Physics II: Mechanics

Summerfield Waldorf School and Farm

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Syllabus

This is a hands-on block, in which we will explore the phenomena of motion and gravity. We will learn about the roots, philosophy, assumptions, successes, failures and challenges of the modern scientific worldview as it took shape in the 17th and 18th centuries. This was a remarkable period in the history of science, when for the first and only time, a few individuals successfully challenged the core orthodoxies of long-established authorities with new, mathematically-defensible ideas about the true nature of the heavens and earth. We will study the lives and works of several great thinkers, in particular Galileo Galilei and Isaac Newton.

Class Guidelines

In order of priority:

1. Safety first.
2. Do your best.
3. Have fun.

Lab Safety

The first guideline is Safety First! Because there may be dangerous equipment or chemicals in use, it is particularly important in science classes to follow safety guidelines as well as good common sense. During the first week of class, we will review lab safety guidelines. Students must read, sign and return the Lab Safety Agreement. A parent signature is also required.

Class Participation and Group Work

This class requires your proactive participation. Successful participation includes:

1. Arriving on-time and prepared for class
2. Proactively supporting a positive learning environment, such as by keeping the classroom clean, safely handling lab equipment, avoiding side-conversations and other distractions, working collaboratively in groups, helping other students when possible.
3. Participating thoughtfully in class discussions by contributing your observations, questions and ideas.

Typical Assignments

1. Journal
2. Lab Reports
3. Projects and Presentations
4. Main lesson Book
5. Quizzes

Journal

You will keep a journal using the Cornel Notes format to record class notes, observations, ideas, sketches, questions, etc. All entries should be dated. Depending on how your journal is bound, it can be turned in separately or as part of your Main Lesson Book.

1. During class, write notes in your journal (using Cornel Notes style when possible). Include important information, sketches of demonstrations, and your own observations, ideas, conclusions and questions.
2. Each evening, review your journal for accuracy and completeness. Add new ideas and questions. Be prepared the next morning to show your notes, and to share your thoughts during class discussion.

Main Lesson Book

You will be given a Duotang folder to organize all main lesson book content. Your completed main lesson book folder should include:

1. Table of Contents
2. All main lesson book pages
3. All lab reports
4. All journal entries (if not bound separately)
5. All other written assignments, such as math worksheets and quizzes

Main Lesson Book Page Requirements

- **Paper:** Use 8.5 x 11 inch, white, bond or better paper; plain, lined or gridded as appropriate for your content. No torn edges.
- **Length:** Minimum one page.
- **Title:** Add a short, one-line title at the top of the page. You can use the title suggested in class, or create one of your own that is relevant to the page content.
- **Text:** Minimum one paragraph; most topics require more than one paragraph. Handwritten or word processed. Summarize observations from demonstrations, labs, discussions, assigned readings, and your own independent research. Add a conclusion and any follow-up questions. Use clear, scientific writing, with accurate terms, definitions and equations. Handwriting must be dark enough to be clearly legible.
- **Mathematics:** Whenever appropriate, include related mathematical variables, equations, formulas, etc.
- **Graphics and Diagrams:** One or more diagrams are required. Illustrate related demonstrations and labs. Always add labels to diagrams. Always use a straight edge to draw lines that are meant to be perfectly straight. Create a legend if there is not enough space in the diagram for longer labels.
- **Data:** Whenever appropriate, include related data in tabular and/or graphic format.
- **Margins:** Use one inch margins. Margins and borders DO NOT need to be colored.
- **Layout:** You can paste printouts (of graphics, data, photos, etc.) onto the main page. Do not use tape.
- **Binding:** Three-hole punched and bound into your Main Lesson Book binder in chronological order.

Main Lesson Book Table of Contents

Make a list of the contents of your Main Lesson Book in chronological order (i.e., by due date). You do not need to add your notes pages to the table of contents, but notes should be bound along with the topics to which they refer. You DO NOT need to add page numbers to the table of contents.

Demonstrations

Demonstrations are in-class, teacher-led presentations of a specific topic. Most demonstrations are planned in advance. However, depending on weather conditions, interesting questions raised during discussions, or other unforeseen events, alternate demonstrations may be attempted at any time. All demonstrations—including those created in the moment–are of equal importance, and must be carefully observed. During demonstrations, students carefully observe the process. In followup discussions, students share their thoughts and add notes to their journal. The information gathered during demonstrations is an important part of a complete main lesson book page. As always in the science lab, safety first.

Labs

During labs, students work together in small groups to complete assignments. As always, safety first. Most Labs follow a three-day cycle.

1. **Day 1:**
   - **Classwork:** Goals and procedures are explained. Student will work on Labs to collect data, take notes and discuss their observations.
   - **Homework:** Students will review their journal entries, tabulate data, and note new ideas or questions.
2. **Day 2:**
   - **Classwork:** In-class discussion of previous day's observations, development of scientifically verifiable conclusions, and suggestions for further questions.
   - **Homework:** Students write the Lab Report, and add it to their Main Lesson Book.
3. **Day 3:**
   - Main Lesson Book pages are due at the start of class.

Lab Report Content Requirements

Lab Reports include the following sections:

1. **Purpose:** A brief statement explaining the purpose of the research.
2. **Materials:** A list of materials needed to perform the research. When applicable, include appropriate quantities and units. *(Note: If the instruction sheet contains a detailed Equipment and Materials section, you do not need to rewrite them again. Simply reference the instruction sheet with, "See Instruction Sheet", and include it with your report.)*
3. **Procedures:** An accurate description of the procedures. Write this so that a knowledgeable researcher in another part of the world will have enough information to duplicate and verify your results.
4. **Observations:** A description of the results using clear and scientific language. **Never alter actual observations to match expectations!**
5. **Diagrams:** One or more illustrations supporting your observations and conclusions. Always label diagrams. Add a legend if there is not enough space in the diagram for longer labels.
6. **Data:** When applicable, include relevant data in tabular and/or graph form.
7. **Conclusion:** A concise and accurate description of your conclusions. Only add information that is scientifically supported (observable, measurable, repeatable) by your observations. In some case, such as when your research is inconclusive, you might list concerns with the research process, or propose follow up questions that might help lead to more useful conclusions.
8. **References:** A list of citations for all quotations taken from other sources.

Lab Report Format

1. One to four pages; 8.5 x 11 inches; 1 inch borders
2. Underline headings.
3. Either handwritten or word processed.
4. If word processed, use 11 or 12 PT type, and 1.5em line leading.
5. You are responsible to print your report *before* it is due. (Do not rush the high school office just before the start of class.)

Math Worksheets

Math worksheets provide practice in thinking through scientific principles and in converting observable patterns into the language of mathematics. If you are unable to solve a problem, show the steps as far as you were able to calculate, and write a short note explaining why you got stuck. Complete solutions must include the following:

1. Original equations, formulas and variables
2. Each algebraic step (lined up vertically on the equality sign)
3. Your solution (including units if applicable)

Bridge Building Project

You will design and build a carefully-constructed model of a truss bridge using balsam wood. Your goal is to build a bridge capable of carrying a specific target load without collapsing. The bridges will be load-tested during the last week of class. Increasing amounts of weight will be suspended from each bridge up to and perhaps beyond it's stated load carrying capacity. There are several award categories:

1. All bridges capable of securely carrying their maximum rated load without collapsing.
2. The bridge with the greatest "carrying capacity"/"mass of materials" ratio.

3. The most beautiful bridge design.
4. The most creative bridge design.

Homework

Homework is due as soon as class starts. It is typically assigned from Mondays through Thursdays. Homework should not take more than one hour/day. New homework will usually NOT be assigned over the weekend, but these are excellent opportunities to catch up on missing work, review for quizzes, or prepare group presentations. Daily homework should include some or all of the following:

1. Reading assignments covering the current topic
2. Review the day's journal entries, and add additional details, thoughts and questions
3. Work on main lesson book pages and lab reports
4. Prepare projects and group presentations
5. Study for quizzes
6. Complete any late or missing assignments

Additional Research

Expanding your understanding through the use of other resources, such as libraries, the Internet, or knowledgeable people in your community, is encouraged. Whenever possible cite your sources.

Citing Sources

1. Include essential source information, such as author, publication, and page number.
2. If you are citing an online source, include the full URL and the date you viewed it. Example:

- https://en.wikipedia.org/wiki/Physics (Accessed: 2023-05-12)

Plagiarism

Do not copy, partially copy, or paraphrase from other sources without adding quotation marks and a matching citation.

There is a fine line between studying with other students *(highly encouraged)* and blindly copying *(highly discouraged)*. The essential difference is whether or not you understand the topic well enough to rephrase it in your own words. If you copy another student's work, but fail to demonstrate a clear understand what you wrote, you may be accused of plagiarism.

Quizzes

1. Frequent (almost daily) short quizzes will check for understanding of the previous day's topics.
2. Weekly quizzes (typically 10 to 25 questions) will test your recall of a wider range of topics.

Some quizzes may be "open notes", in which case you can use your own journal. Such quizzes can be more difficult because they may require a deeper understanding of the topic.

There will most likely not be a final block test. This has two major implications:

1. Every quiz counts, but no one quiz counts too much.
2. You must keep up with the class every day. There is no way to cram in the last week to pass this class.

Grading Policy

Most assignments are graded. Class participation, classwork, homework, lab reports, journal entries, quizzes, projects and presentations all contribute to the final grade. Late work scores are usually reduced about 10%. Work more than a week late is not accepted. Exceptions can be made if arranged in advance. Missing work counts as a F, Several missing assignments can greatly impact the final grade.

Required Student Materials

1. 8.5 x 11, 3-hole punched notepaper
2. A few #2 graphite pencils
3. A few colored pencils (helpful for making diagrams)
4. Eraser
5. Personal scientific calculator (optional)

Grade	%
A+	≥ 98
A	≥ 94
A-	≥ 90
B+	≥ 88
B	≥ 84
B-	≥ 80
C+	≥ 78
C	≥ 74
C-	≥ 70
D+	≥ 68
D	≥ 64
D-	≥ 60
F	< 60

School Supplied Materials

1. All laboratory and safety equipment
2. Ruler, protractor and compass
3. Scientific calculator
4. Duotang folder (for organizing your main lesson book pages)
5. Class Reader (Will be assigned on the first day of class, and must be returned by the last day.)

Contacting the Teacher

- **Email:** ron@summerfieldwaldorf.org
- **Meeting:** Most school days between 10:30 am and 12:30 pm. Other times by appointment.

Physics Laboratory Safety Guidelines

Physics is a hands-on laboratory class. You will be doing laboratory activities which require the use of potentially hazardous equipment. Both the physics and chemistry classes share the laboratory, and some equipment. Safety in the science classroom is the number one priority for students, teachers, and parents.

To ensure a safe science classroom and laboratory, a list of rules has been developed and provided to you in this student safety contract. These laboratory safety rules must be followed at all times. Both you and your parent or guardian must submit a signed laboratory safety contract before you can participate in laboratory experiments, demonstrations, and other activities.

General Rules

1. Conduct yourself in a responsible manner at all times in the laboratory.
2. Follow all written and verbal instructions carefully. If you do not understand a direction or part of a procedure, ask the instructor before proceeding.
3. Never work alone. No student may work in the laboratory without an instructor present.
4. When first entering a science room, do not touch any equipment, chemicals, or other materials in the laboratory area until you are instructed to do so.
5. Do not use laboratory glassware as containers for food or beverages.
6. Perform only those experiments authorized by the instructor. Never do anything in the laboratory that is not called for in the laboratory procedures or by your instructor. Carefully follow all instructions, both written and oral. Unauthorized experiments are prohibited.
7. Be prepared for your work in the laboratory. Read all procedures thoroughly before beginning.
8. Never fool around in the laboratory. Horseplay, practical jokes, and pranks can be dangerous.
9. Observe good housekeeping practices. Work areas should be kept clean and tidy at all times. Bring only your laboratory instructions, worksheets, and/or reports to the work area. Other materials (books, purses, backpacks, etc.) should be stored in the classroom area.
10. Keep aisles clear. Push your stool under the counter when not in use.
11. Know the locations and operating procedures, where appropriate, for all safety equipment including first aid kit, eyewash station, safety shower, fire extinguisher, and fire blanket. Know where the fire alarm and exits are located.
12. Always work in a well-ventilated area. Use the fume hood when working with volatile substances or poisonous vapors. Never place your head into the fume hood.
13. Be alert and proceed with caution at all times in the laboratory. Notify the instructor immediately of any unsafe conditions you observe.
14. Dispose of all chemical waste properly. Never mix chemicals in sink drains. Sinks are to be used only for water and those solutions designated by the instructor. Solid chemicals, metals, matches, filter paper, and all other insoluble materials are to be disposed of in the proper waste containers, not in the sink. Check the label of all waste containers twice before adding your chemical waste to the container.
15. Labels and equipment instructions must be read carefully before use. Set up and use the prescribed apparatus as directed in the laboratory instructions or by your instructor.
16. Keep hands away from face, eyes, mouth and body while using chemicals or preserved specimens. Wash your hands with soap and water after performing all experiments. Clean all work surfaces and apparatus at the end of the experiment. Return all equipment clean and in working order to the proper storage area.

17. Experiments must be personally monitored at all times. You will be assigned a laboratory station at which to work. Do not wander around the room, distract other students, or interfere with the laboratory experiments of others.
18. Students are never permitted in the science storage rooms or preparation areas unless given specific permission by their instructor.
19. Know what to do if there is a fire drill or alarm during a laboratory period; containers must be closed, gas valves turned off, fume hoods turned off, and any electrical equipment turned off.
20. Handle all living organisms used in a laboratory activity in a humane manner. Preserved biological materials are to be treated with respect and disposed of properly.
21. When using knives and other sharp instruments, always carry with tips and points pointing down and away. Always cut away from your body. Never try to catch falling sharp instruments. Grasp sharp instruments only by the handles.
22. If you have a medical condition (e.g., allergies, pregnancy, etc.), check with your physician prior to working in lab.

Protective Clothing and Equipment

23. Any time chemicals, heat, or glassware are used, students will wear laboratory goggles. There will be no exceptions to this rule.
24. Contact lenses may be worn provided adequate face and eye protection is provided by specially marked, non-vented safety goggles. The instructor should know which students are wearing contact lenses in the event of eye exposure to hazardous chemicals.
25. Dress properly for lab activities. Long hair, dangling jewelry, and loose or baggy clothing are hazardous. Long hair must be tied back and dangling jewelry and loose or baggy clothing must be secured. Shoes must completely cover the foot. No sandals allowed.
26. Lab aprons will be provided for your use if needed, and should be worn during such laboratory activities.

Accidents and Injuries

27. Report any accident (spill, breakage, etc.) or injury (cut, burn, etc.) to the instructor immediately, no matter how trivial it may appear.
28. If you or your lab partners are hurt, immediately yell out to get the instructor's attention.
29. If a chemical splashes in your eye(s) or on your skin, immediately flush with running water from the eyewash station or safety shower for at least 20 minutes. Chemically contaminated clothing and contact lenses must be removed during the flushing process. Notify the instructor immediately.
30. We do not use mercury thermometers, however, if a mercury thermometers is brought in and broken, the mercury must not be touched. Notify the instructor immediately so that the mercury can be properly disposed.

Handling Chemicals

31. All chemicals in the laboratory are to be considered dangerous. Do not touch, taste, or smell any chemicals unless specifically instructed to do so. The proper technique for wafting chemical vapors will be demonstrated to you. Never stick your nose into a container to smell a chemical.
32. Check the label on chemical bottles twice before removing any of the contents. Take only as much chemical as you need.

33. Never return unused chemicals to their original containers.
34. Never use mouth suction to fill a pipet. Use a rubber bulb or pipet pump.
35. When transferring reagents from one container to another, hold the containers away from your body.
36. Acids must be handled with extreme care. You will be shown the proper method for diluting strong acids. Always add acid to water, swirl or stir the solution and be careful of the heat produced, particularly with sulfuric acid. Never add water to concentrated acids.
37. Know where the fire pan is located. Handle flammable hazardous liquids over a pan to contain spills. Never dispense or work with flammable liquids anywhere near an open flame or source of heat.
38. Never remove chemicals or other materials from the laboratory area.
39. Take great care when transporting acids and other chemicals from one part of the laboratory to another. Hold them securely and walk carefully.

Proper Handling of Glassware and Lab Equipment

40. Carry glass tubing, especially long pieces, in a vertical position to minimize the likelihood of breakage and injury.
41. Never handle broken glass with your bare hands. Use a brush and dustpan to clean up broken glass. Place broken or waste glassware in the designated glass disposal container. Never place broken glass in the normal garbage can.
42. Inserting and removing glass tubing from rubber stoppers can be dangerous. Always lubricate glassware (tubing, thistle tubes, thermometers, etc.) before attempting to insert it in a stopper. Always protect your hands with towels or cotton gloves when inserting glass tubing into, or removing it from, a rubber stopper. If a piece of glassware becomes “frozen” in a stopper, take it to your instructor for removal.
43. Fill wash bottles only with distilled water and use only as intended, e.g., rinsing glassware and equipment, or adding water to a container.
44. When removing an electrical plug from its socket, grasp the plug, not the electrical cord. Hands must be completely dry before touching an electrical switch, plug, or outlet.
45. Examine glassware carefully before each use. Never use chipped or cracked glassware. Never use dirty glassware.
46. Report damaged electrical equipment immediately. Look for things such as frayed cords, exposed wires, and loose connections. Do not use damaged electrical equipment.
47. If you do not understand how to use a piece of equipment, ask the instructor for help before attempting to use it.
48. Do not immerse hot glassware in cold water; it may shatter.

Heating Substances

49. Exercise extreme caution when using a gas burner. Take care that hair, clothing and hands are a safe distance from the flame at all times. Do not put any substance into the flame unless specifically instructed to do so. Never reach over an exposed flame. Light gas (or alcohol) burners only as instructed by the teacher.
50. Never leave a lit burner unattended. Never leave anything that is being heated or is visibly reacting unattended. Always turn the burner or hot plate off when not in use.
51. You will be instructed in the proper method of heating and boiling liquids in test tubes. Do not point the open end of a test tube being heated at yourself or anyone else.
52. Heated metals, glass, and ceramic remain very hot for a long time. If in doubt, always treat

metal, glassware, and ceramic as if it is hot. They should be set aside to cool and picked up with caution. Use tongs or heat-protective gloves if necessary.

53. Never look into a container that is being heated.
54. Do not place hot apparatus directly on the laboratory desktop. Always use an insulating pad or tile square. Allow plenty of time for a hot apparatus to cool before touching it.
55. When bending glass, allow time for the glass to cool before further handling. Hot and cold glass has the same visual appearance. Determine if an object is hot by bringing the back of your hand close to it prior to grasping it.

