from this value, the orbit will become elliptical rather than circular. Notice that the orbital speed does *not* depend on the satellite's mass m. This is consistent with our previous discovery, for motion on a flat earth, that motion due to gravity is independent of the mass.

FIGURE 13.16 The orbital motion of a satellite due to the force of gravity.





10.5 Planetary Motion

In this section we solve the chapter's main problem: finding the orbit for a planet of mass m moving about a star of mass M under the gravitational interaction

$$U(r) = -G\frac{Mm}{r} \equiv -\frac{C}{r}. \qquad (10.16)$$

Our results would also apply to a satellite of mass m orbiting a planet of

Inserting the potential $U(r)$ from Eq. (10.16) into the orbit equation, Eq. (10.14), we obtain

$$\theta - \theta_0 = L\int \frac{dr}{r\sqrt{(2\mu Er^2 + 2\mu Cr - L^2)}},$$

Physically, r_0 is the radius of the circular orbit corresponding to the given values of L, μ, and C. The dimensionless parameter ϵ, called the *eccentricity*, characterizes the shape of the orbit, as we shall see. With these replacements, Eq. (10.18) becomes

$$r = \frac{r_0}{1 - \epsilon\cos\theta}. \qquad (10.21)$$

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Online Homework

Gravitation

PHYS 125/126

- Prof-designed problems
- Submitted via Canvas
- Multiple submissions per answer box- no penalty

In 1956, Frank Lloyd Wright proposed the construction of a mile-high building in Chicago. Suppose the building had been constructed. Ignoring Earth's rotation, find the change in your weight, in **N**, if you were to ride an elevator from street level, where you weight 600 **N**, to the top of the building. The Earth's radius is 6371 **km**.

A spaceship is on a straight-line path between Earth and the Moon. At what distance from the Earth is the net gravitational force on the spaceship zero? The Earth's mass is 5.972 x 10^{24} **kg**, the mass of the Moon is 7.348 x 10^{22} **kg**, and the separation between their centers is 3.844 x 10^{8} **m**. Give you answer in **m** from the *center* of the Earth.

PHYS 101/102

- Textbook problems & some prof-designed
- Submitted via WebAssign.
- Multiple subs per answer box- no penalty

A satellite of mass 220 kg is placed into Earth orbit at a height of 400 km above the surface.

(a) Assuming a circular orbit, how long does the satellite take to complete one orbit?

h

(b) What is the satellite's speed?

m/s

(c) Starting from the satellite on the Earth's surface at the equator, what is the minimum energy input necessary to place this satellite in orbit? Ignore air resistance but include the effect of the planet's daily rotation.

J

A spacecraft in the shape of a long cylinder has a length of 100 m, and its mass with occupants is 1 980 kg. It has strayed too close to a black hole having a mass 90 times that of the Sun. The nose of the spacecraft points toward the black hole, and the distance between the nose and the center of the black hole is 10.0 km.

(a) Determine the total force on the spacecraft.

N

(b) What is the difference in the gravitational fields acting on the occupants in the nose of the ship and on those in the rear of the ship, farthest from the black hole? (This difference in acceleration grows rapidly as the ship approaches the black hole. It puts the body of the ship under extreme tension and eventually tears it apart.)

N/kg

Some Issues

Math Literacy

Abuse of equals signs:

$\Delta V = 12\ \text{V}$
$R = 6.0\ \Omega$

$12\ V = \frac{I\ R}{R} = 2.0\ A$

Adding fractions:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{2R} + \frac{1}{3R} = \frac{1}{5R}$$

Algorithm vs. understanding:

Can do: $\frac{d}{dx}(ax^2 + bx + c)$

Can't do: $\frac{d}{dt}\left(\theta_0 + \omega t + \frac{\alpha}{2}t^2\right)$

Discomfort with symbolic quantities.

Algebra line by line:

$$x_f = x_i + \frac{1}{2}a_x t^2$$
$$-x_i \qquad -x_i$$
$$x_f - x_i = \frac{1}{2}a_x t^2$$
$$\times 2 \qquad \times 2$$
$$2(x_f - x_i) = a_x t^2$$

$$\frac{a_x t^2}{a_x} = \frac{2(x_f - x_i)}{a_x}$$

$$t = \sqrt{\frac{2(x_f - x_i)}{a_x}}$$

Some Issues

Definitions vs. Special Cases

***E.g.*, kinematics:**

Given $x(t) = A + Bt + Ct^2 + Dt^3$, what is the object's acceleration?

