Physics IV: Optics

Class Reader

Summerfield Waldorf School and Farm

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Syllabus

This block explores the phenomena of light, optics and color. We will trace the history of ideas about light from ancient times through the classic Greek and Arabic cultures, the European Renaissance, and into the current era. We will study multiple models of light, including Aristotle's, Newton's, Goethe's and Einstein's. We will observe the physical phenomena of light, including reflection, refraction, absorption, wave/particle duality, and the Electromagnetic Spectrum. We will study light rays and diffraction using a variety of mirrors and lenses. We will explore additive vs. subtractive color, the human eye, and the phenomenon of sight. Data from our observations will be used to confirm important mathematical models. This is a college preparatory class and is approved by the University of California for transfer credits. All assignments are required.

Class Guidelines

1. Be kind.
2. Do your best.
3. Have fun.

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.

Required Student Materials

1. Journal: A binder or notebook with at least 50 blank pages
2. A few #2 graphite pencils
3. A few colored pencils (helpful for making diagrams)
4. Eraser
5. Scientific calculator (optional)

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. Reader (Will be assigned on the first day of class, and must be returned by the last day.)

Typical Assignments

1. Journal Notes
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 Maih Lesson Book binder in chronological order.

MLB 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.

Labs

During Labs, students work together in small groups to complete assignments. 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 Books 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. **Safety:** A list of all important safety warnings. *(Note: If the instruction sheet contains a detailed Safety section, you do not need to rewrite it again. Simply reference the instruction sheet with, "See Instruction Sheet", and include it with your report.)*
3. **Materials and Equipment:** A list of materials and equipment 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.)*
4. **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.
5. **Observations:** A description of the results using clear and scientific language. **Never alter actual observations to match expectations!**
6. **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.

7. **Data:** When applicable, include relevant data in tabular and/or graph form.
8. **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.
9. **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)

Homework

Homework is due as soon as class starts. There will usually be homework on 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 days to catch up on missing work, review for quizzes, or prepare for group presentations. Homework includes:

1. Review the day's journal entries, and add additional details, thoughts and questions.
2. Work on main lesson book pages and lab reports.
3. Prepare projects and group presentations.
4. Study for quizzes.

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

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

Percentage of grade	%
Participation	20%
Written Work	40%
Quizzes	40%

Late Work

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.

Contacting the Teacher

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

Assignments

Class	Topics	Assignment	Due	X
Mon, 4/17	Nature of Light	HW: Read TB. 17.1 and 17.2	Tue, 4/18	
		CW: Class notes in Journal		
Tues, Apr 18	Creek Walk	HW: Lab 1 Creek Walk: Purpose to Observations	Wed, Apr 19	
		HW: Read TB. 17:3 – 17	Wed, Apr 19	
		CW: Quiz 1: Nature of Light		
Wed, Apr 19	Photometry	HW: Lab 1 Creek Walk: Conclusion		
		CW: Quiz 2: Photometry		
Thurs, Apr 20	Photometry	HW: Lab 2: Photometry Observations	Thurs, Apr 20	
Fri, Apr 21	Quiz	CW: Quiz 3: Refraction	Wed, Apr 21	
Mon, Apr 24	Vision	HW: Demo 4: Phototopic and Scototopic Vision Observations	Tues, Apr 25	
		HW: Demo 5: Angles in Plane Mirrors Observations	Tues, Apr 25	
		HW: Lab 2: Photometry Conclusion	Tues, Apr 26	
Tues, Apr 25	Plain Mirrors	HW: Demo 6: Concave and Convex Mirrors Observations	Wed, Apr 26	
		HW: Read TB. 19:1 – 19:4	Wed, Apr 26	
Wed, Apr 26	Convex Mirrors	HW: Demo 6: Concave and Convex Mirrors	Thurs, Apr 27	
		HW: Create a refraction problem using Snell's Law. Be ready to share it in class.	Thurs, Apr 27	
Fri, Apr 28	Quiz: Mirrors	CW: Quiz4 Mirrors and Reflection		
Mon, May 1	Snell's Law	HW: Demo 6: Mirrors Conclusion	Tues, May 2	
		HW: Lab 4: Snell's Law Observations	Tues, May 2	
Tues, May 2	TiR	HW: Demo 7: TiR Observations	Wed, May 3	
Wed, May 3	Newton and Color	HW: Demo 8: Newton Observations	Thurs, May 4	
Thurs, May 4	Einstein and Theory of Relativity	HW: Complete all previous assignments	Fri, May 5	
		HW: Newton Conclusions	Fri, May 5	
Fri, May 5	Class review	HW: Completed Main Lesson Books	Fri, May 5	
		HW: Return Readers	Fri, May 5	