Health Information

56. Many experiments involve the use of foods and other consumer items. Students must make the teacher aware of any allergies prior to experiments to help avoid possible allergic reactions. These allergies should be listed on the signed laboratory contract that is handed into the teacher.
57. Female students must inform the teacher if they have become pregnant before participating in laboratory experiments. Pregnant women and their developing child can be more sensitive to or at a greater risk of complication when exposed to certain chemicals. This information will remain confidential.

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Student Materials and Safety Agreement

I understand that all assigned school materials must be returned in good condition or purchased before my final grade report will be released. If I am unable to return the Class Reader, I agree to pay Summerfield Waldorf School and Farm $10.00 toward its replacement.

I have read and understand all the rules listed in the Physics Laboratory Safety Guidelines, and agree to abide by them at all times when I am in the Physics Laboratory.

	Printed	**Signature**	**Date**
Student			
Parent or Guardian			

Chapter 1

Inertia

Inertia

Inertia is one of the primary manifestations of *mass*, which is a *quantitative property of physical systems.* Inertia is the idea that an object will continue its current motion until some force causes its speed or direction to change. One aspect of this property is the tendency of objects to keep moving in a straight line at a constant speed when no forces act upon them.

The principle of inertia is one of the fundamental principles in classical (Newtonian) physics. It is still used today to describe the motion of most everyday objects. The term inertia comes from the Latin word *iners*, meaning idle, sluggish.

History of the Idea

The first recorded description of inertia is in the Mozi, an Chinese text from the Warring States period (475 - 221 BCE). Their insight was used by the Chinese to develop many of the earliest inventions, such as the water wheel.

It's worth looking back to realize just how difficult it was for humans to understand inertia. On the surface of the Earth, the inertia property of physical objects is usually masked by gravity and the effects of friction and air resistance, both of which tend to decrease the speed of moving objects, often to the point of rest. This fooled many, including the great Aristotle into imagining that the natural state of all objects was to be at rest.

Aristotle (335 BCE to 322 BCE) believed that objects would move only as long as force was applied to them. He said that all moving objects (on Earth) eventually come to rest unless an external power (or force) continued to move them. He explained the continued motion of projectiles through space as a (yet unexplained) action of the surrounding medium which continued to move the projectile. In other words, Aristotle thought that air somehow pushed arrows through flight.

This view was challenged during the Islamic Golden Age (8th century to 13th century). In the 11th century, Persian polymath Ibn Sina (Avicenna) claimed that a projectile in a vacuum would not stop unless acted upon.

It was not until Galileo, Copernicus, Kepler and Newton during the dawn of the European Renaissance that Westerners began to accept a non-Aristotelian view of inertia. These intellectual giants risked their lives to overturn centuries of church-enforced dogma.

The term "inertia" was first introduced by Johannes Kepler in his *Epitome Astronomiae Copernicanae* (published in three parts from 1617 to 1621); however, the meaning of Kepler's term was not quite what we understand today. Kepler defined inertia only in terms of resistance to movement, once again based on the presumption that rest was a natural state which did not need explanation. It was not until Galileo and Newton unified rest and motion in one principle that the modern idea "inertia" could be understood.

> *”A body moving on a level surface will continue in the same direction at a constant speed unless disturbed.”*
>
> \- Galileo

Concepts of inertia in Galileo's writings would later be refined by Newton as the first of his Three Laws of Motion.

Despite having defined the concept so elegantly, Newton still did not understand "inertia" as we do today. He viewed the phenomenon as being caused by "innate forces" inherent in matter. Given this perspective, and borrowing from Kepler, Newton attributed the term "inertia" to mean "the innate force possessed by an object which resists changes in motion", thus, Newton defined "inertia" to mean the cause of the phenomenon, rather than the phenomenon itself.

The idea of "innate resistive force" was problematic for modern physicists, and most no longer think in these terms. As no alternate mechanism has ever been agreed upon, and it is generally thought that there may not be one that we are capably of knowing, the term "inertia" has come to mean simply the phenomenon itself, rather than any inherent mechanism of matter. Thus, "inertia" in modern classical physics is the name for the same phenomenon described by Newton's First Law of Motion, and the two concepts are now treated as equivalent.

> *"Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon."*
>
> - Isaac Newton

Rotational inertia

A quantity related to inertia is *rotational inertia*, the property that a rotating rigid body maintains its state of uniform rotational motion. Its angular momentum remains unchanged unless an external torque is applied; this is called *conservation of angular momentum.* For example, a gyroscope uses this property to resist any change in the axis of rotation.

Galileo's Motion In Time Experiment

While under house arrest for daring to challenge the dominant world view as understood by the Roman Catholic Church, Galileo wrote down a description of his inclined plane experiment that had led him to his "radical" views. In Galileo's own words:

> *"In a wooden beam or rafter about twelve *braccia* (yards) long, half a *braccia* wide, and three inches thick, a channel was rabbeted in along the narrowest dimension, a little over an inch wide, and made very straight; so that this would be clean and smooth, there was glued within it a piece of vellum, as much smoothed and cleaned as possible. In this there was made to descend a very hard bronze ball, well rounded and polished, the beam having been tilted by elevating one end of it above the horizontal plane from one to two *braccia*, at will. As I said, the ball was allowed to descend along the said groove, and we noted (in the manner I shall presently tell you) the time that it consumed in running all the way, repeating the process many times, in order to be quite sure as to the amount of time, in which we never found a difference of even the tenth part of a pulse-beat."*

Centrifugal Force and Conservation of Angular Momentum

Question: Why does water swirl down the drain?

You might have heard that is caused by the Coriolis effect. However, the Coriolis effect (an apparent force resulting from the Earth's spin) has virtually nothing to do with water swirling down a drain.

The Coriolis Effect is very large and very slow. It has a noticeable effect only on long-lasting motions and very large masses, such as major oceans and large atmospheric phenomena. The Coriolis force is too weak to have any effect on short-lived phenomenon in small basins of water under normal conditions.

Experiment

1. Fill a sink with water. Although it isn't essential, the rounder the sink, the more obvious the effect.
2. Keeping the drain closed, stir the water around in one direction. To make the water's motion more visible, float a few small objects in it.
3. Wait until the water is barely moving, open the drain, and watch the action.
4. Repeat the process, now at first stirring in the opposite direction.

Other Examples of the Same Effect

1. An ice skater spinning slowly with arms and leg extended begins to spin faster while pulling arms and leg in closer to the body.
2. Tornados and hurricanes—The air gets pushed toward the low-pressure region at the center, causing its circulation to speed up.
3. Tetherball—As the ball goes around, the rope winds around the pole, pulling the ball closer, which causes the ball to speed up.
4. Gymnast or diver doing a flip—After divers jump off diving boards, they tuck their bodies into a ball to increase the speed of rotation. Then they extend the body to slow down the rotation for the final plunge. Comet—As a comet orbits the Sun, its orbit is elongated, so it sometimes gets closer to the sun and sometimes farther away. As it gets closer, it speeds up; farther from the Sun, it slows down.

Explanation

Although it might be too slow to notice, the water already has some random motion before opening the drain. As the water moves toward the drain, its rotational motion is amplified, i.e., it starts swirling faster. The change in speed has to do with angular momentum, which is the product of three quantities:

1. the mass of the object
2. the radius of the object
3. the speed of the speed

$$\textit{Angular Momentum } = \textit{mass (kg)} \times \textit{radius (m)} \times \textit{speed (sec)}$$

Conservation of Angular Momentum

If there's no outside force pushing or pulling on a spinning object, the angular momentum stays the same and the "force is conserved". This is known as the Conservation of Angular Momentum.

If the angular momentum is conserved (stays the same), then the product of mass × size × speed must also stay the same. When the radius of spinning object becomes smaller, the total mass has not changed, and the size is reduced. Therefore the speed must increase.

In a simplified example ignoring units for now, When a spinning skater pulls in their arms so that the radius decreases from 6 to 3, the product of all three quantities must remain 48. When the radius was divided by 2 (from 6 to 3), the speed was multiplied by 2.

$$\begin{aligned} \textit{Angular momentum} &= \textit{mass} \times \textit{radius} \times \textit{speed} && (1.1) \\ 48 &= 4 \times 6 \times 2 && (1.2) \\ 48 &= 4 \times 3 \times 4 && (1.3) \end{aligned}$$

In general, if the size decreases by some factor, the speed increases by that same factor. The opposite is also true: If the size increases by some factor, the speed decreases by that same factor.

Scientific Philosophy and Methods

The Scientific Method

The modern scientific method began with a revolution in the thought of the Early Greeks, was refined during the Arabic Golden Age, and began to evolve into its current form during the European Renaissance.

There are many definitions for the scientific method, but they all have certain traits in common. Although the method can be corrupted in humanity's typical ways, no better method for *empirically* learning about reality has been found. The scientific method—for better or worse—seems inseparable from *scientific progress.*

Thales of Miletus

Like so many of our modern ideas, it all seems to have begun in ancient Greece. Around 620 BCE, the Greek philosopher Thales was born in Miletus in Greek Ionia (on the west coast of what is now known as Turkey). Aristotle identified him as the first person to investigate the *basic principles*, the question of the originating substances of matter and, therefore, as the founder of the school of Natural Philosophy—or what we not call science.

Thales was interested in almost everything, and investigated most areas of knowledge, philosophy, history, science, mathematics, engineering, geography, and politics. He proposed theories to explain many of the events of nature, the *primary substance*, the support of the earth, and the *cause of change.*

Thales was much involved in the problems of astronomy and provided a number of explanations of cosmological events which had traditionally been beleived to involve supernatural (*outside of nature*) beings. His questioning approach to the understanding of heavenly phenomena was the beginning of Greek astronomy, and its gradual separation from the self-referential myths of Astrology.

Thales' hypotheses were new and bold, and in freeing phenomena from ideas of godly intervention, he paved the way towards what we think of as science. He founded the Milesian school of natural philosophy, developed an early version of the scientific method, and initiated the first Western Enlightenment. A number of anecdotes are closely connected to Thales' investigations of the cosmos. When considered in association with his hypotheses they take on added meaning.

Thales Quotations

Perspective matters:
"The past is certain, the future obscure."

"We live not, in reality, on the summit of a solid earth
but at the bottom of an ocean of air."

Using geometry to understand the world:
"Placing your stick at the end of the shadow of the pyramid,
you made by the sun's rays two triangles,
and so proved that the pyramid [height] was to the stick [height]
as the shadow of the pyramid to the shadow of the stick."

Evidence that the earth is a sphere:
"From the shore, a ship can be seen to be descending, gradually, below the horizon, with the hull disappearing from view first, to be followed by masts and sails. If one had a companion observing from a higher point, the companion would see the ship for a long period before it disappeared from view."

Summing it all up (pun intended):
"What is it that is most beautiful?
The Universe; for it is the work of God.
What is most powerful?
Necessity; because it triumphs over all things.
What is most difficult?
To know one's self.
What is most easy?
To give advice.
What method must we take to lead a good life?
To do nothing we would condemn in others.
What is necessary to happiness?
A sound body and a contented mind."

Aristotle and the Early Greeks

The earliest examples of what we think of as the scientific method were found in Ancient Egyptian manuscripts. Aristotle further developed the ideas of Thales and other ancient sources by defining the inductive and deductive methods of reasoning.

Induction	making a general rule based on a set of observations
Deduction	predicting a set of observations based on a general rule

However, although induction is mainly what's used by scientists today, Aristotle mostly ignored it as a method for scientific inquiry.

Ibn al-Haytham and the Islamic Golden Age

The origins of the modern scientific method began in the Islamic World. Little is known about Ibn al-Haytham's life, but historians believe he was born around the year 965 CE, during the Golden Age of Arabic science. His father was a civil servant, so the young Ibn al-Haytham received an excellent education, which may have inspired his passion for science. He was also a devout Muslim, believing that an endless quest for truth about the natural world brought him closer to God. At some point, he moved to Cairo in Egypt to study in the great "House of Wisdom", and it was here that he completed his most influential works.

The prevailing wisdom at the time was that we saw what our eyes illuminated before us. Supported by revered thinkers such as Euclid and Ptolemy, "emission theory" stated that sight worked because our eyes emitted rays of light—like flashlights. This didn't make sense to Ibn al-Haytham. If light comes from our eyes, why, he wondered, is it painful to look at the sun? This simple realization catapulted him into researching the behavior and properties of light and optics.

In 1011, Ibn al-Haytham was placed under house arrest by a powerful caliph. The seclusion was just what he needed to explore the nature of light. Over the next decade, Ibn al-Haytham proved

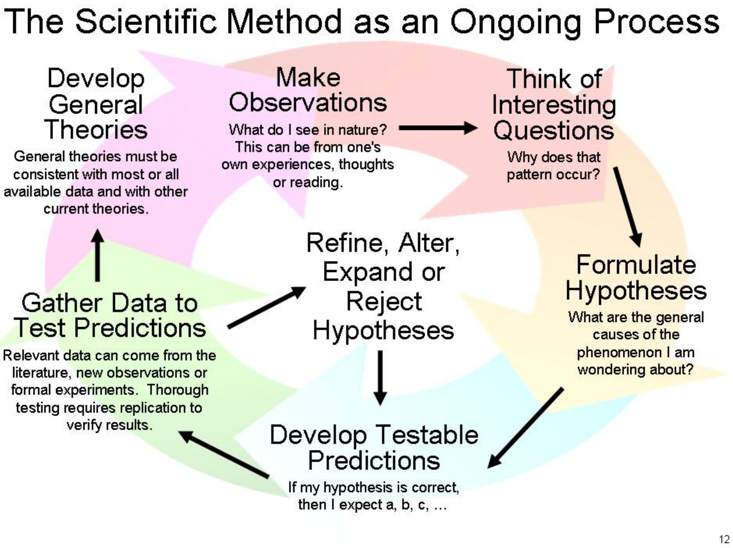

Figure 1.1: A Model of the Scientific Method

that light only travels in straight lines, explained how mirrors work, and argued that light rays can bend when moving through different mediums, such as from air to water.

The Invention of ”Peer Review” and Skeptical Thinking

Ibn al-Haytham wasn't satisfied with developing these theories only to himself; he wanted others to see what he had done. The years of solitary work culminated in his *Book of Optics*, which expounded just as much upon his methods as it did his actual ideas. Anyone who read the book would have instructions on how to repeat every single one of Ibn al-Haytham's experiments.

Ibn al-Haytham was also a progenitor of *critical thinking* and *skepticism.*

> *”The duty of the those who investigate the writings of scientists, if learning the truth is their goal, is to make themselves an enemy of all that they reads, and... attack it from every side... He should also suspect himself as he performs his critical examination of it, so that he may avoid falling into either prejudice or leniency.”*

Sir Francis Bacon and the European Renaissance

In 1620, around the time that people first began to look through microscopes, the English politician Sir Francis Bacon developed a method for philosophers to use in weighing the truthfulness of knowledge. While Bacon agreed with medieval thinkers that humans too often erred in interpreting what their five senses perceived, he believed that people's sensory experiences provided the best possible method for making sense of the world. In other words, he advocated direct experience of the world over Holy Scriptures and philosophical traditions. However, because humans can easily misinterpret what they sense, Bacon insisted that we must doubt each idea, and test carefully before assuming it is true.

Bacon became the most influential proponent for the scientific method at an important time in European history. He debated those who believed dogmatically in Aristotle's method, or who clung blindly to inherited religious traditions. Instead, he advocating repeated experimentation to arrive at observable prove for an idea. Because this is a good description of the scientific method most often used today, Francis Bacon is called the "father of empiricism."

Testing Hypotheses

In order to test for truth, Bacon devised a method in which scientists set up experiments to try to *prove their hypotheses wrong.* For example, in order to test the idea that sickness came from external causes (and not of the Four Humors as Aristotle had taught), Bacon stated that scientists should expose healthy people to outside influences, such as coldness, wetness, or other sick people to discover if any of these external variables resulted in more sick people.

Knowing that many different causes for sickness might be missed by those who are unable or unwilling to perceive them, Bacon insisted that such experiments must be *consistently repeated* before truth could be known.

Although modern scientists have revised many of the truths adopted by Bacon and his contemporaries, we still use Bacon's 1620 method of proving ideas to be true or false through *doubt* and *experimentation.*

The Royal Society

In his work as a politician, Bacon called for the development of an institution that would promote and regulate the acquisition of knowledge derived from observation. After considerable delay caused by a civil war and the execution of King Charles I, the *Royal Society for Improving Natural Knowledge* was founded in 1660 This "gentleman's club" composed of tinkering aristocrats, promoted Bacon's principles of exact observation and measurement of experiments in its periodical, *Philosophical Transactions of the Royal Society*, generally credited as being the first scientific journal.

The Scientific Revolution

Once Bacon's philosophies regarding experimentation and observation were accepted, people began using them to harness nature for profit. The study of nature came to be less about understanding God's creation or correcting traditional beliefs, and more about accumulating personal wealth. This triggered profound changes, first in England, then Western Europe, and ultimately everywhere on earth. By the end of the following century, new ways of thinking that developed during the Scientific Revolution led directly to the Protestant Reformation, the Industrial Revolution, early Capitalism, inter-continental colonialism, economic globalization, and our current technological civilization.

Empiricism

In philosophy, empiricism is an *epistemological* theory that holds that knowledge, or justification for truths, comes only or primarily from sensory experience. Empiricism emphasizes the central role of empirical evidence in helping us form ideas, rather than intuitions, hopes, or the authority of tradition.

Empiricism in the philosophy of science emphasizes *evidence*, especially as discovered in experiments. It is a fundamental part of the scientific method that all hypotheses and theories must be tested against observations of the natural world rather than resting solely on *a priori* reasoning, intuition, or revelation.

Experience, Evidence and Doubt

Empiricism, as used by natural scientists, says that “knowledge is based on experience”, and that “knowledge is always tentative and subject to revision and improvement”. This implies that the scientific project will never be finished. Even if someday in the far future, scientists were to believe that they have discovered everything there is to know about reality, it would require only a single unexplainable experience to put all certainties back into doubt.

Proof

People often argue for what they believe by stating reasons why their ideas are believable. The scientific method turns this around. When developing scientific experiments, the goal is to created conditions to prove the *validity* of a theory. In other words, scientists try to proof their ideas wrong. If after tremendous effort, no one has been able to find a flaw in an theory, it can become a scientific fact. If the fact seems to be absolutely true for all of reality, it can become a *scientific law.*

The Science in the Method

For a theory to be scientific it must be *observable*, *measurable* and *repeatable,*.

1. *Observable:* It must be a phenomenon that we can objectively sense in some way.
2. *Measurable:* It must be a phenomenon that can be objectively measured in some way. Ideally, measurements, relationships and patterns can be stated in clear, unambiguous mathematics.
3. *Repeatable:* It must be a phenomenon that can be observed in different times or places.