Too common: $a_x = 2C$ ✗

Because $x(t) = x_i + v_i t + \frac{1}{2} a_x t^2$

$x(t) = A + Bt + Ct^2 + Dt^3$

Not common enough:

$$v_x = \frac{dx}{dt} = B + 2Ct + 3Dt^2$$

$$a_x = \frac{dv_x}{dt} = 2C + 6Dt \checkmark$$

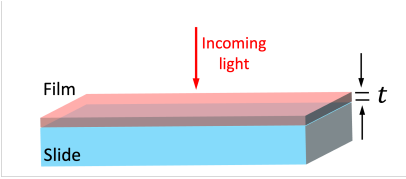
***E.g.*:**

Discussion Question

Magnesium fluoride MgF_2 ($n_1 = 1.4$) is used to make an anti-reflection coating on the upper surface of a glass ($n_2 = 1.5$) microscope slide. The coated surface is illuminated with light of wavelength λ.

Assuming that the film has thickness t, what is the phase difference for reflected light?

1) $\frac{\Delta\phi}{2\pi} = \frac{2nt}{\lambda} + \frac{1}{2}$
2) $\frac{\Delta\phi}{2\pi} = \frac{2nt}{\lambda}$
3) $\frac{\Delta\phi}{2\pi} = \frac{2t}{n\lambda} - \frac{1}{2}$
4) $\frac{\Delta\phi}{2\pi} = \frac{2t}{n\lambda}$
5) None of these.



Too common: Memorize by cases. ✗ ✓

Not common enough:

$$\frac{\Delta\phi}{2\pi} = \frac{2t}{\lambda_{film}} + \frac{\Delta\phi_{refl}}{2\pi} = \ldots \checkmark\checkmark$$

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Some Issues

An informal poll

"Normalize the idea that physics is hard. *Thinking* is hard. This doesn't mean you are at bad it."

"The AP experience is not the same thing as a university course. The pacing of the course is very different. Depth of coverage varies."

"Time management is multi-faceted. Not just for HW, but on exams too."

"Physics sits right between the pure abstraction of math and the tangible reality of everyday life.

Students want to do physics the same way they do biology or chem… or how they did in HS."

"Make things as simple as possible, but not simpler."

Communication & written work.

"It's in my calculator."
(silent scream)

Complete sentences!

"Use your nouns."

Avoid 3PPP.

Checking for self-consistency

Check for physical consistency.

Number sense.

Order of magnitude.

Dimensional consistency.
Write the expletive units!!!

Other Observations

"I got my HW answer, but I don't really understand it."

Current problem vs. larger context.

"How should I study for the exam?"

Cumulative… exam to exam and course to course.

RICE NATURAL SCIENCES
Physics and Astronomy

PHYS 100- "Exploring Physics"

Bite Size Physics

Provides small-group learning support for less-well-prepared students taking PHYS 101/102. Students are invited based on demonstrated need* early in the fall semester at the beginning of the semester. (**E.g.*, math diagnostic, RESP participants, *etc.*)

Racial & Gender Equity in Physics

Explores the underrepresentation of women and racial/ethnic minorities in mainstream physics history and the field at large today. Students from all disciplines are invited and encouraged to take this discussion-based course.

Exploring Physics with a Computer

Explores classic physics problems that are tricky/ near impossible to solve with a pencil and paper alone. *I.e.*, the ones that are "beyond the scope" of a typical intro physics course.

Uses VPython, Trinket, and Mathematica.

Now FWIS: "Science vs. Pseudoscience" and "Foundations of Quantum Physics for Regular People"

RICE NATURAL SCIENCES
Physics and Astronomy

FWIS- Physics Topics

First-Year Writing Intensive Seminars:

- Required for all degrees.
- Strategies for analyzing, synthesizing, and responding to college-level readings.
- Improve their ability to communicate effectively in writing and in speech
- Learn appropriate use and citation.
- Learn to articulate oral arguments and responses in-class and in presentations.

The Meaning and Impact of Quantum Mechanics

Focuses on the debates over the content and meaning of quantum theory. Students learn how theories are formed, how science is done, how these impact day-to-day culture, and the role that humans play in objective science.

Science, Pseudoscience, & Skepticism:
How to tell good science from junk science

Focuses on scientific skepticism and critical thinking. Core topics include the fallibility of perception; mechanisms of self-deception; as well as metacognition, cognitive biases and logical fallacies.

