From Galileo to Newton

The Emergence of Modern Physical Science

Terms 2-3, Deep Springs College, Prof. **Brian Hill**

What We Desire to Cover

- The backbone of our course is pp. 5-489 of **Newton's Principia: The Central Argument, 3rd Edition** by Dana Densmore, with translations and diagrams by William H. Donahue. That is 485 pages of material, but do not be daunted by page-count alone. Newton himself is terse. Only at most one-quarter of the material in Densmore is by Newton. The rest is Densmore's commentary. Assuming most of our 14 weeks together is occupied on this material, we have 35 to 44 pages of reading per week. *However,* there is additional material we must cover.
- Newton presumes an understanding of Galileo's *Two New Sciences* and *Two Chief World Systems*, of Euclid's *Elements*, and of Apollonius' *On Conic Sections.* We will therefore need to budget 2 to 3 of our 14 weeks to pick up something from those works. To be safe we will try to cover 45 pages per week when we are focused on Densmore. This will enable us to get to Newton's brilliant conclusions at the end of our study of *The Principia.*

Daily Schedules

Detailed daily schedules:

- **Daily Schedule Term 2**
- **Daily Schedule Term 3**

Grading

Four major areas:

- Strong preparation for each class: 25%
- Weekly problem sets (except during exam weeks): 30%
- A midterm towards the end of Term 2: 20%
- A final exam towards the end of Term 3: 25%

Miscellaneous Policies

There will be a lot of handouts. Get a three-ring binder to keep all the handouts and problem sets organized. Assignments should be on 8 1/2 x 11 paper (and not torn out from a bound notebook), multi-page assignments should be stapled, and corrections should be erased (if done in pencil) or recopied (if done in pen) so that your work is not covered with scratchouts. Points will be removed from assignment scores when these directions are not followed.

The College's general policies on absences and late work are applicable. There was an email from the Dean on this September 8. The policies below are consistent with that email:

Whereas missed coursework affects both your classmates and professors by lowering the thinking and understanding you bring to a given class, and interrupts the course schedule that has been set up and is adjusted on an ongoing basis by me with substantial consideration. The same is true for absences — whereas a handful of absences might be “normal” at colleges with large lectures or less serious academics, at Deep Springs we expect students to miss *no classes* save for legitimate health issues or emergencies requiring also missing labor and governance obligations.

For a student wishing to submit a course assignment past its required deadline, the student may request an extension on the assignment directly from the professor 48 hours in advance. Within 48 hours of the due date, the student must request an extension directly from the Dean. Exceptions will be granted by the Dean only if the student faces unforeseen and unforeseeable circumstances. A student who misses the deadline will be penalized a number of points that is roughly equivalent to a whole letter grade for each 24-hour period the assignment is late. Assignments cannot be turned in after solutions and graded assignments have been passed back, which generally happens 1-2 classes after they were turned in.

From Galileo to Newton Daily Schedule Term 2

Course **home page**

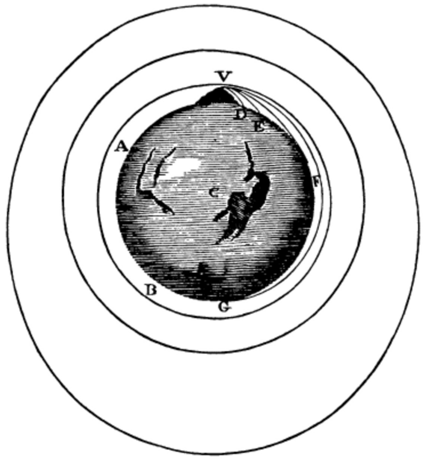
See also: **Daily Schedule Term 3**

Week 1 — Euclid's Understanding of Ratios — Galileo's Understanding of Uniform Motion

- Preparation for Tuesday, Aug. 30 — In a footnote, you will see that Galileo relies upon Book V Definition 5 of Euclid regarding proportionality. Here is an image of the **first page of Book V**. Read the first six definitions critically in tandem with reading the first three theorems. In addition to being prepared to discuss the reading, create example problems with numbers that illustrate what Galileo is saying. 2-3 problems on one page would be a good amount. I will step out and photocopy them. We will spend a bunch of class time solving a selection of each others' problems. In these problems try to avoid using $d = v\ t$. That is not how any of Euclid, Galileo, or Newton write. Instead, they write in terms of ratios. The illustrative problems you create to share with one another should therefore also be posed in terms of ratios.
- Tuesday, Aug. 30 — Euclid's Ratios — Begin Galileo's Uniform Motion — Some **Example Problems for Day 1**
- Preparation for Thursday, Sep. 1 — Do the problems you prepared for one another on Theorems I to III — We won't hand those in, but we should discuss them — Read the remaining three theorems/propositions on Uniform Motion — Ben and Brian will present Theorem IV, Mishel and Sofia Theorem V, and Luke and Declan Theorem VI — A good idea would be to begin your presentation with an illustrative example including example units and numbers
- Thursday, Sep. 1 — Conclude Galileo's Uniform Motion — Ben and Brian's **Proof of Theorem IV** (includes a summary of the first six theorems)