The Modern Scientific Method

1. **Humility:** Remain humble before the great mysteries of reality. Remember that everything we think know is not even a drop in an infinite ocean of the unknown.
2. **Observation:** Carefully observe the world, and learn to notice things that are often miss or taken for granted by others.
3. **Curiosity:** When you notice something that seems odd or surprising, ask yourself questions about it. What was that? How did that just happen? Does it always happen? If so, when, where, why, how…?
4. **Theory:** Develop a *testable* theory that might be able to explain what you observed. Note that a theory that can not be tested might be a great idea. It might even be the truth (whatever that means), but if it can’t be tested, it falls outside of the world of science. That does NOT mean the idea is wrong, it’s just not science. Many good ideas fall outside of science.
5. **Experimentation:** Create testable (or *falsifiable*) experiments that can be used to show if an idea is wrong, and so should be abandoned or revised. Adjust theories and experiments, and try again as needed. Note: Contrary to popular misconception, scientists work by trying to proof their theory to be wrong. If after all their best effort, they are unable to prove a theory wrong, then they may begin to indulge in a slight sliver of hope that the theory approaches some degree of truth.
6. **Publish:** Because all humans are easily fallible, it is important for others to be able to duplicate an experiments and verify the results. Scientific papers are written to share this information. They must be accurate, factual, and detailed. Important papers are published first in *peer reviewed journals* where qualified experts review each submission. Ideally, only those papers deemed most important and interesting are published.

7. **Peer Review:** Once a paper is published, other scientists can duplicate the experiments and verify or refute the findings.
8. **Acceptance or Rejection:** If during peer review, methodological flaws or reasoning errors are found, the paper may be rejected by the scientific community. If a large enough number peers (experts in the field) confirm that a paper has merit, it can become accepted as part of the global scientific knowledgebase".
9. **Progress – Eventual Abandonment, Revision, or Law:** Science is an ongoing process. Over time, most ideas that once seemed certain, are revised or abandoned. If an idea remains apparently true for all times and places, it can become a *scientific law".

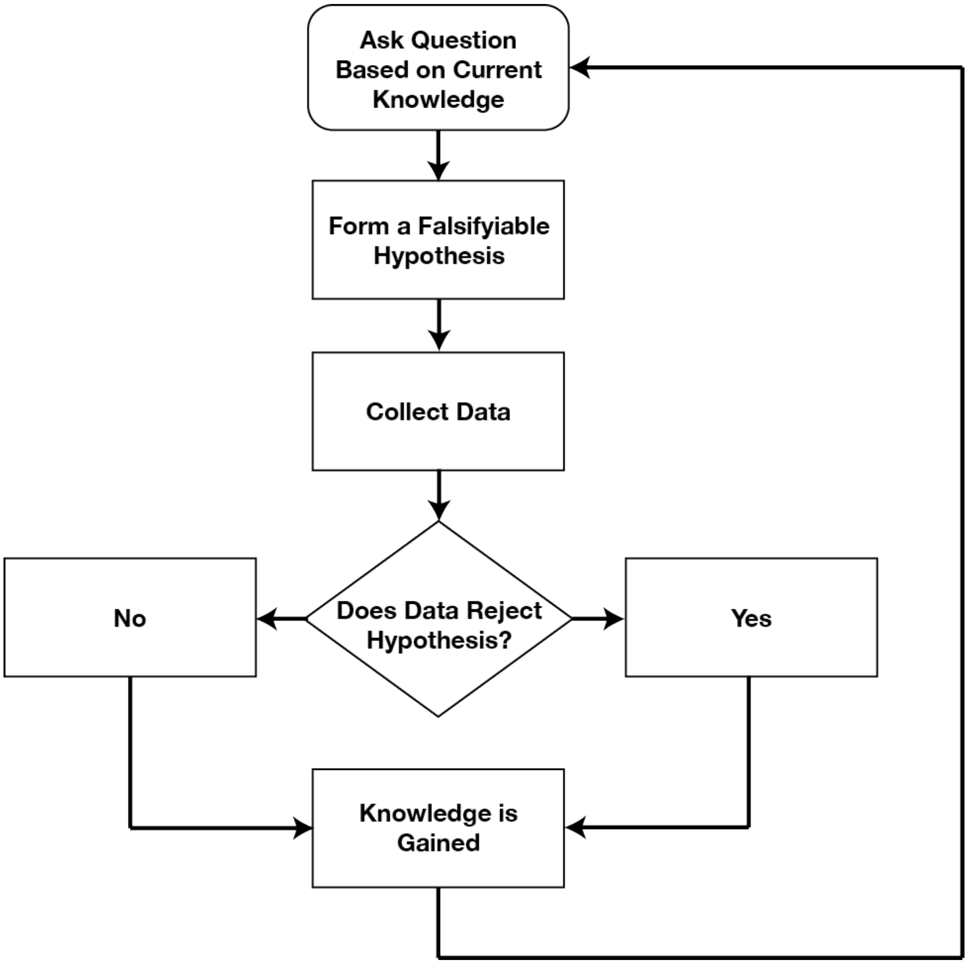

Figure 1.2: Flow Diagram of the Scientific Method

Source: Wikipedia

The Future

In the end, there may be no end. Because the scientific method is based on empiricism, we can never know for certain if what we think we know is correct. The very next experiences might nullify everything we think we know. At the same time, the more scientists learn (or think they have learned) the more they see how little they know. As science progresses, the mysteries deepen and the questions grows.

> *"There's nothing sadder than to see a beautiful idea crash on the hard rocks of reality."*
>
> – Thomas Huxley

The Unreasonable Effectiveness of Mathematics

"The Unreasonable Effectiveness of Mathematics in the Natural Sciences" is a 1960 article by the physicist Eugene Wigner. Wigner observed that a physical theory's mathematical structure often points the way to further advances in that theory and even to completely unexpected future predictions and observations.

Wigner begins with a belief, common among those familiar with mathematics, that mathematical concepts have applicability far beyond the context in which they were originally developed. Based on his experience, he notes that, "the mathematical formulation of the physicist's often crude experience leads in an uncanny number of cases to an amazingly accurate description of a large class of phenomena".

The fundamental law of gravitation (covered in 10th grade physics) is a prime example. Originally used to model freely falling objects on the surface of the earth, the law was extended by Newton on the basis of "very scanty observations" to describe the motion of planets, stars and entire galaxies, where it "has proved accurate beyond all reasonable expectations".

Another oft-cited example is Maxwell's equations (covered in 11th grade physics), which model the electrical and magnetic phenomena. It was later found that these same equations model radio waves, discovered by David Edward Hughes in 1879, around the time of James Clerk Maxwell's death.

Wigner sums up his argument by saying that "the enormous usefulness of mathematics in the natural sciences is something bordering on the mysterious and that there is no rational explanation for it". He concludes his paper with the same question with which he began:

> *"The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve. We should be grateful for it and hope that it will remain valid in future research and that it will extend, for better or for worse, to our pleasure, even though perhaps also to our bafflement, to wide branches of learning."*

The Limits of Human Knowing

"Know theyself."

– Oracle of Delphi

"Wise are they who know they know not."

– Socrates

How do we actually know what we think we know? Whether humans checking the results of humans (the peer review process in the scientific method) can be considered an objective basis for knowing the universe is an interesting and still unanswered question.

The tables were turned by Michael Atiyah in his essay *"The unreasonable effectiveness of physics in mathematics"*. He argued that the concepts of physics go far beyond common sense experience as well as standard mathematics. For example ideas about the geometry of 4-manifolds in the space-time continuum, quantum field theory, special relativity, non-abelian gauge theory, spin, chirality, supersymmetry, and electromagnetic duality are often beyond our ability to conceptualize, and may be stretching mathematics beyond what we are capable of knowing.

Russell's Paradox

Can we really rely on math as the language of proof? What if math has a fundamental flaw that we have been unable to see? How would we know? One possibility is to try to use math itself to prove that math is true. Bertrand Russell and Alfred North Whitehead set out to do this—and failed. Even worse they were able to prove mathematically that math CAN NOT prove itself to be true. This is known as Russell's Paradox, which can be surprisingly easily stated:

According to the unrestricted comprehension principle, for any sufficiently well-defined property, there is the set of all and only the objects that have that property. Let R be the set of all sets that are not members of themselves. If R is not a member of itself, then its definition entails that it is a member of itself; yet, if it is a member of itself, then it is not a member of itself, since it is the set of all sets that are not members of themselves.

The resulting contradiction is Russell's Paradox, which (of course) can be most elegantly stated mathematically:

$$Let\ R\ = \{x \mid x \notin x\}, \text{ then } R \in R \iff R \notin R$$

Is Math Invented or Discovered?

Joseph Auslander pointed out that we not only observe nature, we are a part of it. Perhaps the math that we invent takes its form because math plays a part in forming who we are. It's one thing to fit equations to aspects of reality that are already known. It's something else for that math to tell us of phenomena never previously suspected.

When Paul Dirac's equations describing electrons produced more than one solution, he surmised that nature must possess other particles. But scientists did not discover such particles (now known as antimatter) until after Dirac's math showed that they must exist. If math is a human invention, nature seems to know in advance what we will invent.

Sources

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- Kahn Academy: Francis Bacon and the Scientific Revolution (Accessed: 2023-05-12)
- Wikipedia: The Unreasonable Effectiveness of Mathematics in the Natural Sciences (Accessed: 2023-05-17)
- Wikipedia: Where Mathematics Comes From (Accessed: 2023-05-17)

Chapter 2

Galileo

Biography of Galileo

Galileo Galilei, (born February 15, 1564, Pisa, Italy, died January 8, 1642, Arcetri, near Florence), was an Italian natural philosopher, astronomer, and mathematician who made fundamental contributions to the sciences of motion, astronomy, and strength of materials and to the development of the scientific method.

His formulation of (circular) inertia, the law of falling bodies, and parabolic trajectories marked the beginning of a fundamental change in the study of motion.

His insistence that the book of nature was written in the language of mathematics changed natural philosophy from a verbal, qualitative account to a mathematical one in which experimentation became a recognized method for discovering the facts of nature.

Finally, his discoveries with the telescope revolutionized astronomy and paved the way for the acceptance of the Copernican heliocentric system, but his advocacy of that system resulted in Inquisition by the Roman Catholic Church, resulting in house arrest for the rest of his life.

Early life and career

Galileo was the oldest son of Vincenzo Galilei, a musician who made important contributions to the theory and practice of music and who may have performed some experiments with Galileo on the relationship between pitch and the tension of strings.

In his middle teens Galileo attended the monastery school at Vallombrosa, near Florence, and then in 1581 matriculated at the University of Pisa, where he was to study medicine. However, he became enamored with mathematics and decided to make the mathematical subjects and philosophy his profession, against the protests of his father.

Galileo then began to prepare himself to teach Aristotelian philosophy and mathematics. Several of these lectures have survived. In 1585 Galileo left the university without having obtained a degree, and for several years he gave private lessons in the mathematical subjects. During this period he designed a new form of hydrostatic balance for weighing small quantities and wrote a short treatise, *La bilancetta* (“The Little Balance”). He also began his studies on motion, which he pursued steadily for the next two decades.

Galileo demonstrated, by dropping bodies of different weights from the top of the famous Leaning Tower of Piza, that the speed of fall of a heavy object is not proportional to its weight, as Aristotle had claimed. The manuscript tract De motu (On Motion), finished during this period, shows that Galileo was abandoning Aristotelian notions about motion and was instead taking an Archimedean approach (boldness and originality of thought and extreme rigor of method) to the problem. But his attacks on Aristotle made him unpopular.

At this point, however, Galileo’s career took a dramatic turn. In the spring of 1609 he heard that in the Netherlands an instrument had been invented that showed distant things as though they were nearby. By trial and error, and perhaps with the help of his daughter, he figured out the secret of the invention and made his own three-powered spyglass from lenses for sale in spectacle makers’ shops. Others had done the same; what set Galileo apart was that he quickly understood how to improve the instrument, taught himself the art of lens grinding, and produced increasingly powerful telescopes. In August of that year he presented an eight-powered (× 8) instrument to the Venetian Senate. He was rewarded with life tenure and a doubling of his salary, making him one of the highest-paid professors. In the fall of 1609 Galileo began observing the heavens with instruments that magnified up to 20 times.

In December he drew the Moon's phases as seen through the telescope, showing that the Moon's surface is not smooth, as had been thought, but is rough and uneven. In January 1610 he discovered four moons revolving around Jupiter. He also found that the telescope showed many more stars than are visible with the naked eye. These discoveries were "earthshaking" (from as less-than-humble point of view).

Through his increasingly high-powered telescopes Galileo discovered the puzzling appearance of Saturn, later to be shown as caused by a ring surrounding it, and that Venus goes through phases just as the Moon does. Although these discoveries did not prove that Earth is a planet orbiting the Sun, they shook Galileo's faith in Aristotelian cosmology.

Galileo's Copernicanism

1. The idea that there was an absolute difference between the corrupt earthly region and the perfect and unchanging heavens was proved wrong by the mountainous surface of the Moon.
2. The moons of Jupiter showed that there had to be more than one center of motion in the universe, which seriously contradicted the notion that the earth was the center of the universe.
3. The phases of Venus showed that it (and, by implication, Mercury) revolved around the Sun, not the Earth.

As a result, Galileo was confirmed in his belief that the Sun is the center of the universe and that Earth is a planet orbit the sun, as Copernicus had argued. Galileo's conversion to Copernicanism would be a key turning point in the Scientific Revolution.

Galileo's increasingly overt Copernicanism began to cause trouble. In 1613 he wrote a letter to a student about the problem of squaring the Copernican theory with certain biblical passages. Inaccurate copies of this letter were sent by Galileo's enemies to the Inquisition in Rome, and he had to retrieve the letter and send an accurate copy.

Several Dominican fathers lodged complaints against Galileo, and Galileo went to Rome to defend the Copernican cause and his good name. Before leaving, he finished an expanded version of the letter. In it Galileo discussed the problem of interpreting biblical passages with regard to scientific discoveries but, except for one example, wisely did not interpret the Bible—a task reserved only for "approved theologians" in the wake of the Council of Trent (1545-63) and the beginning of the Catholic Counter-Reformation.

But the tide in Rome was turning against Galileo and the Copernican theory. In 1615, when the cleric Paolo Antonio Foscarini published a book arguing that the Copernican theory did not conflict with scripture, Inquisition consultants examined the question and pronounced the Copernican theory heretical. Foscarini's book was banned, as were more technical and nontheological works, such as Johannes Kepler's *Epitome of Copernican Astronomy.* Copernicus's own 1543 book, *De revolutionibus orbium coelestium libri vi* ("Six Books Concerning the Revolutions of the Heavenly Orbs"), was suspended until "corrected".

Galileo was not mentioned directly in the decree, but he was admonished not to "hold or defend" the Copernican theory. A document placed in the Inquisition files at this time states that Galileo was admonished "not to hold, teach, or defend" the Copernican theory "in any way whatever, either orally or in writing."

Galileo's Inquisition

In time, Galileo again spoke out, directly challenging the authority of the Bible as the only word of God, as well as the authority of those who presumed to be the Bible's only true interpreters.

> *"Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it."*

Galileo's approach to cosmology was fundamentally spatial and geometric, i.e., mathematical rather than theological: Earth's axis retains its orientation in space as Earth circles the Sun, and bodies not under a force retain their velocity (although this inertia is ultimately circular). He also drew a distinction between the properties of external objects and the sensations they cause in us—i.e., the distinction between primary and secondary qualities, or what we might call "subjective and objective reality".

The reaction against his ideas was swift. Galileo was summoned to Rome in 1633. During his first appearance before the Inquisition, he was confronted with the 1616 edict recording that he was forbidden to discuss the Copernican theory. In his defense Galileo produced a letter from Cardinal Bellarmine, by then dead, stating that he was admonished only not to hold or defend the theory. The case was at an impasse, and, in what can only be called a plea bargain, Galileo confessed to having overstated his case. He was pronounced to be vehemently suspect of heresy and was condemned to life imprisonment and was made to abjure formally. Despite rumors, there is no historical evidence that he whispered, "Eppur si muove" ("And yet it moves").

Galileo was then 70 years old, yet he kept working. He had begun a new book on the sciences of motion and strength of materials. There he wrote up his unpublished studies that had been interrupted by his interest in the telescope. The book was secretly carried out of Italy and published in Leiden, the Netherlands, in 1638 under the title *Discorsi e dimostrazioni matematiche intorno a due nuove scienze attenenti alla meccanica* (Dialogues Concerning Two New Sciences).

Galileo wrote for the first time about the bending and breaking of beams and summarized his mathematical and experimental investigations of motion, including the law of falling bodies and the parabolic path of projectiles as a result of the mixing of two motions—constant speed and uniform acceleration. By then Galileo had become blind, and he spent his time working with a young student, Vincenzo Viviani, who was with him when he died on January 8, 1642.

Sources

- Britanica: Galileo
- Wikipedia: Equations for a falling body

Lab 1 — Motion in Time

Purpose

To reproduce Galileo's ramp experiments for slowing down the effect of gravity on falling objects.

Materials

L-track, Two different sized small metal or glass balls, Electronic stopwatch, Yard stick, Clamp stand and clamp, A few inches of masking tape

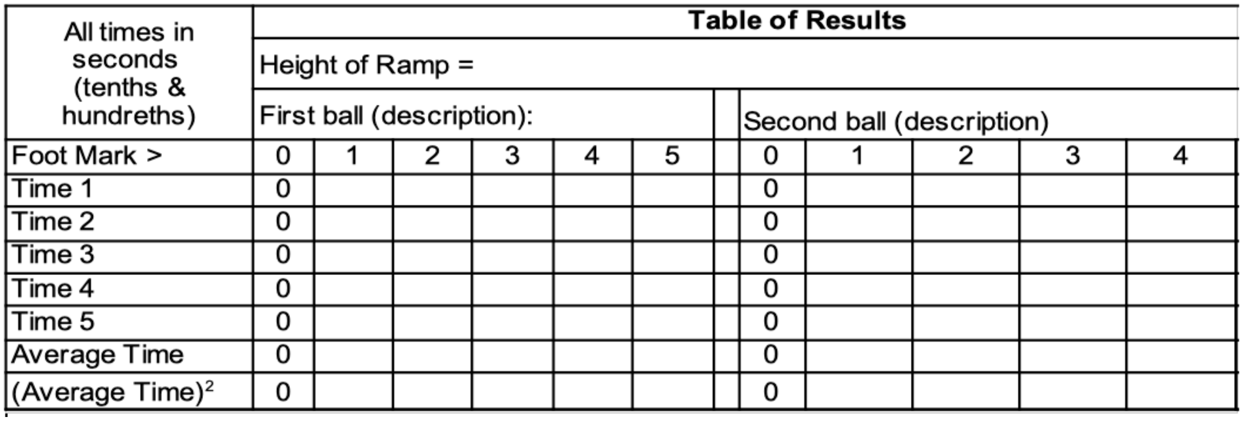
Procedures

1. Mark the L-Track at one foot increments from 1 foot to 5 feet. Accuracy matters!
2. Set up the clamp stand so that it can hold one end of the L-Track at a height that is somewhere between horizontal (flat) and 6" with the other end resting on the counter. (Note: Working with a lower height (<6") allows for a slower roll and more accurate measurements.)