Review of Physics Blocks

Grade 6

1. Acoustics: vibration, pitch, volume, tone…
2. Optics: darkness and light, color, after images, complimentary colors, shadows
3. Magnetism: magnetite, compass
4. Electricity: static, friction, heat and combustion

Grade 7

1. Mechanics: 6 simple machines, levers, balance, inclined plane, wedge, screw, pulley, force over distance
2. Acoustics: Cladni plate, echoes
3. Optics: Shadows, planes and curves, illusions, pin-hole camera
4. Heat: Conduction, thermometers
5. Magnetism: Earth as a magnet
6. Electricity: electric current, sources of electricity, electromagnets, electric appliances

Grade 8

1. Hydrostatics: Archimedes' Principal, hydraulic scales, Cartesian diver, buoyancy, stability, pumps, vortices and resistance
2. Meteorology: weather, climate, clouds, wind, precipitation, earth maps
3. Electricity: motors, dynamos, generators

Grade 9: Thermodynamics heat and energy, heating metals, states of matter, steam engine, internal combustion engine

Grade 10: Mechanics Sci method, inertia, pendulum, measurement of motion, bridge building

Grade 11: Electricity static, Ben Franklin, capacitors, batteries, Ohm's Law, DC and AC current, telegraph, telephone, power generation and transmission, electromagnetism, tesla coil, alternators

Grade 12: Light Electromagnetic spectrum, reflection, refraction, diffraction, absorption, mirrors, Snell's Law, wave/particle duality, speed of light, bending light, relation to sound waves, rainbows, visible light, light spectrum, Theory of Relativity, Quantum Mechanics

The Nature of Light

Electromagnetism is one of the **four fundamental forces (or interactions)** of nature, which include the **strong interaction**, the **weak interaction**, and **gravitation**. It seems to be a combination of two fields—the electric field and the magnetic field.

We understand surprisingly little about electromagnetic energy, despite the fact that we are utterly reliant on it for everything from the electrical impulses in our brain and nervous system to global wireless communications. It warms the Earth, creates what we call light and colors, and produces rainbows and the Northern Lights.

Electromagnetic Energy Wave

An electromagnetic energy wave is a complex form of energy composed of oscillating electric and magnetic fields joined together and capable of conveying energy through space to the matter it meets.

Qualities of Electromagnetic Waves

Electromagnetic energy follows predictable patterns from the moment it is formed to the the moment it meets matter. These patterns can be defined with mathematically precise equations.

One fact (or pattern) that all the equations have in common is that what the energy does to the the matter it interactis with is dependent on the wavelength or frequency of the wave. Exactly how each physical object (including living beings) is affected by electromagnetic energy is completely dependent on how that particular object blocks or interacts with particular electromagnetic waves.

An obvious example is our eyes. We see visible light because our eyes are designed to capture wavelengths of that specific size. Other wavelengths are invisible to us, athough they may be visible to other animals with different kinds of eyes.

On the other hand, visible light passes through clear glass without affecting the glass. Colored glass contains chemicals that absorb or reflect visible light at specific wavelengths while letting other wavelengths pass through undisturbed.

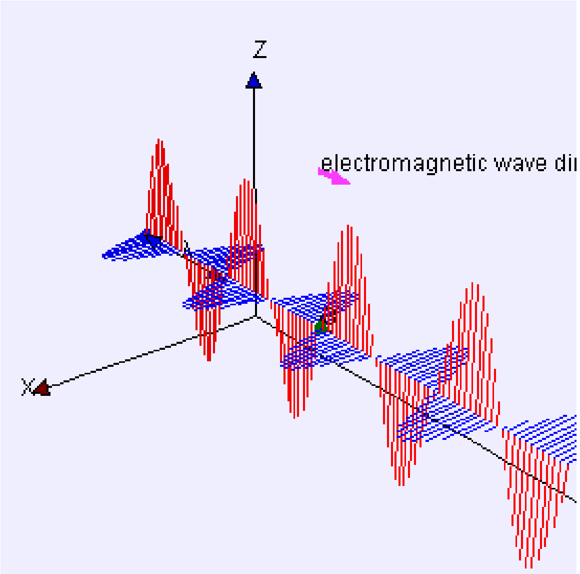


Figure 1: Electromagnetic Wave

Source: Lookang

Absorption of Electromagnetic Energy

When electromagnetic energy reaches matter and is partially or totally absorbed by it, the electric and magnetic characteristics of the matter determine how much and at what frequency the energy is absorbed.