Week 2 — Galileo's Understanding of Uniform Acceleration — Galilean Relativity — Begin Newton

- Preparation for Monday, Sep. 5 — Read Theorem I, Theorem II, and Corollary I (through p. 175) on uniform acceleration from **the second excerpt from Two New Sciences**
- Preparation for Tuesday, Sep. 6 — Read Corollary II, Theorem III, and Theorem IV (through p. 187) on uniform acceleration from **the third excerpt from Two New Sciences** — In addition, glance ahead to get a hint of where Galileo is going, even though we are about to part ways with *The Dialogues Concerning Two New Sciences,* and especially glance at the very next theorem, Theorem V — Finally, in addition, read this excerpt from Galileo's **Dialogue Concerning the Two Chief World Systems**.
- NB/Context: *The Dialogue Concerning the Two Chief World Systems,* published in 1632 is the book that got Galileo on trial. It was banned in 1633 and not permitted to be published in Catholic countries until 1835. Galileo makes many arguments with the ultimate conclusions being that the Earth revolves daily, it is in motion around the Sun, and that the Sun and the Moon raise the tides. The specific argument we are reading is an argument for what is now known as Galilean Relativity. The idea is that you cannot detect if you are in uniform motion. This does not quite address either revolution around the Earth's axis or circular motion around the Sun, but it nonetheless goes a very long way toward explaining why we do not sense that we are hurtling through space at 67,000 miles per hour.
- We will now leave Galileo and turn to Newton, but in addition to your first Newton reading, you will have your **1st Problem Set** on Galileo due Thursday.
- Preparation for Thursday, Sep. 8 — In addition to doing the problem set on Newton, study pp. 5-19 of the Densmore edition of *The Principia.*
- Thursday, Sep. 8 — *Inherent force, aka inertia,* L. vis insita — The need for **a glossary** — Newton's Cannon (see Densmore pp. 14-15)



Week 3 — Finish Newton's Definitions — Begin Book I Section I

- Preparation for Tuesday, Sep. 13 (we begin meeting Tu/Th/Fr from 9:40-10:40) — Study pp. 20-46 of the Densmore edition
- Tuesday, Sep. 13 — **Solution to 1st Problem Set** — **2nd Problem Set** due Friday.
- Preparation for Thursday, Sep. 15 — Study pp. 47-62 of the Densmore edition (Lemmas 1 to 3)
- Preparation for Friday, Sep. 16 — Study pp. 62-71 of the Densmore edition (Lemmas 4 and 5)

Week 4 — The Lemmas (Mostly Riemann Integrals and Properties of Curves) — Continue Book I Section I

- Preparation for Tuesday, Sep. 20 — Study pp. 72-94, Lemmas 6 to 8
- Tuesday, Sep. 20 — Discussion focused on Lemmas 6 and 7, especially on the construction in Lemma 7 — **Solution to 2nd Problem Set**
- Preparation for Thursday, Sep. 22 — Study Lemma 9
- Preparation for Friday, Sep. 23 — Study Lemma 10

Week 5 — Begin Book I Section II — Wherein Kepler's 2nd and 3rd Laws Emerge as do Glimmers of Kepler's 1st Law and the Universal Theory of Gravitation

- Preparation for Tuesday, Sep. 27 — Conclude Book I Section I (Lemma 11) — Do **Problem Set 3**
- Preparation for Thursday, Sep. 29 — In Book I Section II, Study Propositions 1 and 2
- Preparation for Friday, Sep. 30 — Study Propositions 3 and 4 — For Proposition 4, Corollaries 8 and 9 are subtle and also quite distinct from the series of Corollaries 2-7, so let's not include them in this reading
- Note on Proposition 3 — This proposition is easy and intuitive. It says that if, for example, a moon (L) orbits a planet (T), and the moon by observation or assumption, appears to obey an equal area law, but we know that some other forces are causing an additional *and equal* acceleration of the moon and the planet, then this does not disturb the equal area law. Furthermore, we can conclude, just as we would if there were no additional acceleration (Newton would say no additional “accelerative force”), that the moon is under the influence of a centripetal force with the planet at its center. The one complication is *the quite important real-world situation,* which Densmore brings out on the top half of p. 149, which is that the moon and the planet actually have slightly different accelerative forces due to the Sun being a different distance and direction from them

Week 6 — Centripetal Force Laws — Complete Book I Section II

As usual, the extent of each reading is subject to adjustment.