3. Measure the time the ball takes to reach each of the 5 one-foot marks. To ensure accuracy, each time measurement should be done five times. The easiest way is to roll the ball five times for each mark (5 rolls to 1 foot mark, 5 rolls to 2 foot mark, etc.).
4. Record your data in the below table. Enter each measurement as you make it.
5. Repeat the entire procedure for a second ball of a different size at the same ramp height.

Observations

For each ball type, plot 2 graphs on grid paper with distance measured in 1 foot increments on the vertical axis. The horizontal axis of the first graph time is marked in seconds and tenths of a second. On the second graph, time^2 is marked on the horizontal axis. Originate your graph from 0 seconds(2) and 0 feet to see accurate graphs (ball starting from rest).



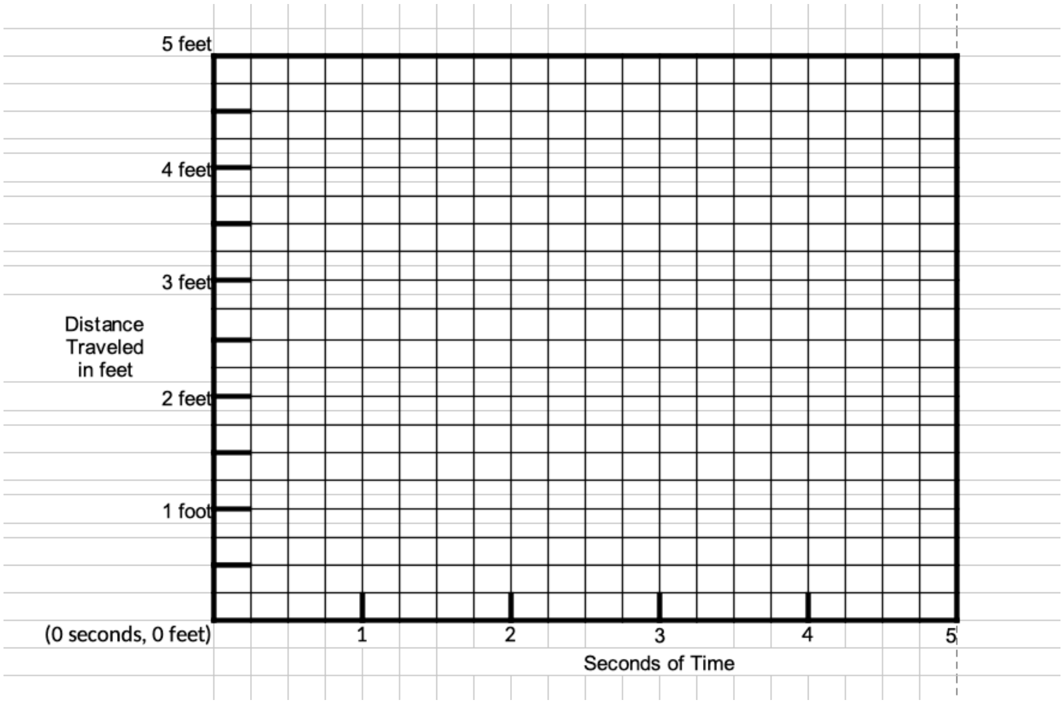
All times in seconds (tenths & hundreths)	**Table of Results**											
	Height of Ramp =											
	First ball (description):							Second ball (description)				
Foot Mark >	0	1	2	3	4	5		0	1	2	3	4
Time 1	0							0				
Time 2	0							0				
Time 3	0							0				
Time 4	0							0				
Time 5	0							0				
Average Time	0							0				
(Average Time)^2	0							0				

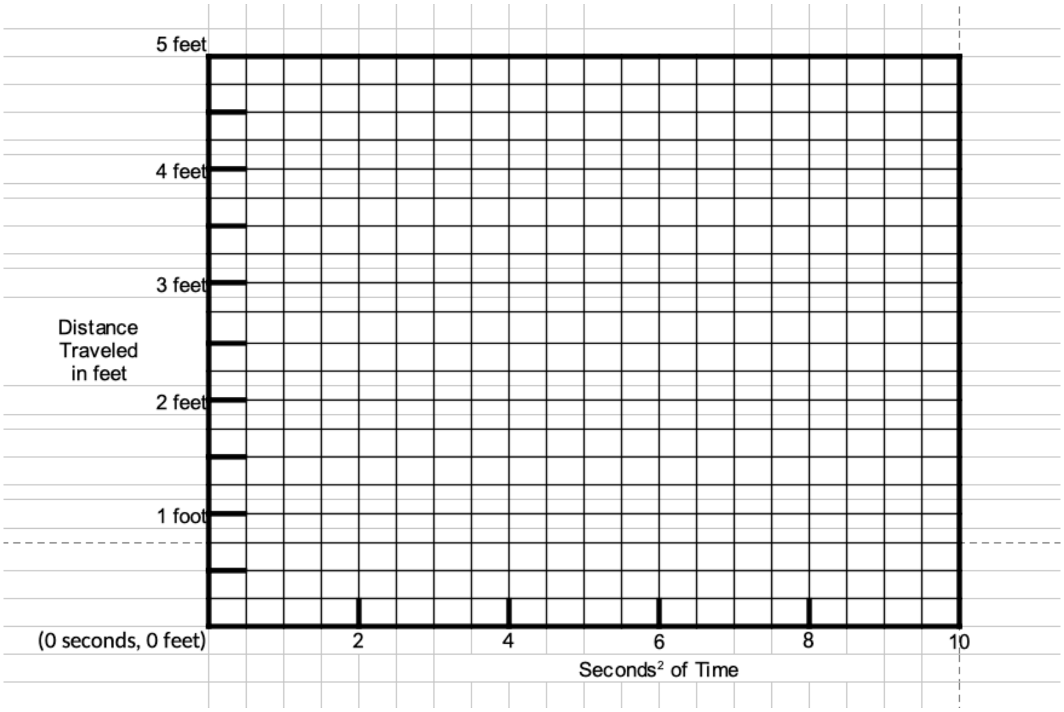
Conclusion

What seems to affect the accuracy of your measurements? Carefully note any sources of error.

What is the relationship between distance and time^2?

Write up you report on a separate sheet following standard lab report directions.


5 feet
4 feet
3 feet
Distance Traveled in feet
2 feet
1 foot
(0 seconds, 0 feet)
1
2
3
4
5
Seconds of Time


5 feet
4 feet
3 feet
Distance Traveled in feet
2 feet
1 foot
(0 seconds, 0 feet)
2
4
6
8
10
Seconds² of Time

Galileo's Equation for Falling Objects

Galileo was the first to demonstrate and then formulate equations for falling objects. He used a ramp to study rolling balls, the ramp slowing the acceleration enough to measure the time taken for the ball to roll a known distance. He measured elapsed time with a water clock, using an "extremely accurate balance" to measure the amount of water.

$$d = \frac{1}{2}gt^2$$

Where d is distance, g is the acceleration to to gravity, and t is time. Near the surface of the Earth, the acceleration due to gravity $g = 9.807m/s^2$ (meters per second squared, which might be thought of as "meters per second, per second"; or approximately $32.18ft/s^2$ as "feet per second per second").

This showes that after one second, an object will have fallen a distance of $\frac{1}{2} \times 9.8 \times 1^2 = 4.9m$. After two seconds it will have fallen $\frac{1}{2} \times 9.8 \times 2^2 = 19.6m$

SI Units

For scientists to communicate across time and space, a coherent set of units for g, d, t and v is essential. Assuming SI units, g is measured in meters per second squared, so d must be measured in meters, t in seconds and v in meters per second.

In all cases, the object is assumed to start from rest, and air resistance is neglected. Generally, in Earth's atmosphere, all results are inaccurate after only 5 seconds of fall (at which time an object's velocity will be a little less than the vacuum value of 49 m/s (9.8 m/s2 × 5 s) due to air resistance).

Terminal velocity depends on **atmospheric drag**, the **coefficient of drag for the object**, the **(instantaneous) velocity** of the object, and the **area presented to the airflow**.

Apart from the last formula, these formulas also assume that g negligibly varies with height during the fall (that is, they assume constant acceleration). The last equation is more accurate where significant changes in fractional distance from the center of the planet during the fall cause significant changes in g. This equation occurs in many applications of basic physics.

The Effect of Air Resistance

The equations ignored air resistance, which has a dramatic effect on objects falling an appreciable distance in air, causing them to quickly approach a terminal velocity. The effect of air resistance varies enormously depending on the size and geometry of the falling object. For example, the equations are hopelessly wrong for a feather, which has a low mass but offers a large resistance to the air. In the absence of an atmosphere all objects fall at the same rate, as astronaut David Scott demonstrated by dropping a hammer and a feather on the surface of the Moon. Air resistance induces a drag force on any body that falls through any atmosphere other than a perfect vacuum, and this drag force increases with velocity until it equals the gravitational force, leaving the object to fall at a constant terminal velocity.

The Effect of the Coriolis Effect

The equations also ignore the rotation of the Earth, failing to describe the Coriolis effect for example. Nevertheless, they are usually accurate enough for dense and compact objects falling over heights not exceeding tall buildings.

Equations for Falling Objects

Distance d traveled by an object falling for time t	$d = \frac{1}{2}gt^2$
Time t taken for an object to fall distance d	$t = \sqrt{\frac{2d}{g}}$
Instantaneous velocity v_i of a falling object after elapsed time t	$v_i = gt$
Instantaneous velocity v_i of a falling object that has travelled distance d	$v_i = \sqrt{2gd}$
Average velocity v_a of an object that has been falling for time t (averaged over time)	$v_a = \frac{1}{2}gt$
Average velocity v_a of a falling object that has traveled distance d (averaged over time)	$v_a = \frac{\sqrt{2gd}}{2}$
Instantaneous velocity v_i of a falling object that has traveled distance d on a planet with mass M, with the combined radius of the planet and altitude of the falling object being r, this equation is used for larger radii where g is smaller than standard g at the surface of Earth, but assumes a small distance of fall, so the change in g is small and relatively constant	$v_i = \sqrt{\frac{2GMd}{r^2}}$
Instantaneous velocity v_i of a falling object that has traveled distance d on a planet with mass M and radius r (used for large fall distances where g can change significantly)	$v_i = \sqrt{2GM\left(\frac{1}{r} - \frac{1}{r+d}\right)}$

Sources

- Britanica: Galileo
- Wikipedia: Equations for a falling body

Mathematics of Free Fall

An object that falls through a vacuum is subjected to only one external force, the gravitational force. An object that is moving only because of the action of gravity is said to be free falling. The acceleration is constant and equal to the gravitational acceleration g, which is about 9.8 meters per square second at sea level on the Earth. The weight, size, and shape of the object are not a factor in free fall.

In a vacuum, small scraps of paper fall with the same acceleration as much heavier metal coins. Knowing the acceleration of an object, we can determine its velocity and location at any time using Galileo's equations. If objects fall through atmosphere, air resistance acts on the object and the mathematics is more complex. For now, we will assume ideal (vacuum) conditions, and work with the simpler equations. These equations are very closely related. Try to see how they relate to each other.

$$d = \frac{1}{2}gt^2$$

$$V = a \times t$$

$$X = .5 \times a \times t^2$$

where g is the **gravitational constant** a is the **acceleration** (equal to the gravitational constant), V is the **velocity**, and X is the **displacement** (or distance) from the initial location.

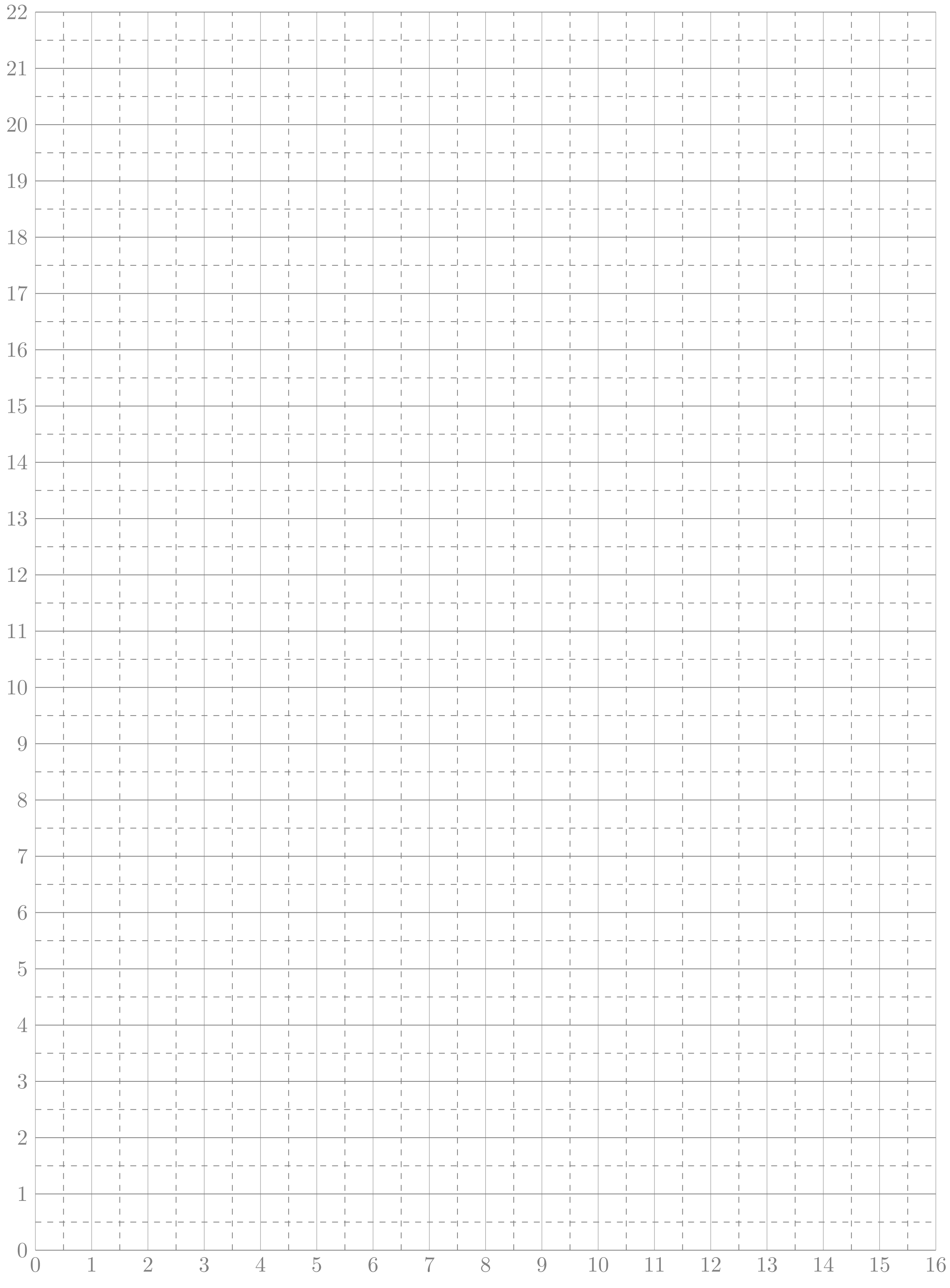
Here is a table of calculated acceleration (in meters per second squared, velocity (meters per second), and displacement (meters) at 1 second intervals. Notice that acceleration is a **constant** (rounded to 9.8 m/sec^2), velocity **increases linearly**, and displacement (location) **increases quadratically**.