Storytelling in the Sciences

Scientists communicate through articles, press releases, podcasts, and books. Students explore how scientific ideas transform across formats for different audiences.

RICE NATURAL SCIENCES
Physics and Astronomy

Hidden Curriculum

Internal Resources

RICE UNIVERSITY
Office of Academic Advising

Academic Fellows/Mentors

- Course-Specific Academic Assistance
  - Office Hours
  - Group study sessions
  - Paper editing
  - Exam review sessions
  - One-on-one tutoring
- Academic Enrichment Events/Workshops
  - Research, fellowship, and internship opportunities

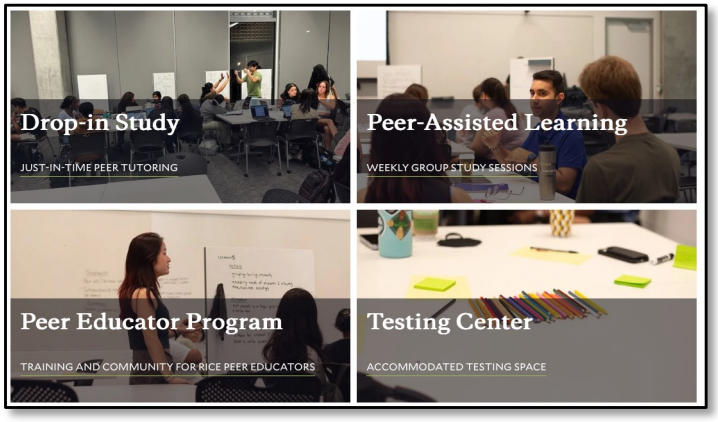
What students can and/or should do…
but isn't officially part of any one course.