- Preparation for Tuesday, Oct. 4 — Study the remainder of Proposition 4, and Propositions 5, 6, and 7 — For Proposition 7, it is enough to understand the idea, (because it is unclear whether we actually need the result) — The idea is that it is possible to construct a force that keeps an object on a circle that is offset from the center of force — Newton is probably concerned with the situation of circles with offset centers, which Kepler toppled, only because of its historical importance — Or maybe he doesn't want to be tried for heresy! — Do **Problem Set 4** (perhaps you will want these **Problem Set 4 Plotting Resources**)

- Tuesday, Oct. 4 — For Proposition 7, **Euclid III.36** is a non-obvious and needed prerequisite — **Problem Set 4 Solution**
- Preparation for Thursday, Oct. 6 — Proposition 9 (Spirals) and Appendix A (a property of hyperbolae and ellipses that will be needed needed for Proposition 10)
- Thursday, Oct. 6 — Discussion of Proposition 9 — A simple explanation of the result of Appendix A for ellipses (using the fact that ellipses are "squashed" circles)
- Preparation for Friday, Oct. 7 — Proposition 10 (Ellipses but with the central force coming from the center of the ellipse, not a focus)
- Friday, Oct. 7 — A **two-column proof of Proposition 10** — A summation of Book I Section II

Week 7 — Term 2 Exam — Some Biography — Begin Apollonius

- Tuesday, Oct. 11 — Term 2 Exam
- Thursday, Oct. 13 — Exchange of Letters with Leibniz (provided by Ben) — Some biographical information (by Eugenia "Gena" Gorlin, a practicing therapist at Tufts when she wrote the article and now a clinical associate professor at UT Austin — We need to at least get a flavor of Apollonius because Newton has started using results about conic sections (e.g., Book I, Proposition 22)

Are we on track? We set out to cover the central argument, pp. 5-489. Completing Book I Section II means we can start our first reading for Term 3 at p. 227. So we will have covered 223 out of the total of 485 pages in Term 2. Allowing for the fact that we had to spend quite a bit of time on Galileo, we are in good shape. On the other hand, we may need to spend quite a bit of time getting results for conic sections that Newton assumes we know from Apollonius, so we shouldn't get over-confident.

From Galileo to Newton Daily Schedule Term 3

Course **home page**

See also: **Daily Schedule Term 2**

Week 8 — Apollonius Propositions 1-3 — Begin Newton Proposition 11

- Tuesday, Oct. 25 — **Apollonius Proposition 1** — Gleick Chapters 1-3
- Thursday, Oct. 27 — Begin Newton Proposition 11 — **Apollonius Propositions 2 and 3**
- Friday, Oct. 28 — Course feedback discussion

Week 9 — Properties of Ellipses — Continue Gleick through Chapter 8

- Preparation for Tuesday, Nov. 1 — Turned in **Problem Set 5** on Properties of Ellipses — **Problem Set 5 Solution** — Gleick Chapters 4-5 — This class was cancelled due to a majority of students having COVID
- Remainder of this week's classes cancelled due to COVID — Makeup classes Nov. 19 and 20

Week 10 — Continue Newton Proposition 11

Context: With the possible exception of Proposition 1 and Proposition 6, Corollary 1, upon which Proposition 11 directly depends, Proposition 11 is probably the single most important Proposition we have encountered. It was also composed of a lot of steps, many of which used special properties of ellipses.

Why is this Proposition so important? Because Kepler has demonstrated, using Brahe's observations, that the planets go around the Sun in ellipses with the Sun at one focus, and they trace out equal areas in equal times.

We know that for an orbit of any shape, equal areas in equal times implies a centripetal force. In Proposition 11, Newton shows that for ellipses with the centripetal force originating from one focus the force obeys an inverse square law. He is going to show many more things, but with this, he could already close up shop. He has rigorously demonstrated in Proposition 11 what others have only conjectured: that the motion of the planets are caused by a centripetal force in the direction of the Sun, and that the strength of this force follows an inverse square law. Because of this Proposition's importance and difficulty, we must spend more time on it.