Time/Sec	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Accel (m/sec^2)	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Velocity (m/sec)	0.0	9.8	19.6	29.4	39.2	49.0	58.8	68.6	78.4
Distance (meters)	0.0	4.9	19.6	44.1	78.4	122.5	176.4	240.1	313.6

1. Use the correct equations to calculate the missing values in the below table.

Time/Sec	**1.5**	**4.25**	**15**	**30**
Accel (m/sec^2)	9.8	9.8	9.8	9.8
Velocity (m/sec)				
Distance (meters)				

2. On the other side (or on another sheet), create two graphs for the above data.
3. Write a conclusion describing the mathematical patterns and relationships illustrated in the graphs.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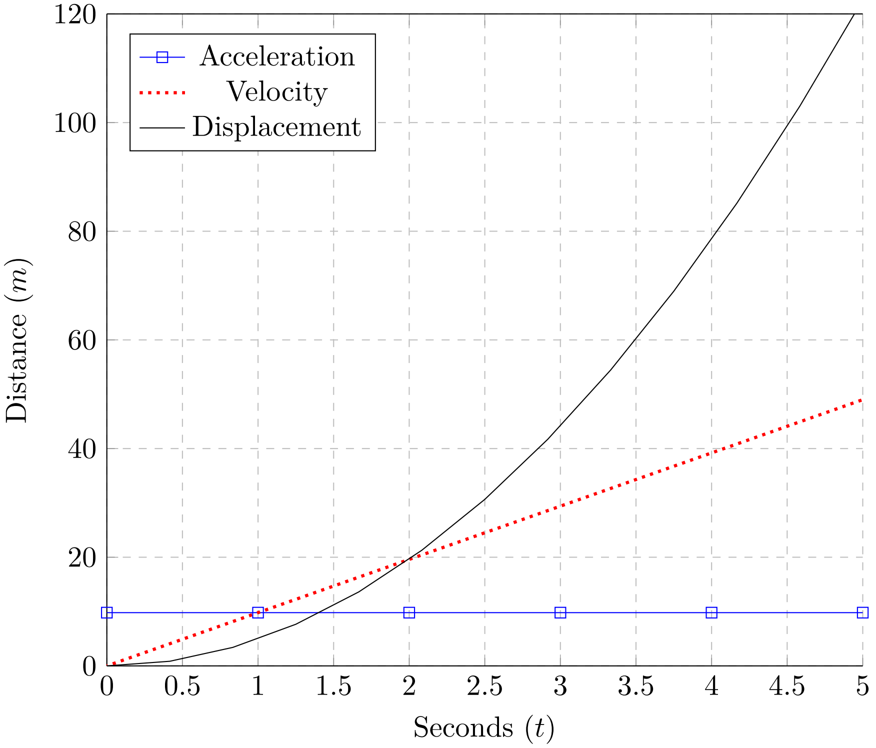
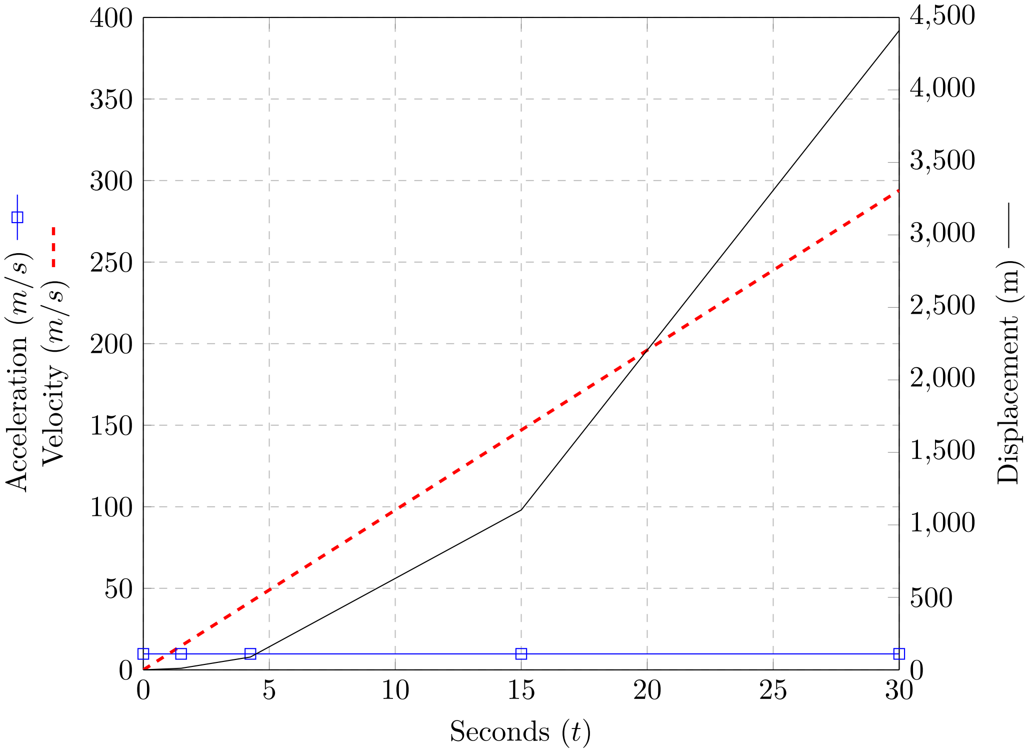
Example Graph 1: Free falling object on earth in a vacuum (0 to 5 seconds)



Example Graph 2: Free falling object on earth in a vacuum (various times)



Data for Graph 2

Seconds	1.5	4.25	15	30
Acceleration (a)	9.8	9.8	9.8	9.8
Velocity($a \times t$)	14.7	41.65	147	294
Displacement ($\frac{1}{2}gt^2$)	11.025	88.50625	1102.5	4410

Conclusion

The gravitational constant (g) on earth is about 9.8 m/s. This is the rate at which objects fall in ideal conditions (such as in a vacuum, or if in atmosphere, during the first five seconds of fall). The Acceleration (a) is the same as the gravitational constant. To simplify our calculations, we assume that the gravitational force is constant (unchanging). This is accurate enough for most every day situations.

Velocity is the speed at which an object is falling at a particular moment. The longer an object falls the greater the velocity. This is a linear relationship, which can be seen in both graphs.

Displacement is the distance an object has falling from it's starting position of 0 meters. Displacement increases quadratically. This can be seen by the curved lines in the above graphs. Over time, quadratic functions increase far faster than linear functions.

For example, in the second chart the velocity increases linearly (in a straight line) from 0 to 294 m/s, while during the same time period (30 seconds) the displacement increased from 0 meters to 4410 meters. The difference is so great that we needed to create two y-axes scales to display both lines in a single graph.

Lab 2: Measuring the Acceleration of Gravity in Free Fall

Purpose

To measure the acceleration of gravity (g) in free fall at the earth's surface near sea level.

Materials

- 2 small differently sized lead weights
- 1 stop watch
- 1 measuring tape
- art room steps

Procedures

1. Measure the mass of each lead weight.
2. Go to Art room steps and measure a distance (in inches) for your first drop height.
3. The "timer" starts the timer when the weight is released and stops it when the weight hits the ground.
4. Take five measurements for each lead weight, and record times in the below table.
5. Measure a second height and repeat.
6. Calculate average of each set. ($AVG = \frac{Total}{Count}$)

Observations

- Try different techniques for measuring the time of the weight drop (stop watch on top vs bottom, stop watch handled by dropper, ball watcher at top or ball watcher at bottom, etc). What seems to affect the accuracy of your measurements? Note any sources of error.
- Record the mass of each weight.
- Mass of lead weight 1: ____________
- Mass of lead weight 2: ____________
- Calculate the acceleration of gravity for each height and weight in $\frac{inches}{seconds^2}$.
- Use $d = \frac{1}{2}at^2$ transformed into $\frac{2d}{t^2} = a$ to calculate the acceleration of gravity.
- Multiply $\frac{inches}{seconds^2}$ by $\frac{1\,meter}{39.37\,inches}$ to convert to $\frac{meters}{second^2}$.
- How do your observed results compare against the "known" value for the acceleration of gravity? Calculate your percentage of error against the known value using the following equations:

$$Percent\ error = \frac{g_{calculated} - g_{known}}{g_{known}} \times 100$$

$$Known\ acceleration\ of\ gravity \approx \frac{9.8\,meters}{second^2}$$

	Height 1		**Height 2**	
Time	**Weight 1**	**Weight 2**	**Weight 1**	**Weight 2**
Time 1				
Time 1				
Time 1				
Time 1				
Time 1				
Avg. Time				
Avg. Time^2				

Lab 2b: Electronically Measure Acceleration of Gravity

Purpose

To measure the value of the acceleration of gravity (g).

Materials

- Vertical stand
- Electronic timer with two sensors
- Two small metal balls or marbles

Procedures

1. Set a ball in the clip.
2. Set one sensor on the vertical stand just below the clip.
3. Set the other sensor at 50 cm ($\frac{1}{2}$ *meter*) lower than the first.
4. Set the timer for "Interval" and "Reset" it.
5. Release the ball five times and record the intervals (in seconds).
6. Calculate the average time for all five drops.
7. Switch to a second ball of a different weight, and repeat.
8. Adjust the vertical stand to a different height, and repeat all steps for each ball.

Observations

1. Record your drop times in the table below.
2. Record the mass of each lead weight.
    1. Mass of ball 1: ____________________________
    2. Mass of ball 2: ____________________________
3. Calculate the acceleration of gravity for each height and weight in $\frac{meters}{second^2}$.
4. Use $d = \frac{1}{2}at^2$ transformed into $\frac{2d}{t^2} = a$ to calculate your experimentally derived acceleration of gravity.

	Height 1		**Height 2**	
Time	**Weight 1**	**Weight 2**	**Weight 1**	**Weight 2**
Time 1				
Time 1				
Time 1				
Time 1				
Time 1				
Avg. Time				
Avg. Time^2				

Chapter 3

Gravity

Newton's Law of Gravity

> *"Every particle of matter in the universe attracts every other particle with a force that is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them."*
>
> – Issac Newton

This translates to:

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

Where,

- F is the force,
- m_1 and m_2 are masses of the objects interacting,
- r is the distance between the centre of the masses. (In some equations called distance d.)
- G is the gravitational constant $(6.674 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2})$.

Anything that has mass also has gravity. More massive objects have more gravity. All of an object's mass make a combined gravitational pull on all the mass of other objects. Gravity gets weaker with distance. The closer objects are to each other, the stronger their gravitational pull toward each other.

The gravitational force between two objects is created by the combined gravitational forces of both objects.The Earth pulls on us; we pull on the Earth. Because the Earth is so much more massive, the combined force does not have an obvious effect on the planet. Even the smallest particles of dust have a slight gravitational pull on each other. It is this small gravitational pull that causes the universe's vast expanse of star dust to slowly gather into stars, planets and galaxies.

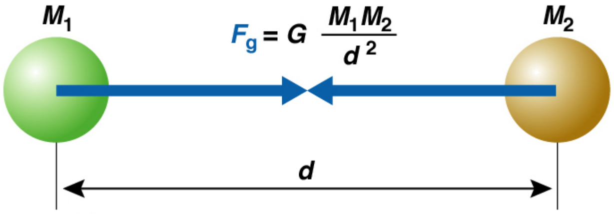


Figure 3.1: Force of Gravity Between Two Objects

Gravity Everywhere

Gravity creates stars and planets by pulling together the interstellar dust from which they are made.Gravity holds planets in orbit around stars, and keeps the moon in orbit around Earth. The gravitational pull of the moon pulls the Earth's oceans towards it, creating the tides. Gravity keeps the atmosphere close to the surface of the Earth, allowing us to breath. Gravity makes the rain fall, the rivers flow, dropped an apple on poor Newton's head, and—combined with humidity—is a known contributor to seriously "bad hair days".

The Universal Gravitational Constant (Big G)

The gravitational constant was first defined by Isaac Newton in his paper, *Law of Universal Gravitation*, formulated in 1680. It is thought to be one of the fundamental constants of nature.

The universal gravitational constant is a key to understanding our universe—including its size, mass, age, beginning, future, as well as the secrets of gravity, space-time, time travel, dark-matter, black holes, 42, and more or less everything else. It describes the intrinsic strength of gravity, and can be used to calculate the gravitational pull between any two objects, from individual particles of dust to massive galaxy clusters.

A Predictable Universe?

Most scientists today think the value of G is always the same everywhere in the universe. Although this fact can not yet be scientifically proven, all evidence on earth and from deep space research so far seems to confirm it. However, there are several interesting theories that challenge this view. If any of them could be proven closer to the truth, it would fundamentally alter our understanding of reality.

Acceleration of Gravity (Little g)

Galileo was the first to create equations for the behavior of falling objects. He discovered that a free-falling object near the earth's surface has an acceleration of about 9.8 m/s^2. This value is called the **Acceleration of Gravity**, and is given the symbol g. If the earth were heavier or lighter, g would be a different value.

Differences Between "Big G" and "Little g"

G and g are closely related ideas, but the relationship is not proportional. Although formulas can be created to relate G and g for a given location, there is no universal correlation between them. This is because the value of g is different for different locations due to many independent variables.

	Symbol	**Definition**	**Nature of Value**	**Unit**
Acceleration due to gravity	g	The acceleration experienced by a body under free fall due to the gravitational force of the massive body	Changes from place to place. Acceleration due to gravity of the earth is 9.8 m/s^2	m/s^2
Universal Gravitational Constant	G	The force of attraction between two objects with unit mass separated by a unit distance at any part of this universe.	Constant at any point in this universe. $G = 6.67 \times 10^{-11}\ Nm^2/kg^2$	Nm^2/kg^2

Table 3.1: Differences Between "Big G" and "Little g"

The Newton

The newton N is the unit of force in the International System of Units (SI). It is defined as $1kg\frac{m}{s^2}$, the force which gives a mass of 1 kilogram an acceleration of 1 meter per second per second. It is named after Isaac Newton in recognition of his work on classical mechanics, specifically Newton's second law of motion.

The units "meter per second squared" can be understood as measuring a rate of change in velocity per unit of time, i.e. an increase in velocity of 1 meter/second, every second.

As with every SI unit named for a person, its symbol starts with an upper case letter N, but when written in full it follows the rules for capitalization of common nouns; i.e., "newton" becomes capitalized at the beginning of a sentence and in titles, but is otherwise in lower case.

$$1\ \mathrm{N} = 1\ \frac{\mathrm{kg{\cdot}m}}{\mathrm{s}^2}$$

Examples

At average gravity on Earth ($g = 9.80665m/s^2$), a kilogram mass exerts a force of about 9.8 newtons.

1. How much force does an apple exert on the Earth's surface?

$$0.200kg \times 9.80665m/s^2 = 1.961N$$

The mass of an average-sized apple at 200 g, exerts about two newtons of force at Earth's surface, which we measure as the apple's weight on Earth.

2. How much force does the average adult human exert on the surface of the Earth?

$$62kg \times 9.80665m/s^2 = 608N$$

The average adult human exerts a force of about 608 N on the Earth's surface (where 62 kg is the average mass of an adult human).

Calculating Gravitational Force

The gravitational force between two objects can be calculated by multiplying the mass of the objects (m1 and m2) and G, and then dividing by the square of the distance between the them, or to put it more elegantly:

$$F = \frac{(G \times m_1 \times m_2)}{d^2}$$

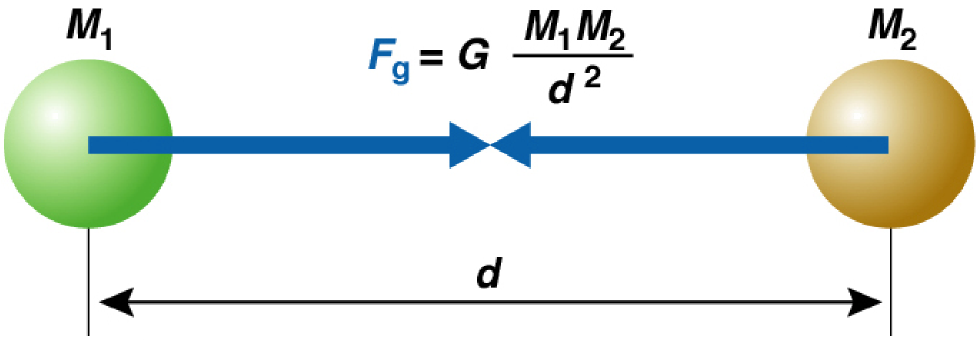


Figure 3.2: Force of Gravity Between Two Objects

Deriving the relationship between g and G for a particular location

1. According to the universal law of gravitation:

$$F = \frac{GMm}{R^2}$$

2. From Newton's second law, we know that "force equals mass × acceleration" ($F = ma$).
3. If acceleration due to gravity is g at a given location, we can substitute $F = ma$ with $F = Mg$.
4. Substitute F with Mg in the original equation:

$$mg = \frac{GMm}{R^2}$$

5. Simplify:

$$g = \frac{GM}{R^2}$$

Finding the Acceleration of Gravity on the Moon

Universal Gravitational Constant: $6.674 \times 10^{-11}\ m^3\ kg^1\ s^2$

Formula for acceleration due to gravity: $g = \frac{GM}{R^2}$

Mass of the moon: $7.35 \times 1022\ kg$.

Radius of the moon: $1.74 \times 106\ m$

Newton's Laws of Motion

Newton's laws of motion are three statements describing the relations between the forces acting on an object and the motion of the object. They are the foundation of classical mechanics.

1. The Law of Inertia

If an object is at rest
or moving at a constant speed in a straight line,
it will remain at rest
or moving in a straight line at constant speed
unless acted upon by a force.

The law of inertia was deduced by Galileo in his experiments with balls rolling down inclined planes, and was later mathematically generalized by René Descartes. In Newtonian mechanics, there is no real distinction between rest and uniform motion in a straight line. They are treated as the same state of motion, but seen by different observers, one moving at the same velocity as the object, and one moving at a different velocity to the object.

Although the principle of inertia is the starting point and the fundamental assumption of classical mechanics, it is not intuitively obvious. In ordinary experience, in Aristotelian mechanics, and in most other ancient philosophies, objects that are not actively pushed will come to rest. This led the ancients to believe that all things have a natural resting place. For example, earth naturally rests below water, which naturally rests below air, which naturally rests below fire.

Why Invent the Idea of Inertia?

For Galileo, the principle of inertia was fundamental to his scientific search: he needed to explain how it is possible for the Earth to spin on its axis and orbit the Sun, yet without our sensing the motion. The idea of inertia helped answer this riddle.

Since we are in motion along with the Earth, and like all other objects our natural tendency is to retain our motion, Earth appears to us to be at rest. Thus, the principle of inertia, which may seem fairly obvious today, upended millennia of common sense, sacred scriptures, and entrenched authorities.

Galileo found the path, Newton found the math. Newton sorted out the details and created the equations that make it possible to accurately account for even minor deviations in planetary paths.

In the Newtonian formulation, the observation that objects that are not pushed tend to come to rest is attributed to the fact that there are "unbalanced forces" acting on them, such as friction and air resistance.

2. The Law of Acceleration

The time rate of change
of the momentum of an object
is equal in both magnitude and direction
to the force imposed on it.
The momentum of an object
is equal to the product of
its mass times its velocity.

Newton's second law is one of the most important in all of physics. It tells us exactly how much an object will accelerate for a given net force. If an object has a net force acting on it, it is accelerated in accordance with the equation. Alternatively, if an object is not accelerating, then there is no net force acting on it.

We can state it far more clearly in mathematics. For an object whose mass m is constant, it can be written in the form $F = ma$, where F (force) and a (acceleration) are both vector quantities.

$$a = \frac{\Sigma F}{m}$$

Where a is the acceleration of the object, ΣF is the net force on the object, and m is the mass of the object. Momentum, like velocity, is a vector quantity, having both magnitude and direction. A force applied to an object can change the magnitude of momentum, thw direction, or both. This formula shows that:

1. acceleration is **proportional to** the net force (ΣF), and
2. acceleration is **inversely proportional to** the mass, m.

Note: Newton's second law is often written: $F = ma$. This is the same formula, but with acceleration a isolated (by dividing both sides by mass m), and for convenience, dropping the Σ sign, although it is still implied.

$$F = ma$$

Don't Confuse Mathematical Models with Reality!

Don't confuse mathematical equations with reality! Just as the mathematical equation, $1c = 4l$, *"one cat equals 4 legs"*, does not mean that a cat IS "four legs", the mathematical expression ma IS NOT a force, it is what the net force equals. The two sides of the equation have a mathematical relationship, nothing more.

In other words, if the net force is doubled, the acceleration of the object will be twice as large, and if the mass of the object is doubled, its acceleration will be half as large. The equality symbol implies a relationship; it does NOT mean that each side of the equation are the same thing.

Net Force and Vectors

In mechanics, a force is a push or a pull on an object, and a Net Force (ΣF) is the sum of all forces on an object. Both the *average speed* and the *instantaneous speed* tell us how fast something is going, but they don't tell us which direction. As the ancient Chinese sage noted, *"If we don't watch where we're going, we'll end up where we're headed." Therefore we need to understand vectors.