Society of Physics and Astronomy Students
RICE UNIVERSITY

Owlchemy
Rice University's Chemistry Club

RICE ECLIPSE
Rice University's Student Rocketry Team

RICE UNIVERSITY
Office of Academic Support for Undergraduate Students

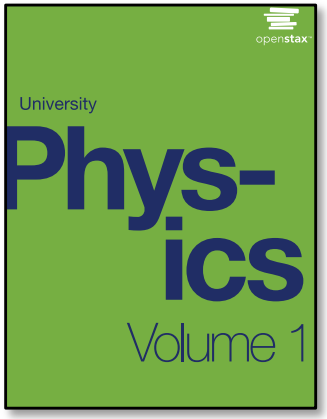


RICE UNIVERSITY
Wiess School of Natural Sciences

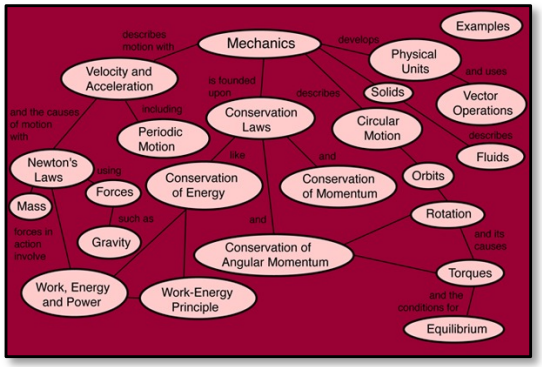
Hidden Curriculum

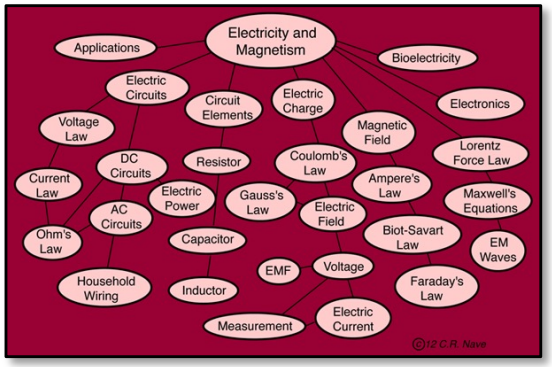
External Resources

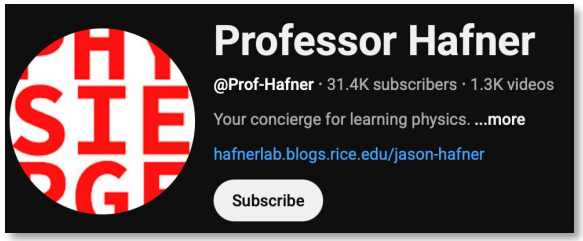
https://openstax.org



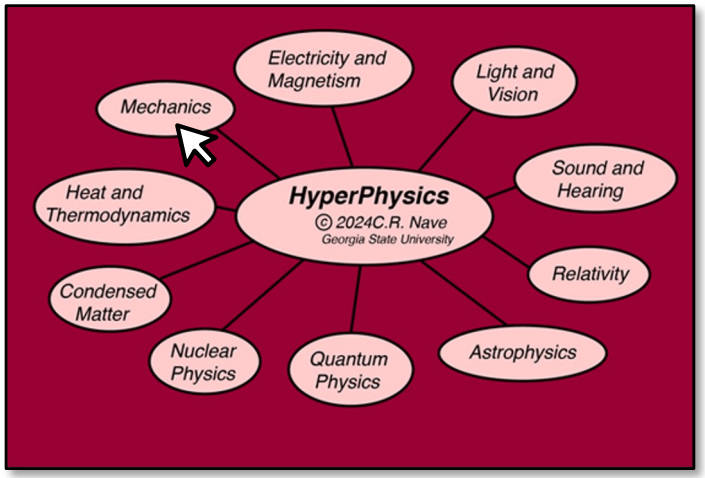
Ok, not "external", but publicly available.