- Preparation for Tuesday, Nov. 8 — Write out *your own version* of Proposition 11 (organize it as it makes sense to you, clearly demarcate results needed from other sources, and clearly identify steps that are required but do not understand — don't simply regurgitate Newton or Densmore even though you are depending on both of them for a full understanding!)
- Thursday, Nov. 10 — Write out your own version of Proposition 13 (we are skipping Proposition 12)
- For Friday, Nov. 11 — Gleick through Chapter 10

Week 11 — Newton Propositions 13 to 16 — Book III: The 4 Rules of Philosophizing

More Context: Proposition 11 is for ellipses, Proposition 12 is for hyperbolas, and Proposition 13 is for parabolas. All three come to the conclusion that an inverse square law force is causing the observed motion. Parabolas are important because the very long-period comets seem to follow parabolas. Hyperbolas describe extremely rare objects that pass once through our solar system, never to return. The first ever observed was **'Oumuamua**.

- For Tuesday, Nov. 15 — **Apollonius Through Proposition 11** — Focus on what is needed to understand Newton Proposition 13
- Tuesday, Nov. 15 — Frustratingly, different translations of Apollonius have different numbering — what is referred to as Proposition 11 in the translation by Densmore and Donahue is what we already new as Proposition 1 in the **Apollonius translation by Halley**
- Problem Set 6, due in my box 9am, Thursday, Nov. 17 — Your write-up of Proposition 13: clearly delineate steps that you understand, what you must take on faith from other sources but nonetheless clearly understand the consequences of, and what you do not understand

- Preparation for Thursday Nov. 17 — Press on to Newton Propositions 14, 15, and 16
- Preparation for Friday, Nov. 18 — Skip Densmore's terse summary of Book II (we will return to it as needed and as she refers to it) — Read the 4 Rules of Philosophizing at the opening of Book III — Read **Barnard Chapter 1** (provided by Luke)

Week 12 — The Modern Treatment of Elliptical Orbits — Finish Book I — Book III: Begin The Phenomena

- Saturday, Nov. 19 — The modern calculus-based treatment of elliptical orbits in polar (r, θ) coordinates
- Sunday, Nov. 20 — Finish Book I (through Proposition 17)
- Preparation for Tuesday, Nov. 22 — Phenomena 1 (the moons of Jupiter) and 2 (the moons of Saturn) — Problem Set 7: choose an additional selection of moons of Jupiter and moons of Saturn, and extend Newton's tables in Phenomena 1 and 2
- Tuesday, Nov. 22 — Discussed Phenomena 1 to 5 (including retrograde motion, Luke's Desmos epicycle demonstration, and a Ptolemaic model animation on YouTube)

Week 13 — Book III: The Phenomena (Continued)

Compressed schedule this week due to Friday all-hands preg check

- Monday, Nov. 28 — Cover Propositions 3 and 4 on the orbit of the Moon (including the scholium to Proposition 4)
- Preparation for Philosophy Tuesday, Nov. 29 — Read the preface to the Principia and the last scholium (you will find them on pp. 3-4 and pp. 485-489 of Densmore) — Read the second chapter of **Barnard**
- Preparation for Thursday, Dec. 1 — **Problem Set 8** on planetary motion (including the addition of Problem 3, handed out on Tuesday, on lunar acceleration) — For Thursday's reading, begin with Proposition 5 on p. 380, but after p. 387, skip pp. 388-401, which is a brilliant and challenging discussion of objects on pendula, and after skipping that, tackle pp. 402-421

Week 14 — The Remainder of Book III (pp. 422-484) — The Shell Theorem and Its Consequences

And when is Newton going to explain to us the origin of Ocean Tides!?! Is there only the brief comment in III.5 Corollary 3 (Densmore p. 385): hence, "the sun and moon perturb our sea," as will be explained? If there is no more on the tides in our reading, I will make a problem for you.

- Preparation for Tuesday, Dec. 6 — pp. 422-449, The Shell Theorem
- Preparation for Thursday, Dec. 8 — pp. 450-459, Propositions following The Shell Theorem
- Friday, Dec. 9 — The final few Propositions and Corollaries, pp. 459-484 and also return to the pendulum material that we skipped, pp. 388-401 — **Problem Set 9** on The 2-D Shell Theorem (I can call that "The Ring Theorem"), and on Ocean Tides — **Problem Set 9 Solution**

Week 15

Thursday's class moved to Monday because Monday was regarded by most people as best for an exam

- Monday, Dec. 12 — **Term 3 Exam** — **Term 3 Exam Solution**
- Tuesday, Dec. 13 — We will discuss Kuhn's essay, "Mathematical versus Experimental Traditions in the Development of Physical Science"
- Bonus class, Thursday, Dec. 15th — As we did on Saturday, Nov. 19th, we will see how Newton's results are obtained with calculus — On Nov. 19th, we used polar coordinates and differential equations to show that ellipses are a solution of Newton's laws — For this class, we will set up and do the triple integral that proves the Shell Theorem (the azimuthal and radial integrals are straightforward, which leaves us a potentially-tricky integration over the polar angle)