Any force is made up of two scalar values—one for direction and one for distance. Objects can speed up, slow down, and change direction. We need a more complex mathematical idea to describe such situations. This is where *vectors* come in. **Quantities that have both a magnitude (aize) and a direction are called *vectors.***

$$Average\ speed = \frac{Distance\ traveled}{Time\ taken} \tag{3.1}$$

$$Average\ velocity = \frac{Displacement\ (change\ in\ location)}{Time\ taken\ (change\ in\ time)} \tag{3.2}$$

$$v = \frac{\Delta x}{\Delta t} \tag{3.3}$$

Where Δ is change, x is position, t is time, and v is velocity.

Displacement is a vector quantity. Its *magnitude* is the straight-line difference between the initial and final locations of an object, and its *direction* is the change from the initial to final locations.

The term "velocity" is a vector combining values for *speed* (the magnitude) and *direction.* When we talk about *instantaneous velocity*, we state the instantaneous speed, such as "15 miles per hour" and add the direction, such as "north", "south", or "30 degrees above the horizontal".

3. The Law of Action and Reaction

> *When two objects interact,*
> *they apply forces to each other*
> *that are equal in magnitude*
> *and opposite in direction.*

This law is important in analyzing problems of static equilibrium, where all forces are balanced, but it also applies to objects in uniform or accelerated motion. The forces it describes are real. For example, a book resting on a table applies a downward force equal to its weight on the table. According to the third law, the table applies an equal and opposite force causing the table to push back at the book.

If an object has a net force acting on it, it undergoes accelerated motion in accordance with the second law. If there is no net force acting on an object, either because there are no forces or because all forces are in balance, the object does not accelerate, and thus is in equilibrium. Alternatively, an object that is not accelerating has no net force acting on it.

Newton's Giants

Newton's laws first appeared in his masterpiece, *Philosophiae Naturalis Principia Mathematica* (1687), commonly known as the *Principia*.

In 1543 Nicolaus Copernicus suggested that the Sun, rather than Earth, might be at the center of the universe. Galileo, Kepler, and Descartes laid the foundations of a new science that would both replace the Aristotelian worldview, inherited from the ancient Greeks, and explain the workings of a heliocentric universe.

In the *Principia*, Newton developed his three laws in order to explain why the orbits of the planets are ellipses rather than perfect circles as had previously been believed. He succeeded in this, but he explained far more. He created the modern world. The series of ideas leading from Copernicus and ending with Newton are known as the Scientific Revolution.

Why Stop There?

In the 20th century Newton's laws were augmented by Quantum Mechanics and the Theory of Relativity. Newton's laws continue to provide an accurate account of nature in all situations, except for sub-atomic particles and objects moving close to the speed of light.

Over time, humanity has learned a little. But with each answered question, many new questions emerge. Why does light have a particular speed? Why does light sometimes act like a particle and sometimes like a wave? What is gravity? How is gravity able to affect objects across empty space? Why is gravity there at all? What is matter? What are black holes? What is time? Is the universe conscious or only made of blind mechanical matter? What is consciousness? What is mind? Most importantly, why 42?

E: Review

Static Forces, Balance and Equilibrium

Physics II: Mechanics: **Name** ____________
Summerfield Waldorf School and Farm **Date** ____________

The Design of Bridges

Momentum, Collisions, Momentum vs. Energy

Biography of Issac Newton

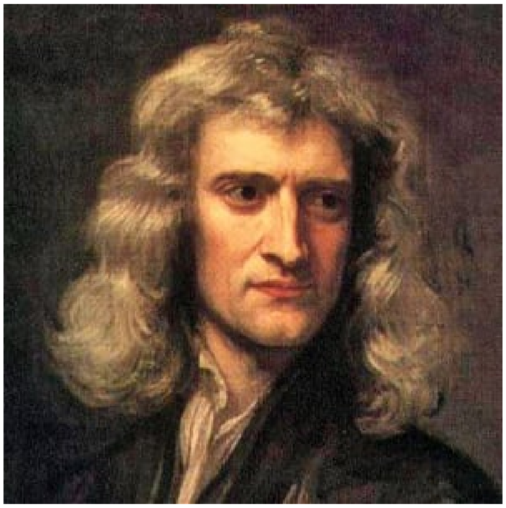


Figure 3.3: Issac Newton

Sometimes called the father of modern science, Isaac Newton revolutionized our understanding of the world. He was a "Renaissance Person" with major accomplishments in many fields, including astronomy, optics, physics and mathematics. Newton gave the world revolutionary new theories on gravity, planetary motion and optics.

With the publication of *Philosophiae Naturalis Principia Mathematica* in 1687, Newton laid the groundwork for modern physics. The publication become known as the *"first great unification"*, as it unified our understanding of gravity on Earth with the behavior of planets, solar systems, and stars. This publication cemented Newton's position as one of the leading scientists of all time

Early Life

Newton was born on January 4, 1643, in Woolsthorpe, Lincolnshire, England. He never knew his father, who had died three months before he was born. Newton's own chances of survival seemed slim. He was a premature and sickly infant that some thought would not live long.

Newton was dealt another blow when he was only three years old. His mother, Hannah, remarried, and his new stepfather, the Right Reverend Barnabas Smith, wanted nothing to do with the child. This was a time when women and children had no rights in England, and his mother had no choice but to honor the wishes of her new husband. The child was left with his maternal grandmother. The loss of his mother left Newton with a lingering sense of insecurity that stayed with him for the rest of life.

Education

Newton was enrolled at the King's School in Grantham, a town in Lincolnshire, where he lodged with a local apothecary (pharmacist). Here, he was introduced to the fascinating world of chemistry and began his livelong appreciation of science. At the age of 12, his mother pulled him out of school to have him tend the family farm. Newton failed miserably at farming, as he found the work boring and monotonous. He was soon sent back to school to finish his basic education.

Perhaps sensing the young man's abilities, his uncle, a graduate of the University of Cambridge's Trinity College, persuaded Newton's mother to have him enter the university. Newton financed his education by working as a waiter and taking care of the rooms of wealthier students.

Cambridge and the Scientific Revolution

When Newton arrived at Cambridge, the Scientific Revolution was in full force. The heliocentric (Sun at the center) view of the universe—theorized by astronomers Nicolaus Copernicus and Johannes Kepler, and refined by Galileo—was already well known. The philosopher René Descartes had begun to formulate a new concept of nature as an intricate, impersonal and inert machine that humans could learn and understand through reason alone.

At the time, Cambridge still followed the ancient Aristotelian and geocentric (Earth at the center) view of the universe, and science was still studied in qualitative (descriptive) rather than quan-

Figure 3.4: Cambridge University

titative (measurable) terms. During his first three years at Cambridge, Newton was taught the standard curriculum, but he was fascinated with the newer ideas. In his spare time he read the modern philosophers. The result was a less-than-stellar performance in collage. Clearly, the disdain was two-way. Newton's groundbreaking book, *Principia* begins:

"A stirring freshness in the air, and ruddy streaks upon the horizon of the moral world betoken the grateful dawning of a new ara. The days of a driveling instruction are departing. With us is the opening promise of a better time..."

Source: *Principia*, by Isaac Newton

Quaestiones Quaedam Philosophicae

Newton kept a second and secret set of notes, entitled *"Quaestiones Quaedam Philosophicae"* ("Certain Philosophical Questions"). The *"Quaestiones"* reveal that Newton had already discovered a new conception of nature that would soon provide a solid theoretical framework for the emerging Scientific Revolution.

The Plague and the Apple

Figure 3.5: The Plague

Newton completed his bachelor's degree at Cambridge University's Trinity College in 1665 and wanted to continue his studies, but an epidemic of the bubonic plague soon altered his plans. During the first seven months of the outbreak, roughly 100,000 London residents died. The university closed its doors as the disease swept through London.

During the time of the Great Plague, Newton stayed on the family farm. It was during this 18-month break from student life that Newton conceived many of his most important insights—including the method of infinitesimal calculus, the foundations for his theory of light and color, and the laws of planetary motion—that eventually led to the publication of his physics book *Principia* and his theory of gravity.

Newton experienced his famous insight on the nature of gravity while thinking about a falling apple. Legend has it that as he sat under a tree, an apple fell and hit him on the head. The famous "bonk on the head" led him to wonder why, given that the earth was spinning and orbiting the sun at great speed, the apple fell straight down and not at an angle. Consequently, he began exploring theories of motion and gravity.

Return to Cambridge

Once the Plague passed, Newton returned to Cambridge. Slowly, his fortunes improved as his original ideas were noticed by others. Newton received his Master of Arts degree in 1669, before he was 27. During this time, he came across Nicholas Mercator's published book on methods for dealing with infinite series. Newton quickly wrote a treatise, *De Analysi*, explaining his own wider-ranging results. He shared this with his friend and mentor Isaac Barrow, but didn't include his name as author.

Newton's first major achievement was designing and constructing a reflecting telescope in 1668. As a professor at Cambridge, Newton was required to deliver an annual course of lectures and chose optics as his initial topic. He used his telescope to study optics and help prove his theory of light and color.

The Royal Society asked for a demonstration of his reflecting telescope in 1671, and the organization's interest encouraged Newton to publish his notes on light, optics and color in 1672. These notes were later published as part of Newton's *Opticks: Or, A treatise of the Reflections, Refractions, Inflections and Colours of Light.*

In June 1669, Barrow shared the manuscript with British mathematician John Collins. In August 1669, Barrow identified its author to Collins as "Mr. Newton ... very young ... but of an extraordinary genius and proficiency in these things." Newton's work was then brought to the attention of the mathematics community for the first time.

Competition and Conflict

Not everyone was enthusiastic about Newton's discoveries in optics, nor his publication in 1672 of *Opticks: Or, A treatise of the Reflections, Refractions, Inflections and Colours of Light.* Among the dissenters was Robert Hooke, one of the original members of the Royal Academy and a scientist accomplished in several areas, including mechanics and optics. While Newton theorized that light was composed of particles, Hooke believed it was composed of waves. Hooke quickly condemned Newton's paper in condescending terms, and attacked his methodology and conclusions.

Hooke was not the only one to question Newton's work in optics. Renowned Dutch scientist Christiaan Huygens and a number of French Jesuits also raised serious objections. But because of Hooke's association with the Royal Society and his own work in optics, his criticism stung Newton the worst.

Unable to handle the critique, he went into a rage—a reaction to criticism that was to continue throughout his life. Newton denied Hooke's charge that his theories had any shortcomings and argued the importance of his own discoveries to all of science. The exchange grew more acrimonious, and soon Newton threatened to quit the Royal Society altogether. He remained only when several other members assured him that the Fellows held him in high esteem.

The rivalry between Newton and Hooke would continue for years. Finally, in 1678, Newton suffered a nervous breakdown. The death of his mother the following year caused him to become even more isolated, and for six years he withdrew from the world. During this time, Newton returned to his study of gravitation and the planets. Ironically, the ideas that put Newton on the right direction came from Robert Hooke.

In 1679, Hooke had brought up the question of planetary motion, suggesting that a formula involving the inverse squares might explain the attraction between planets and the shape of their orbits. Hooke's idea was incorporated into Newton's work on planetary motion.

In early 1684, in a conversation with fellow Royal Society members Christopher Wren and Edmond Halley, Hooke made his case on the proof for planetary motion. Both Wren and Halley thought he was on to something, but pointed out that a mathematical demonstration was needed.

In August 1684, Halley visited Newton, who was coming out of his seclusion. Halley idly asked him what shape the orbit of a planet would take if its attraction to the sun followed the inverse square of the distance between them (Hooke's theory).

Newton knew the answer, due to his concentrated work for the past six years, and instantly replied, "An ellipse."

Newton claimed to have solved the problem some 18 years prior, during his break from Cambridge and the plague, but he was unable to find his notes. Halley persuaded him to work out the problem mathematically and offered to pay all costs so that the ideas might be published.

Upon the publication of the first edition of *Principia* in 1687, Robert Hooke immediately accused Newton of plagiarism, claiming that he had discovered the theory of inverse squares and that Newton had stolen his work. The charge was unfounded, as most scientists knew, for Hooke had only theorized on the idea and never found a mathematical proof.

The Great Unification

"Every particle attracts every other particle in the universe with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between their centers."

Source: *Principea*, by Issac Newton

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

Where F is the gravitational force acting between two objects, m_1 and m_2 are the masses of the objects, r is the distance between the centers of their masses, and G is the gravitational constant.

A theory capable of unifying all of observable reality is one of the primary goals of physics. The “first great unification” was Isaac Newton’s 17th century unification of gravity, which brought together understandings of gravity on Earth with the observable behavior of celestial bodies in space. This process of “unifying” forces continues today, with the ultimate goal of finding a theory of everything.

Old Age and Death

By the end of his life, Newton was one of the most famous men in England, his pre-eminence in matters of science was unchallenged. He had also become wealthy, and invested his income wisely. He had enough to make sizable gifts to charity and leave a small fortune in his will.

Whether he was happy or not is another question. He never made friends easily, and in his later years his peculiar combination of pride, insecurity, and distraction interfered with his relationships. He never married, and lived as the “monk of science,” having channeled all his energy into his work.

In later life, he ate mainly vegetables and broth, and was plagued by a stone in the bladder. In 1725 he fell ill with gout, and endured hemorrhoids the following year. Meanwhile, the pain from his bladder stones grew worse, and on March 19, 1727, he blacked out, never to regain consciousness.

He died on March 20, at the age of eighty-five, and was buried in Westminster Abbey. His funeral was attended by all of England’s *self-described* “most eminent”, and his coffin was carried by those who fancied themselves “noblemen.” It was, as a contemporary noted, a funeral fit for a king.

”If I have seen further it is by standing on the shoulders of Giants.”

Source: Isaac Newton

Discoveries

Newton’s fame grew after his death, as many of his contemporaries proclaimed him the greatest genius who ever lived. This may be a slight exaggeration, but his discoveries had a huge impact on Western thought, modern science and technology, and shaping of the modern world. He made significant discoveries in astronomy, optics, physics of motion, and mathematics.

1. He theorized that white light was a composite of all colors of the visible spectrum, and that light was composed of particles.

2. His momentous book on physics, *Principia*, contains information on nearly all the essential concepts of physics except energy, helping him explain the Laws of Motion and the Theory of Gravity.
3. Along with Leibniz, Newton developed the modern mathematics of calculus.
4. In 1687, he published his most acclaimed work, *Philosophiae Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*), which is the single most influential book on physics of all time.
5. In 1705, he was knighted by Queen Anne of England, making him Sir Isaac Newton.

Legacy

Newton's Law of Gravitation has since been superseded by Albert Einstein's Theory of General Relativity, but it continues to be used as an excellent approximation of the effects of gravity in most situations. Relativity is required only when extreme accuracy is needed, or when dealing with very strong gravitational fields, such as near very massive and dense objects (such as Black Holes), or at relatively small distances (such as Mercury's orbit around the Sun).

In time, Newton was proven wrong on some of his key assumptions. As Hooke thought, light energy does act like a wave. More significantly, Albert Einstein overturned Newton's concept of the universe, stating that space, distance and motion were not absolute but relative, and showing that space and time are one fabric, now known as "space-time," and that the universe was a larger and far more fantastical place than Newton could have dreamed. Yet, perhaps these later discoveries would not have surprised the great scientist. As an old man, when asked for an assessment of his achievements, Newton replied:

> *"I do not know what I may appear to the world; but to myself I seem to have been only like a boy playing on the seashore, and diverting myself now and then in finding a smoother pebble or prettier shell than ordinary, while the great ocean of truth lay all undiscovered before me."*

Seeing Further...

- *Principia* in English (PDF)
- *Principia* in English (HTML)
- *Principia* in Latin at Project Guttenberg (PDF)
- *Opticks* in English at Project Guttenberg (HTML)

Sources

- https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/newtons-laws-of-motion/
- https://en.wikipedia.org/wiki/Newton%27s_law_of_universal_gravitation
- https://en.wikipedia.org/wiki/Unification_(physics)

Review

Newton's Bio, Impulse and Momentum

Elastic and Inelastic Collisions

Potential and Kinetic Energy

Physics II: Mechanics: **Name** ________________
Summerfield Waldorf School and Farm **Date** ________________

Review

Kepler's Three Laws of Planetary Motion, Centripetal Acceleration

Newton's Derivation of Universal Force of Gravity

Bridge Project Contest

Competition Rules

1. Evaluate fairly. (Let the math be your guide.)
2. Vote fairly.
3. In case of disagreement, ye humble teacher's decision shall be final. *Basta!*

Team	**Bridge Capacity**	**Bridge Weight**	**Efficiency** $= \frac{Capacity}{Weight}$
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Ballot	**Winning Team**	**Runner Up Team**
Most Efficient Bridge		
Most Beautiful Bridge		
Most Original Bridge		
Most Strong Bridge[1]		
Most Awesome Bridge[1]		
Most Crazy Bridge[1]		
Most "None of the Above" Bridge[1]		

1. Apologies to English teachers everywhere. Sometimes consistency matters more than rules.

Most Handy Unit Conversions

- 1 $lb = 453.59237\ g$
- 1 $kg = 1000\ g$

Review, Last day of school

Assignments

✓	**Assignment**	**Due**	**Grade**
	HW **Signed Lab Safety Agreement**	Next class	
	CW **Opening Questions and Journal Notes**	Next class	
	HW **Lab 1 — Inclined Plane Observations**	5/19	
	HW **MLB Page — Inertia**	5/19	
	CW **Opening Questions and Journal Notes**	Next class	
	HW **Lab 2 — Acceleration of Gravity Observations**	5/19	
	HW **Worksheet — Inductive vs. Deductive Reasoning**	5/19	
	HW **MLB Page — Philosophy of Science**	5/19	
	CW **Opening Questions and Journal Notes**	Next class	
	HW **Lab 2 — Acceleration of Gravity Conclusion**	5/19	
	HW **Lab 3 — Gravity and the Pendulum Observations**	5/18	
	CW **Opening Questions and Journal Notes**	Next class	
	HW **Lab 3 — Gravity and the Pendulum Conclusions**	asdf	
	QZ **Quiz 1 — Recent Topics**	asdf	
	HW **First Main Lesson Book Check**	5/19	
	CW **Opening Questions and Journal Notes**		
	Project **Bridge Building Project Begins**	6/7	
	QZ **Quiz 2 — Recent Topics**	5/26	
	HW **Second Main Lesson Book Check**	5/26	
	CW **Opening Questions and Journal Notes**		
	CW **Opening Questions and Journal Notes**		
	CW **Opening Questions and Journal Notes**		
	HW **Study for Quiz 3**	6/2	
	QZ **Quiz 3 — Recent Topics**		
	HW **Third Main Lesson Book Check**	6/2	
	CW **Opening Questions and Journal Notes**	6/5	
	CW **pening Questions and Journal Notes**		
	CW **Opening Questions and Journal Notes**		
	CW **ridge Building Project Presentations**		
	HW **Study for Quiz 4**	6/8	
	QZ **Quiz 4 — Recent Topics**		
	HW **Final Main Lesson Book Check**	6/9	