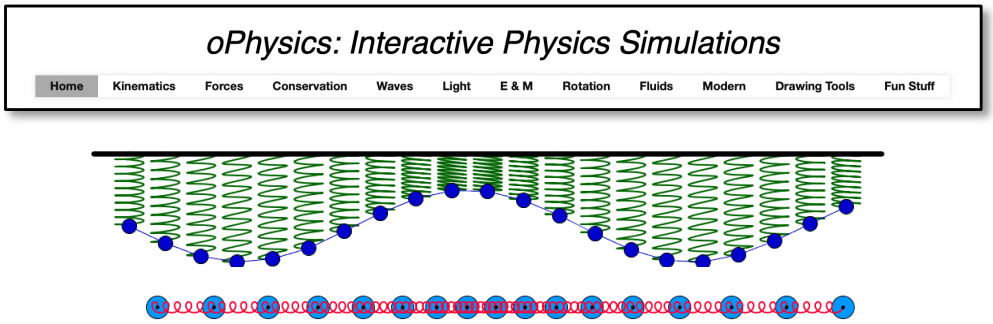




https://www.youtube.com/c/PHYSIERGE



http://hyperphysics.phy-astr.gsu.edu/



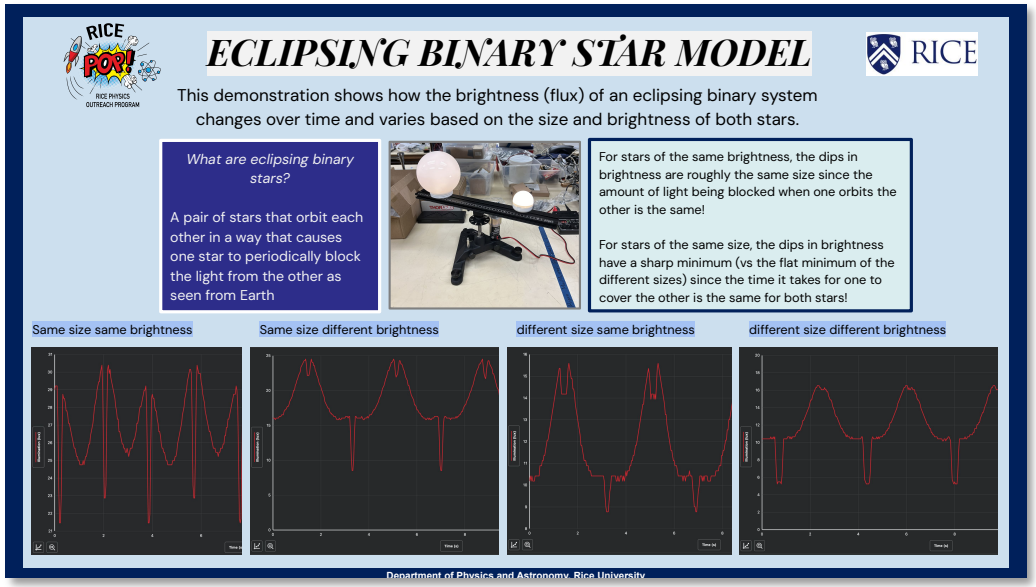
https://ophysics.com/

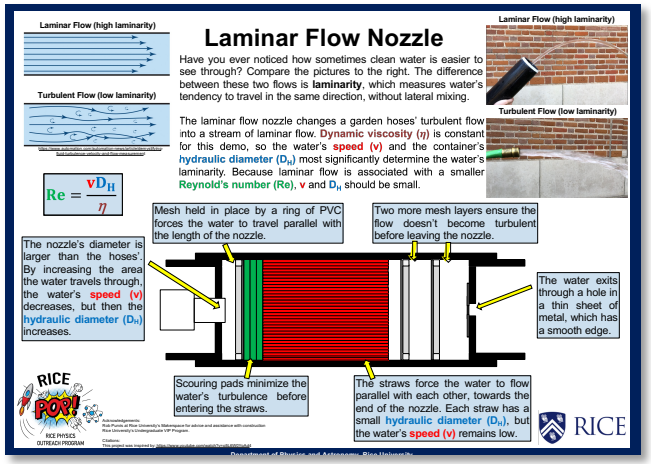
RICE NATURAL SCIENCES
Physics and Astronomy

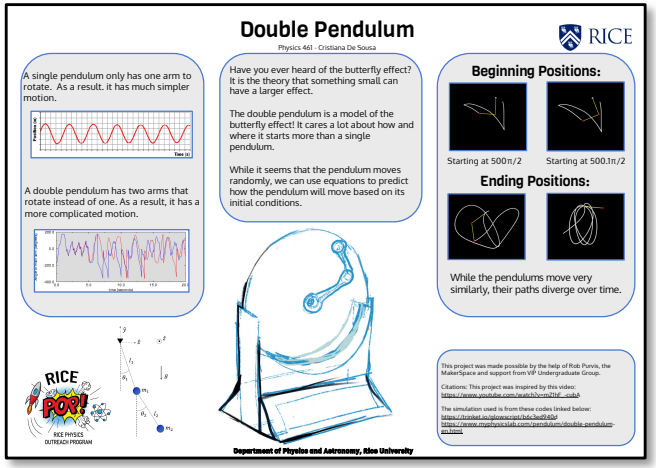
RicePOP

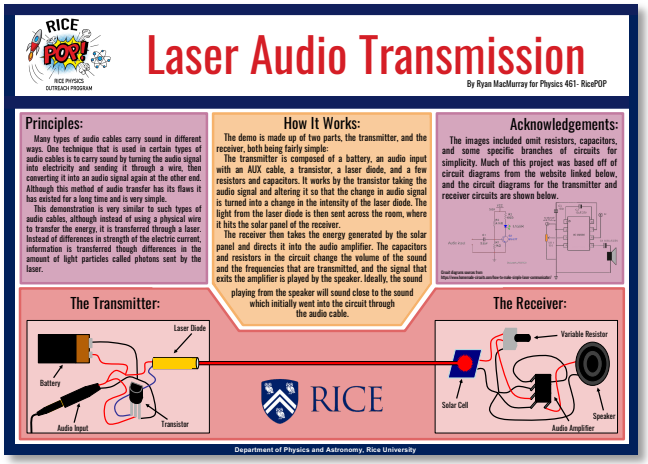
Rice Physics Outreach Program:

- Demos for in-class use and outreach
- Student designed and made (if possible)
- Students from all majors.
- PHYS 461/462- 1 hour research credit
- Brown Teaching Grants (2017 & 2024)
  Teaching Innovation Grant (2018)
  Departmental Funds (~$5K annually)









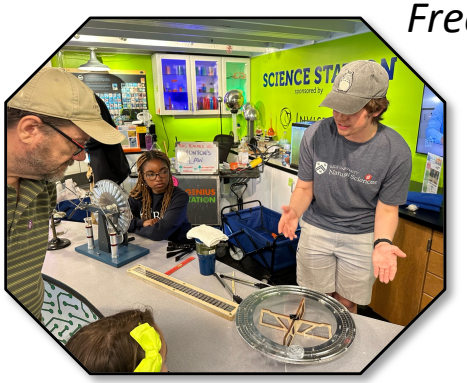
RICE NATURAL SCIENCES
Physics and Astronomy

RicePOP

RICE POP! RICE PHYSICS OUTREACH PROGRAM

Children's Museum Houston

Free Family Night



Children's Museum Houston

Houston Science Festival

Casa to College

HSF

Reach for the Stars

Rice STEM Festival