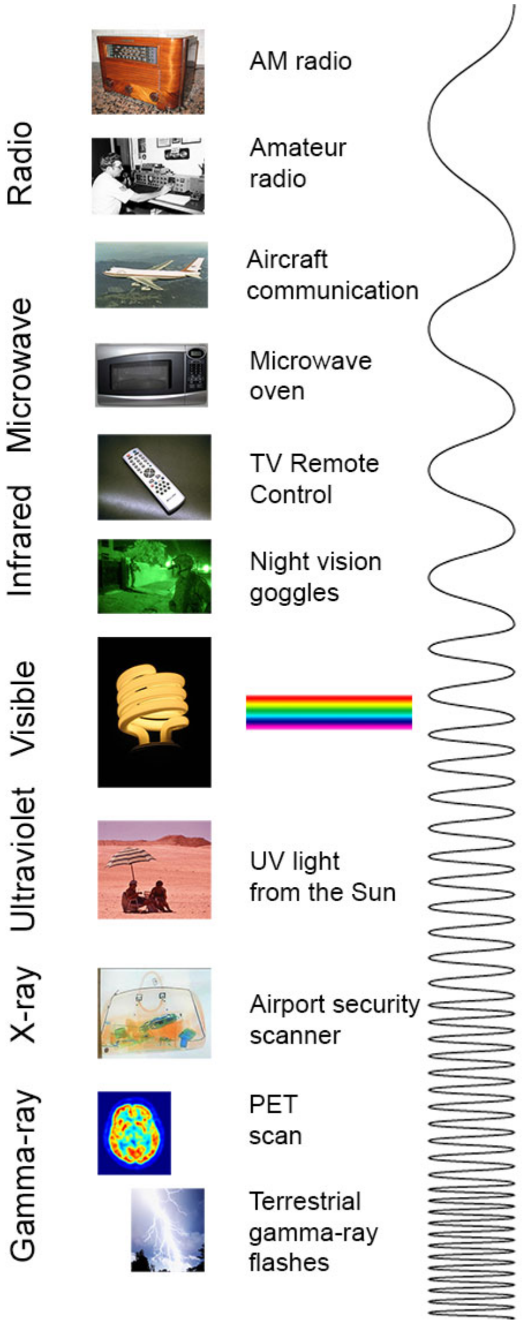
This can be seen by the absorption of electromagnetic energy in the atmosphere by oxygen, carbon dioxide, and other gases, which gives our atmosphere its color and warmth. The colors we see are the energy of reflected wavelengths. The warmth of the atmosphere is due to absorbed energy.

Electromagnetic Resonance

Absorption of electromagnetic energy is also affected by the length of whatever the wave meets. If the height of a person is close to the wavelength of the electromagnetic energy, **resonance** enhances the absorption of the energy. This is why the length of a radio antenna is important. Each antenna is designed to absorb specific wavelengths and frequencies based on it's physical length.

Electromagnetic Spectrum

The electromagnetic spectrum is the range of all types of electromagnetic radiation. Radiation is energy that travels and spreads out as it goes—the visible light from a lamp and the radio waves a radio station are two types of electromagnetic radiation. The other types of electromagnetic radiation are microwaves, infrared light, ultraviolet light, X-rays and gamma-rays.



Radio

Radio captures radio waves emitted by radio stations. Radio waves are also emitted by stars and gases in space.

Microwave

Microwave radiation cooks popcorn in minutes, but is also used by astronomers to learn about the structure of nearby galaxies.

Infrared

Night vision goggles pick up the infrared light emitted by our skin and other warm objects. In space, infrared light helps us map the dust between stars.

Visible

Our eyes detect visible light. Fireflies, light bulbs, and stars all emit visible light.

Ultraviolet

Ultraviolet radiation is emitted by the Sun and is the cause of skin tans and burns. ”Hot” objects in space emit UV radiation as well.

X-ray

A dentist uses X-rays to image our teeth, and airport security uses them to see through our luggage. Hot gases in the Universe also emit X-rays.

Gamma ray

Doctors use gamma-ray imaging to see inside your body. The biggest gamma-ray generator of all is the Universe.

Lab 1: Photometry

Purpose

The purpose of this lab is to explore the properties of illumination on a surface as a function of the distance of the surface from the light source.

Safety

1. Locate fire extinguishers.
2. Turn off gas valves.
3. Remove combustable materials.
4. Tie back long hair and loose clothes.
5. Place candles on secure, fire proof bases.
6. Deposit used matches in fireproof containers.