Lab Report **Student**

Points	1	2	3	Score
Layout	Paper and/or layout not appropriate for content. Important elements missing or poorly arranged. Some creases, smudges, or torn edges. Margins not adequate for binding. Page not bound into MLB.	Paper and layout mostly appropriate for content. All important elements present and adequately arranged. Few creases, smudges, or torn edges. Margins adequate for binding. Page bound into MLB.	Paper and layout appropriate for content. All important elements present and neatly arranged. No creases, smudges, or torn edges. Margins adequate for binding. Page bound into MLB.	
Text	Statement of Purpose, List of Materials, Procedures, Observation, Diagrams, Data, or Conclusion missing or inadequate. Titles illegible or not underlined. Length not adequate for topic. Few relevant scientific terms included. Significant errors in grammar, spelling, punctuation or word choice. Text is messy or illegible.	Statement of Purpose, List of Materials, Procedures, Observation, Diagrams, Data, or Conclusion sections adequate. Titles legible. Length not adequate for topic. Some relevant scientific terms included. A few significant errors in grammar, spelling, punctuation or word choice. Text is sufficiently legible.	Statement of Purpose, List of Materials, Procedures, Observation, Diagrams, Data, or Conclusion sections all complete, clear and accurate. Titles legible and underlined. Length appropriate for topic. All relevant scientific terms included. No significant errors in grammar, spelling, punctuation or word choice. All text is neat and clearly legible.	
Math	Few or no mathematical variables, equations, or formulas support the topic.	Some relevant mathematical variables, equations, and formulas support the topic.	All relevant mathematical variables, equations, and formulas support the topic.	
Diagrams	Diagrams incomplete or missing. Lines that should be straight, are not. Key elements not labeled.	One or more diagrams included. Most lines that should be straight, are. Most key elements labeled.	One or more diagrams included. All lines that should be straight, are. All key elements labeled.	
Data	Related data missing, inaccurate, or unclear. Many units or symbols missing.	Related data presented in a clear and logical tabular or graphic format. Data complete and accurate. A few units or symbols missing.	Related data presented in a clear and logical tabular or graphic format. Data complete and accurate. Units or symbols shown as needed.	
Timeliness	Significantly late	Late	On time	

Main Lesson Book Page **Student**

Points	**1**	**2**	**3**	**Score**
Layout	Paper and/or layout not appropriate for content. Important elements missing or poorly arranged. Some creases, smudges, or torn edges. Margins not adequate for binding. Page not bound into MLB.	Paper and layout mostly appropriate for content. All important elements present and adequately arranged. Few creases, smudges, or torn edges. Margins adequate for binding. Page bound into MLB.	Paper and layout appropriate for content. All important elements present and neatly arranged. No creases, smudges, or torn edges. Margins adequate for binding. Page bound into MLB.	
Text	Text is scientifically inaccurate. Length of text not appropriate for the topic. Titles illegible or not underlined. Length inadequate for topic. Relevant scientific terms missing or misused. Many significant errors in grammar, spelling, punctuation or word choice. Text is messy or illegible.	Text is scientifically fairly accurate. Length of text adequate for the topic. Titles legible and underlined. Length adequate for topic. Most relevant scientific terms included. Few significant errors in grammar, spelling, punctuation or word choice. All text is adequately legible.	Text is scientifically accurate. Length of text appropriate for the topic. Titles clearly legible and underlined. Length appropriate for topic. All relevant scientific terms included. No significant errors in grammar, spelling, punctuation or word choice. All text is neat and clearly legible.	
Math	Few or no mathematical variables, equations, or formulas added to support the topic.	Some relevant mathematical variables, equations, and formulas added to support the topic.	All relevant mathematical variables, equations, and formulas added to support the topic.	
Diagrams	Diagrams incomplete or missing. Lines that should be straight, are not. Key elements not labeled.	One or more diagrams included. Most lines that should be straight, are. Most key elements labeled.	One or more diagrams included. All lines that should be straight, are. All key elements labeled.	
Data	Related data missing, inaccurate, or unclear. Many units or symbols missing.	Related data presented in a clear and logical tabular or graphic format. Data complete and accurate. A few units or symbols missing.	Related data presented in a clear and logical tabular or graphic format. Data complete and accurate. Units or symbols shown as needed.	
Timeliness	Significantly late	Late	On time	

Review of Exponents

What are Exponents?

Exponents are a shorthand way to show how many times a number (called the base) is multiplied to itself. For example, in the **power** 8^2, 8 is the **base** and 2 is the **exponent**. This expression tells us to multiply 8 to itself twice, or "8 to the power of 2".

$$8^2 = (8 \times 8) = 64$$

Warning: Watch for the Karat! Sometimes we use the karat symbol ^ (Shift-6 on a computer keyboard) to indicate an exponent. For example: 2^4 $= 2^4 = 2 \times 2 \times 2 \times 2 = 16$.

Negative Exponents

In mathematics, the negative symbol actually means "the opposite of". The opposite of a positive number is a negative number. The opposite of a negative number is a positive number ($-(-x) = x$). The opposite of addition is subtraction. The opposite of multiplication is division.

Because exponents mean multiple-multiplication, the opposite of an exponent means multiple-division. To turn a negative exponent into a positive exponent, simply move the power to the other side of the division line, and make the exponent positive.

$$\frac{a^3 b^{-5}}{c^{-4} d^7} = \frac{a^3 c^4}{b^5 d^7}$$

$$\frac{3}{x^{-4}} = 3x^4$$

Example 1: Moving a negative power in the numerator to the denominator.

$$8^{-1} = \frac{1}{8^1} = \frac{1}{8} = 1 \div 8 = 0.125$$

Example 2: Moving a negative power in the denominator to the numerator.

$$\frac{1}{12^{-3}} = \frac{12^3}{1} = \frac{(12 \times 12 \times 12)}{1} = 1,728$$

Example 3: Removing a negative exponent in detail

$$\begin{aligned}
5^{-3} &= \left(\frac{5}{1}\right)^{-3} && \textit{Write the power as a fraction} \\
&= \left(\frac{1}{5}\right)^{3} && \textit{Invert the fraction; the exponent becomes positive} \\
&= \left(\frac{1}{5} \times \frac{1}{5} \times \frac{1}{5}\right) = \frac{1}{(5 \times 5 \times 5)} = \frac{1}{5^3} && \textit{Equivalent forms; simplify to solve} \\
&= \frac{1}{125} = 0.008 && \textit{Solution as fraction and decimal}
\end{aligned}$$

Zero Exponents

The value of a zero exponent (x^0) is always 1.

$$1 = 2^0 = 3^0 = 4^0 = 5^0 = 6^0 = 7^0 = n^0$$

Power	Factored = Solution	Pattern
2^4	$(2 \times 2 \times 2 \times 2) = 16$	
2^3	$(2 \times 2 \times 2) = 8$	$(16 \div 2)$
2^2	$(2 \times 2) = 4$	$(8 \div 2)$
2^1	$(2) = 2$	$(4 \div 2)$
2^0	$= 1$	$(2 \div 2)$
$2^{-1} = \frac{1}{2^1}$	$= \frac{1}{2}$	$(1 \div 2)$
$2^{-2} = \frac{1}{2^2}$	$\frac{1}{(2 \times 2)} = \frac{1}{4}$	$\left(\frac{1}{2} \div 2\right)$
$2^{-3} = \frac{1}{2^3}$	$\frac{1}{(2 \times 2 \times 2)} = \frac{1}{8}$	$\left(\frac{1}{4} \div 2\right)$
$2^{-4} = \frac{1}{2^4}$	$\frac{1}{(2 \times 2 \times 2 \times 2)} = \frac{1}{16}$	$\left(\frac{1}{8} \div 2\right)$

Adding Exponents

Subtracting Exponents

Multiplying Exponents

Dividing Exponents

Greek Alphabet

While there are common usages for many symbols, other letters are often used for the same purpose. This is because there are only so many symbols in the Greek and Latin alphabets, and by tradition scientists rarely use symbols from other languages. Be careful NOT to associate a symbol exclusively with one particular meaning rather than understanding the underlying relations.

	Letter	**Lowercase**	**Uppercase**
1	Alpha	α	A (Angular acceleration, Coefficient)
2	Beta	β	B (Sound intensity)
3	Gamma	γ	Γ (Gamma ray)
4	Delta	δ ("Infinitesimal change in")	Δ ("Change in")
5	Epsilon	ϵ	E
6	Zeta	ζ	Z
7	Eta	η	E
8	Theta	θ (Angle (°, rad))	Θ
9	Iota	ι	I
10	Kappa	κ	K
11	Lambda	λ	Λ (Wavelength)
12	Mu	μ (Coefficient of friction)	M
13	Nu	ν	N (Frequency)
14	Xi	ξ	Ξ
15	Omicron	O	0 (Damping coefficient)
16	Pi	π (diameter to circumference)	Π
17	Rho	ρ	R (Volume density, Resistivity)
18	Sigma	σ	Σ (Sum)
19	Tau	τ	T (Torque)
20	Upsilon	υ	Υ
21	Phi	ϕ	Φ
22	Chi	χ	X
23	Psi	ψ	Ψ (Wave function)
24	Omega	ω (Angular velocity)	Ω (Ohms (unit of electrical resistance)

Sources

- Wikipedia: Greek Alphabet

Review of Scientific Notation

What is Scientific Notation?

We sometimes need to deal with numbers that have many leading or trailing zeros. This can be time consuming and error prone. An elegant solution is Scientific Notation (SN), which takes advantage of the power of exponents. To avoid possible confusion, the constant term is always shown with exactly one digit to the left of the decimal point. For example, the number 23,000 is written as 2.3×10^4 rather than 23×10^3, and the number 4,602,000,000,000 is written as 4.602×10^{12}.

1. Move the decimal point until there is only one significant (non-zero) digit to the left of the point. This digit must be ($1 \leq \mathrm{M} < 10$).
2. Multiply this new term to the power of 10 that is equal to the number of digits the decimal point was moved.

$$\begin{aligned} 100 &= 1 \times 10^2 && \textit{Decimal point moves 2 places to the left.} \\ 2,000 &= 2 \times 10^3 && \textit{Decimal point moves 3 places to the left.} \\ 4,000,000,000 &= 4 \times 10^9 && \textit{Decimal point moves 9 places to the left.} \end{aligned}$$

Very small values are shown using negative exponents.

$$\begin{aligned} .0002 &= 2 \times 10^{-4} && \textit{Decimal point moves 4 places to the right.} \\ .00054 &= 5.4 \times 10^{-4} && \textit{Decimal point moves 4 places to the right.} \end{aligned}$$

Adding and Subtracting (with Like Exponents)

If the numbers have the same exponent, use the Distributive Property of Algebra.

1. Add or subtract the constant terms.
2. Keep the value of the exponent.

$$\begin{aligned} (4 \times 10^8) + (3 \times 10^8) &= (4 + 3) \times 10^8 &&= 7 \times 10^8 \\ (6.2 \times 10^{-3}) - (2.8 \times 10^{-3}) &= (6.2 - 2.8) \times 10^{-3} &&= 3.4 \times 10^{-3} \end{aligned}$$

Adding and Subtracting (with Unlike Exponents)

If the exponents are not the same, they must be made the same before the values can be added or subtracted. Move the decimal points and adjust the exponents until all exponents are the same.

$$\begin{aligned} (4 \times 10^6) + (3 \times 10^5) &= (4 \times 10^6) + (\color{red}{0.3} \times \color{teal}{10^6}) \\ &= (4 + \color{red}{0.3}) \times \color{teal}{10^6} \\ &= 4.3 \times 10^6 \end{aligned}$$

Multiplying and Dividing

Values in Scientific Notation can be multiplied and divided whether or not the exponents are the same. We simply add the exponents to multiply, or subtract the exponents to divide.

Multiplying

1. Multiply the constant terms.
2. Add the exponents.

$$\begin{aligned} &(3\times 10^6)\times(2\times 10^3) &&= (3\times 2)\times 10^9 \\ &(3\times 10^6 m)\times(2\times 10^3 m) &&= (3\times 2)\times 10^9 m^2 \quad \textit{With units in meters.} \end{aligned}$$

Dividing

1. Divide the constant terms
2. Subtract the exponent of the divisor (denominator) from the exponent of the dividend (numerator).

$$\frac{(6\times 10^8)}{(2\times 10^5)} = \left(\frac{6}{2}\right)\times 10^{(8-5)} = (3\times 10^3)$$

Warning: Watch for the Karat! Sometimes we use the karat symbol ^ (Shift-6 on a computer keyboard) to indicate an exponent. For example: 2^4 $= 2^4 = 2\times 2\times 2\times 2 = 16$.

Study Guide: Physics Jokes

Chemistry jokes are funny periodically, but physics jokes...

...have more potential!

The science of Physics creates long, complicated equations to explain why...

...round balls roll.

A photon checks into a hotel.

The front desk asks *"Do you need help with your luggage?"* What does the photon reply?

"I don't have any luggage. I'm traveling light."

Frames of Reference

A bar walks into a man...

oops, wrong frame of reference.

A neutrino walks through a bar...

Dead Physicists

It has been scientifically proven that old physicists never die. What actually happens to them (scientifically-speaking of course)?

Their wave functions go to zero as time goes to infinity.

What did the Nuclear Physicist have for lunch?

Fission Chips

What did one electron say to the other electron?

Don't get excited. You'll only get into a state!

Why should you always travel with neutrons?

Wherever they go, there's no charge.

Where does bad light go?

To prism.

How many theoretical physicists does it take to change a light bulb?

Two. One to hold the bulb and one to rotate the universe.

What looks blue and smells like red paint?

Red paint moving very fast towards you.

Schrodinger and the Cop

Schrodinger and Heisenberg were out driving together when they were pulled over by a policeman.

The cop walks up to the window and asks, *"Sir, do you know how fast you were going?"*

Heisenberg replies, *"No, but I know exactly where I was."*

The cop is not amused and orders the physicists to open their trunk. He looks inside and sees a dead cat. *"Do you know there's a dead cat in your trunk?"*

Schrodinger replies, *"Well, I do now!"*

How many lives do radioactive cats have?

18 half-lives

Two atoms are walking down the street.

One turns to the other and says, *"Oh, no! I think I lost an electron!"*

The other responds, *Are you sure?"*

"Yes, I'm positive!"

Studying radioactivity is as easy as...

alpha, beta and gamma

Newton's Square

Einstein, Newton and Pascal were playing Hide and Seek. Einstein slowly counted to 100 while Pascal ran off and hid. Newton carefully drew a square on the ground with a side measure of exactly 1 meter, and sat down in the middle it.

When Einstein finished counting and opened his eyes, he immediately spotted Newton. *"That was easy, I found you Newton!"* he proclaimed with pride. Newton replied *"No you didn't, I'm Pascal."*

$$1\ Pascal = \frac{1\ Newton}{M^2}$$

Two cats slide off a roof. Which one hit the ground first?

The cat with smaller "mu" hits the ground first.

Note: "mu" is the coefficient of friction.*

What did the male magnet say to the female magnet?

From your backside, I thought you were repulsive. However, after seeing you from the front, I find you rather attractive.

What did one quantum physicist say when he wanted to fight another quantum physicist?

Let me atom.

Have you heard of the physicist who got chilled to absolute zero.

He's 0K (zero k) now.

What's the difference between an auto mechanic and a quantum mechanic?

The quantum mechanic can get the car inside the garage without opening the door.

What did the subatomic duck say?

Quark!

The Physicist's Husband

A newlywed husband is discouraged by his wife's obsession with physics. Afraid of being second fiddle to her profession, he finally confronts her: *"Do you love physics more than me?"*

"Of course not, dear–I love you much more!"

Happy, although skeptical, he challenges her: *"Well, then prove it!"*

Pondering a bit, she responds: *"Ok... Let epsilon be greater than zero..."*

Physics Limerick

There was an old lady called Wright

Who could travel much faster than light.

She departed one day

In a relative way

And returned on the previous night.

Glossary: Scientific Thinking

accuracy: the degree to which a measured value agrees with correct value for that measurement

approximation: an estimated value based on prior experience and reasoning

classical physics: physics that was developed from the Renaissance to the end of the 19th century

conversion factor: a ratio expressing how many of one unit are equal to another unit

derived units: units that can be calculated using algebraic combinations of the fundamental units

English units: system of measurement used in the United States; includes units of measurement such as feet, gallons, and pounds

fundamental units: units that can only be expressed relative to the procedure used to measure them

kilogram: the SI unit for mass, abbreviated (kg)

law: a description, using concise language or a mathematical formula, a generalized pattern in nature that is supported by scientific evidence and repeated experiments

meter: the SI unit for length, abbreviated (m)

method of adding percents: the percent uncertainty in a quantity calculated by multiplication or division is the sum of the percent uncertainties in the items used to make the calculation

metric system: a system in which values can be calculated in factors of 10

model: representation of something that is often too difficult (or impossible) to display directly

modern physics: the study of relativity, quantum mechanics, or both

order of magnitude: refers to the size of a quantity as it relates to a power of 10

percent uncertainty: the ratio of the uncertainty of a measurement to the measured value, expressed as a percentage

physical quantity: characteristic or property of an object that can be measured or calculated from other measurements

physics: the science concerned with describing the interactions of energy, matter, space, and time; it is especially interested in what fundamental mechanisms underlie every phenomenon

precision: the degree to which repeated measurements agree with each other

quantum mechanics: the study of objects smaller than can be seen with a microscope

relativity: the study of objects moving at speeds greater than about 1% of the speed of light, or of objects being affected by a strong gravitational field

scientific method: a method that typically begins with an observation and question that the scientist will research; next, the scientist typically performs some research about the topic and then devises a hypothesis; then, the scientist will test the hypothesis by performing an experiment; finally, the scientist analyzes the results of the experiment and draws a conclusion

second: the SI unit for time, abbreviated (s)

SI units: the international system of units that scientists in most countries have agreed to use; includes units such as meters, liters, and grams

significant figures: express the precision of a measuring tool used to measure a value

theory: an explanation for patterns in nature that is supported by scientific evidence and verified multiple times by various groups of researchers

uncertainty: a quantitative measure of how much your measured values deviate from a standard or expected value

units: a standard used for expressing and comparing measurements penstax.org/books/college-physics Source: OpenStax College Physics (Accessed: 2023-05-08)

Glossary: Bridges

Abutment: Part of a structure which supports the end of a span or accepts the thrust of an arch; often supports and retains the approach embankment.

Anchor span: Located at the outermost end, it counterbalances the arm of span extending in the opposite direction from a major point of support. Often attached to an abutment.

Anchorage: Located at the outermost ends, the part of a suspension bridge to which the cables are attached. Similar in location to an abutment of a beam bridge.

Aqueduct: A pipe or channel, open or enclosed, which carries water. May also be used as part of a canal to carry boats. Sometimes carried by a bridge.

Arch: A curved structure which supports a vertical load mainly by axial compression.

Arch barrel: The inner surface of an arch extending the full width of the structure.

Arch ring: An outer course of stone forming the arch. Made of a series of voussoirs. An archivolt is an arch ring with decorating moldings.

Ballustrade: A decorative railing, especially one constructed of concrete or stone, including the top and bottom rail and the vertical supports called ballusters. May also include larger vertical supports called stanchions.

Baltimore truss: A subdivided Pratt truss commonly constructed for the Baltimore and Ohio Railroad. It has angled end posts and a top chord which is straight and horizontal. Compare to camelback truss and Pennsylvania truss.

Bascule bridge: From the French word for ”see-saw,” a bascule bridge features a movable span (leaf) which rotates on a horizontal hinged axis (trunnion) to raise one end vertically. A large counterweight is used to offset to weight of the raised leaf. May have a single raising leaf or two which meet in the center when closed. Compare to swing bridge and vertical lift bridge.

Beam: A horizontal structure member supporting vertical loads by resisting bending. A girder is a larger beam, especially when made of multiple plates. Deeper, longer members are created by using trusses.

Bearing: A device at the ends of beams which is placed on top of a pier or abutment. The ends of the beam rest on the bearing.

Bent: Part of a bridge substructure. A rigid frame commonly made of reinforced concrete or steel which supports a vertical load and is placed transverse to the length of a structure. Bents are commonly used to support beams and girders. An end bent is the supporting frame forming part of an abutment. Each vertical member of a bent may be called a column, pier, or pile. The horizontal member resting on top of the columns is a bent cap. The columns stand on top of some type of foundation or footer which is usually hidden below grade. A bent commonly has at least two or more vertical supports. Another term used to describe a bent is capped pile pier. A support having a single column with bent cap is sometimes called a ”hammerhead” pier.

Bowstring truss: A truss having a curved top chord and straight bottom chord meeting at each end.

Box girder: A steel beam built-up from many shapes to form a hollow cross-section.

Brace-ribbed arch (trussed arch): An arch with parallel chords connected by open webbing.

Bridge: A raised structure built to carry vehicles or pedestrians over an obstacle.

Buttress: A wall projecting perpendicularly from another wall which prevents its outward movement. Usually wider at its base and tapering toward the top.

Cable: Part of a suspension bridge extending from an anchorage over the tops of the towers and down to the opposite anchorage. Suspenders or hangers are attached along its length to support the deck.

Cable-stayed bridge: A variation of suspension bridge in which the tension members extend from one or more towers at varying angles to carry the deck. Allowing much more freedom in design form, this type does not use cables draped over towers, nor the anchorages at each end, as in a traditional suspension bridge.

Camber: A positive, upward curve built into a beam which compensates for some of the vertical load and anticipated deflection.

Camelback truss: A truss having a curved top chord and straight bottom chord meeting at each end, especially when there are more than one used end to end. Compare to Baltimore truss and Pennsylvania truss.

Cantilever: A structural member which projects beyond a supporting column or wall and is counterbalanced and/or supported at only one end.

Castellated girder: A steel beam fabricated by making a zig-zag cut along its web, then welding the two sides together at their peaks. This creates a beam which has increased depth and therefore greater strength, but is not increased in weight.

Catenary: Curve formed by a rope or chain hanging freely between two supports. The curved cables or chains used to support suspension bridges may be referred to as catenaries.

Centering: Temporary structure or falsework supporting an arch during construction.

Chord: Either of the two principal members of a truss extending from end to end, connected by web members.

Column: A vertical structural member used to support compressive loads. Also see pier and pile.

Continuous span: A superstructure which extends as one piece over multiple supports.

Corbelled arch: Masonry built over an opening by progressively overlapping the courses from each side until they meet at the top center. Not a true arch as the structure relies on strictly vertical compression, not axial compression.

Counter: A truss web member which functions only when a structure is partially loaded.

Cradle: Part of a suspension bridge which carries the cable over the top of the tower.

Cripple: A structural member which does not extend the full height of others around it and does not carry as much load.

Crown: On road surfaces, where the center is the highest point and the surface slopes downward in opposite directions, assisting in drainage. Also a point at the top of an arch.

Culvert: A drain, pipe or channel which allows water to pass under a road, railroad or embankment.

Deck: The top surface of a bridge which carries the traffic.

Deck truss: A truss which carries its deck on its top chord. Compare to pony truss and through truss.

Elliptical arch: An arch formed by mutiple arcs each of which is drawn from its own center. Compare to a roman arch which is a semi-circular arc drawn from a single centerpoint.

Embankment: Angled grading of the ground.

End post: The outwardmost vertical or angled compression member of a truss.

Expansion joint: A meeting point between two parts of a structure which is designed to allow for movement of the parts due to thermal or moisture factors while protecting the parts from damage.

Commonly visible on a bridge deck as a hinged or movable connection.

Extrados: The outer exposed curve of an arch; defines the lower arc of a spandrel.

Eye bar: A structural member having a long body and an enlarged head at each end. Each head has a hole though which a pin is inserted to connect to other members.

Falsework: Temporary structure used as support during construction. Falsework for arch construction is called "centering."

Fill: Earth, stone or other material used to raise the ground level, form an embankment or fill the inside of an abutment, pier or closed spandrel.

Finial: A sculpted decorative element placed at the top of a spire or highpoint of a structure.

Fixed arch: A structure anchored in its position. Compare to hinged arch.

Floor beam: Horizontal members which are placed transversely to the major beams, girders, or trusses; used to support the deck.

Footing: The enlarged lower portion of the substructure or foundation which rests directly on the soil, bedrock, or piles; usually below grade and not visible.

Gabion: A galvanized wire box filled with stones used to form an abutment or retaining wall.

Girder: A horizontal structure member supporting vertical loads by resisting bending. A girder is a larger beam, especially when made of multiple metal plates. The plates are usually riveted or welded together.

Gusset plate: A metal plate used to unite multiple structural members of a truss.

Haunch: The enlarged part of a beam near its supported ends which results in increased strength; visible as the curved or angled bottom edge of a beam.

Hinged arch: A two-hinged arch is supported by a pinned connection at each end. A three-hinged arch also includes a third pinned connection at the crown of the arch near the middle of a span. Compare to fixed arch.

Howe truss: A type of truss in which vertical web members are in tension and diagonal web members in compression. Maybe be recognized by diagonal members which appear to form an "A" shape (without the crossbar) toward the center of the truss when viewed in profile. Compare to Pratt truss and Warren truss.

Humpback: A description of the sideview of a bridge having relatively steep approach embankments leading to the bridge deck.

Impost: The surface which receives the vertical weight at the bottom of an arch.

Intrados: The interior arc of an arch.

Jersey barrier: A low, reinforced concrete wall wider at the base, tapering vertically to near mid-height, then continuing straight up to its top. The shape is designed to direct automotive traffic back toward its own lane of travel and prevent crossing of a median or leaving the roadway. Commonly used on new and reconstructed bridges in place of decorative ballustrades, railings or parapets.

Keystone: The uppermost wedge-shaped voussoir at the crown of an arch which locks the other voussoirs into place.

King Truss: Two triangular shapes sharing a common center vertical member (king post); the simplest triangular truss system. Compare to queen truss.

Knee brace: Additional support connecting the deck with the main beam which keep the beam from buckling outward. Commonly made from plates and angles.

Lag: Crosspieces used to connect the ribs in centering.

Lateral bracing: Members used to stabilize a structure by introducing diagonal connections.

Lattice: An assembly of smaller pieces arranged in a gridlike pattern; sometimes used a decorative element or to form a truss of primarily diagonal members.

Lenticular truss: A truss which uses curved top and bottom chords placed opposite one another to form a lens shape. The chords are connected by additional truss web members.

Member: One of many parts of a structure, especially one of the parts of a truss.

Parabola: A form of arch defined by a moving point which remains equidistant from a fixed point inside the arch and a moving point along a line. This shape when inverted into an arch structure results in a form which allows equal vertical loading along its length.

Parapet: A low wall along the outside edge of a bridge deck used to protect vehicles and pedestrians.

Pennsylvania truss: A subdivided Pratt truss invented for use by the Pennsylvania Railroad. The Pennsylvania truss is similar in bracing to a Baltimore truss, but the former has a camelback profile while the latter has angled end posts only, leaving the upper chord straight and horizontal. Compare to camelback truss and Baltimore truss.

Pier: A vertical structure which supports the ends of a multi-span superstructure at a location between abutments. Also see column and pile.

Pile: A long column driven deep into the ground to form part of a foundation or substructure. Also see column and pier.

Pin: A cylindrical bar which is used to connect various members of a truss; such as those inserted through the holes of a meeting pair of eyebars.

Pony truss: A truss which carries its traffic near its top chord but not low enough to allow crossbracing between the parallel top chords. Compare to deck truss and through truss.

Portal: The opening at the ends of a through truss with forms the entrance. Also the open entrance of a tunnel.

Post: One of the vertical compression members of a truss which is perpendicular to the bottom chord.

Pratt truss: A type of truss in which vertical web members are in compression and diagonal web members in tension. Many possible configuartions include pitched, flat, or camelback top chords. Maybe be recognized by diagonal members which appear to form a ”V” shape toward the center of the truss when viewed in profile. Variations include the Baltimore truss and Pennsylvania truss. Compare to Warren truss and Howe truss.

Pylon: A monumental vertical structure marking the entrance to a bridge or forming part of a gateway.

Queen Truss: A truss having two triangular shapes spaced on either side of central apex connected by horizontal top and bottom chords. Compare to king truss.

Reinforcement: Adding strength or bearing capacity to a structural member. Examples include the placing of metal rebar into forms before pouring concrete, or attaching gusset plates at the intersection of multiple members of a truss.

Revet: The process of covering an embankment with stones.

Revetment: A facing of masonry or stones to protect an embankment from erosion.

Rib: Any one of the arched series of members which is parallel to the length of a bridge, especially those on a metal arch bridge.

Rigid frame bridge: A type of girder bridge in which the piers and deck girder are fastened to form a single unit. Unlike typical girder bridges which are constructed so that the deck rests on bearings atop the piers, a rigid frame bridge acts as a unit. Pier design may vary.

Rise: The measure of an arch from the spring line to the highest part of the intrados, which is to say from its base support to the crown.

Segmental arch: An arch formed along an arc which is drawn from a point below its spring line, thus forming a less than semicircular arch. The intrados of a Roman arch follows an arc drawn from a point on its spring line, thus forming a semi-circle.

Simple span: A span in which the effective length is the same as the length of the spanning structure. The spanning superstructure extends from one vertical support, abutment or pier, to another, without crossing over an intermediate support or creating a cantilever.

Skew: When the superstructure is not perpendicular to the substructure, a skew angle is created. The skew angle is the acute angle between the alignment of the superstructure and the alignment of the substructure.

Span: The horizontal space between two supports of a structure. Also refers to the structure itself. May be used as a noun or a verb. The clear span is the space between the inside surfaces of piers or other vertical supports. The effective span is the distance between the centers of two supports.

Spandrel: The roughly triangular area above an arch and below a horizontal bridge deck. A closed spandrel encloses fill material. An open spandrel carries its load using interior walls or columns.

Splice plate: A plate which joins two girders. Commonly riveted or bolted.

Springer: The first voussoir resting on the impost of an arch.

Spring line: The place where an arch rises from its support; a line drawn from the impost.

Stanchion: One of the larger vertical posts supporting a railing. Smaller, closely spaced vertical supports are ballusters. Also see ballustrade.

Stiffener: On plate girders, structural steel shapes, such as an angle, are attached to the web to add intermediate strength.

Stringer: A beam aligned with the length of a span which supports the deck.

Strut: A compressive member.

Substructure: The portion of a bridge structure including abutments and piers which supports the superstructure.

Superstructure: The portion of a bridge structure which carries the traffic load and passes that load to the substructure.

Suspended span: A simple beam supported by cantilevers of adjacent spans, commonly connected by pins.

Suspenders: Tension members of a suspension bridge which hang from the main cable to support the deck. Also similar tension members of an arch bridge which features a suspended deck. Also called hangers.

Suspension bridge: A bridge which carries its deck with many tension members attached to cables draped over tower piers.

Swing bridge: A movable deck bridge which opens by rotating horizontally on an axis. Compare to bascule bridge and vertical lift bridge.

Through truss: A truss which carries its traffic through the interior of the structure with crossbracing between the parallel top and bottom chords. Compare to deck truss and pony truss.

Tie: A tension member of a truss.

Tied arch: An arch which has a tension member across its base which connects one end to the other.

Tower: A tall pier or frame supporting the cable of a suspension bridge.

Trestle: A longer, multi-span structure – a series of shorter spans in which most of the spans are of similar length. Trestle is a more common term in relation to railroads, while viaduct is commonly used for streets.

Truss: A structural form which is used in the same way as a beam, but because it is made of an web-like assembly of smaller members it can be made longer, deeper, and therefore, stronger than a beam or girder while being lighter than a beam of similar dimensions.

Trussed arch: A metal arch bridge which features a curved truss.

Upper chord: Top chord of a truss.

Vault: An enclosing structure formed by building a series of adjacent arches.

Vertical lift bridge: A movable deck bridge in which the deck may be raised vertically by synchronized machinery at each end. Compare to swing bridge and vertical lift bridge.

Viaduct: A long, multi-span structure, especially one constructed of concrete. More commonly used in relation to structures carrying motor vehicles. Trestle is the term for a similar structure when used in relation to railroads.

Voussoir: Any one of the wedge shaped block used to form an arch.

Warren truss: A type of truss in which vertical web members inclined to form equilateral triangles. May be be recognized by diagonal members which appear to form a series of alternating ”V” and ”A” shapes (without the crossbar) along the length of the truss when viewed in profile. Often the triangles are bisected by vertical members to reduce the length of the members of the top chord. Compare to Pratt truss and Howe truss.

Web: The system of members connecting the top and bottom chords of a truss. Or the vertical portion of an I-beam or girder.

Wing walls: Extensions of a retaining wall as part of an abutment; used to contain the fill of an approach embankment

ttp://pghbridges.com/ Source: The pghbridges Project (Accessed: 2023-05-08)

Glossary: Motion

acceleration: the rate at which an object's velocity changes over a period of time

acceleration due to gravity: acceleration of an object as a result of gravity

average acceleration: the change in velocity divided by the time over which it changes

average speed: distance traveled divided by time during which motion occurs

average velocity: displacement divided by time over which displacement occurs

carrier particle: a fundamental particle of nature that is surrounded by a characteristic force field; photons are carrier particles of the electromagnetic force

deceleration: acceleration in the direction opposite to velocity; acceleration that results in a decrease in velocity

dependent variable: the variable that is being measured; usually plotted along the -axis

displacement: the change in position of an object

distance: the magnitude of displacement between two positions

distance traveled: the total length of the path traveled between two positions

dynamics: the study of how forces affect the motion of objects and systems

elapsed time: the difference between the ending time and beginning time

external force: a force acting on an object or system that originates outside of the object or system

force: a push or pull on an object with a specific magnitude and direction; can be represented by vectors; can be expressed as a multiple of a standard force

force field: a region in which a test particle will experience a force

free-body diagram: a sketch showing all of the external forces acting on an object or system; the system is represented by a dot, and the forces are represented by vectors extending outward from the dot

free-fall: the state of movement that results from gravitational force only

friction: a force past each other of objects that are touching; examples include rough surfaces and air resistance

independent variable: the variable that the dependent variable is measured with respect to; usually plotted along the x-axis

inertia: the tendency of an object to remain at rest or remain in motion

inertial frame of reference: a coordinate system that is not accelerating; all forces acting in an inertial frame of reference are real forces, as opposed to fictitious forces that are observed due to an accelerating frame of reference

instantaneous acceleration: acceleration at a specific point in time

instantaneous speed: magnitude of the instantaneous velocity

instantaneous velocity: velocity at a specific instant, or the average velocity over an infinitesimal time interval

kinematics: the study of motion without considering its causes

law of inertia: see Newton's first law of motion

mass: the quantity of matter in a substance; measured in kilograms

model: simplified description that contains only those elements necessary to describe the physics of a physical situation; not to be confused with actual reality, which so far remains completely unknowable

net external force: the vector sum of all external forces acting on an object or system; causes a mass to accelerate

Newton's first law of motion: a body at rest remains at rest, or, if in motion, remains in motion at a constant velocity unless acted on by a net external force; also known as the law of inertia

Newton's second law of motion: the net external force on an object with mass proportional to and in the same direction as the acceleration of the object, and inversely proportional to the mass

Newton's third law of motion: whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that the first body exerts

normal force: the force that a surface applies to an object to support the weight of the object; acts perpendicular to the surface on which the object rests

position: the location of an object at a particular time

scalar: a quantity that is described by magnitude, but not direction

slope: the difference in -value (the rise) divided by the difference in -value (the run) of two points on a straight line

system: defined by the boundaries of an object or collection of objects being observed; all forces originating from outside of the system are considered external forces

tension: the pulling force that acts along a medium, especially a stretched flexible connector, such as a rope or cable; when a rope supports the weight of an object, the force on the object due to the rope is called a tension force

thrust: a reaction force that pushes a body forward in response to a backward force; rockets, airplanes, and cars are pushed forward by a thrust reaction force

time: change, or the interval over which change occurs

vector: a quantity that is described by both magnitude and direction

weight: 'the force mathematically as: $w = mg$ where g is the magnitude and direction of the acceleration due to gravity

y-intercept: the -value when $x = 0$, or when the graph crosses the y-axis

penstax.org/books/college-physics Source: OpenStax College Physics (Accessed: 2023-05-08)

Bibliography

Physics II: Mechanics: **Name** ____________
Summerfield Waldorf School and Farm **Date** ____________

Colophon

Custom publishing system using a variety of GNU/OpenSource tools, including:

Tool	Description	Value	Cost
GNU Make	Automated builds	Priceless	\$0
LaTeX and TeX	Advanced publishing system optimized for complex documents	Priceless	\$0
LibreOffice	Excellent office suite; far superior to that bloatware of a Trojan Horse promoted by *”Small and Limp”*	Priceless	\$0
Markdown	Fast and minimal markup language	Priceless	\$0
Pandoc	The Swiss Army knife of document converters	Priceless	\$0
Python	Great programming language	Priceless	\$0