Materials

1. 5 candles
2. Matches
3. Scissor for adjusting candle wicks
4. 1 large sheet of stiff white paper
5. 1 meter stick
6. Dark room

Procedures

1. **Paper setup:**
    1. Orient paper in landscape position (long side toward you) and create a vertical fold down the middle such that you can stand the paper on the table at a 90 degree angle.
2. **Reference candle setup:**
    1. Place one candle at an exactly measured distance from one side of the paper (**reference side**) such that the other side of the paper (**test side**) is in the candle's shadow. (Note: This reference candle will not be moved for the rest of the lab.)
3. **Test candle(s) setup:**
    1. Place the first **test candle** in front of the **test side** of the paper (opposite the 90 degree angle and on the same side of the paper) such that when you light it, the reference side will be in the shadow of the test candle. Position the test candle the same distance from the paper as the reference candle.
    2. Light both candles and look at the paper from a head on position (nose pointing toward the bent edge), such that you can see both sides equally. When each side is equally illuminated, the folded paper edge will nearly disappear.
    3. If both sides are not equally illuminated when the candles are positioned at equal distances, trim the wicks to create equal light from each candle.
    4. Record the distances.
    5. Add a second candle to the test side, checking that its flame is of nearly equal size to the other candle's flame. Trim the wick as needed.
    6. Record record its distance from the paper.
    7. The test side will now be more luminous than the reference side. Move the test candles away from the paper until the two sides of paper appear to be of equal luminosity when viewed from the head-on position.
    8. Record the distance of the test candles in the table.
4. Repeat with a third test candle, and record your results.
5. Repeat with a forth test candle, and record your results.

Observations

In the table below, record the distances of the candle placements for equal illumination. When computing the ratio of distance of multiple candles to one candle, reduce this ratio so it is in the form $X : 1$ where X is the quotient of the distance of all test candles from the paper divided by the distance of the single candle from the paper. Two decimal place accuracy is good enough. Example: 1.41 : 1.

$$\frac{\textit{Total distance of all test candles}}{\textit{Distance of reference candle}} = X$$

Total Test Candles	**Distance**	**Ratio of Distances**	$\sqrt{\# \text{ of candles}}$
1			$\sqrt{1} = 1$
2			$\sqrt{2} \approx 1.414$
3			$\sqrt{3} \approx 1.73$
4			$\sqrt{4} = 2$

Study Guide: Photometry

About Photometry

Photometry is the science of the measurement of light, in terms of its perceived brightness to the human eye (visible light). It is distinct from radiometry, which is the science of measurement of all radiant energy (including visible light) in terms of absolute power.

Photometry and the eye

The human eye is not equally sensitive to all wavelengths of visible light. Photometry attempts to account for this by weighting the measured power at each wavelength with a factor that represents how sensitive the eye is at that wavelength.

The standardized model of the eye's response to light as a function of wavelength is given by the luminosity function. The eye has different responses as a function of wavelength when it is adapted to light conditions (**photopic vision**) and dark conditions (**scotopic vision**).

Photometry is typically based on the eye's **photopic response**, and so photometric measurements may not accurately indicate the perceived brightness of sources in dim lighting conditions where colors are not discernible, such as under moonlight or starlight.

Photopic vision is characteristic of the eye's response at luminance levels over three candela per square meter. **Scotopic vision** occurs below $2 \times 10^{-5} cd/m^2$. **Mesopic vision** occurs between these limits and is not well characterized. ("Meso" means "between", as in Mesoamerica or Mesopotamia.)

Photometric quantities

Measurement of the effects of electromagnetic radiation became a field of scientific study around the end of the 18th century. Measurement techniques varied depending on the effects under study. This gave rise to many different nomenclature (or naming conventions).

For example, use of the human eye as a detector and measuring device led to **photometric units**, weighted by the typical human eye's response to light. On the other hand, the total heating effect of infrared radiation as measured by thermometers led to the development of **radiometric units** of total energy and power. Each systems is measuring the same phenomenon, but one measures only what the human eye can see, while the other measures total radiance.

Many different units of measure are used for photometric measurements. People sometimes ask why we need so many different units, or they may ask for conversions between units that can't be compared in that way, such as *lumens* and *candelas*.

As an example, we are familiar with the idea that "heavy" can refer to weight or density, but these are fundamentally different ideas. One is related to the effect of gravity and changes with location, while the other is an inherent, and unchanging quality of all matter.

Similarly, "bright" can refer to a light source that delivers a high luminous flux (measured in lumens), or a light source that concentrates its luminous flux into a narrow beam (measured in candelas), or a light source that is seen against a dark background.

Because of the ways in which light propagates through three-dimensional space—spreading out, becoming concentrated, or reflecting off surfaces—and because light consists of many different wavelengths, many different types of measurements and units are needed.

Photometric versus radiometric quantities

There are two parallel systems of quantities known as **photometric** and **radiometric** quantities.

In **photometric quantities**, every wavelength is weighted according to how sensitive the human eye is to it. For example, the eye responds much more strongly to green light than to red or blue, so a green source will have greater **luminous flux** than a red or blue source with equal **radiant flux**.

Radiometric quantities measure the unweighted absolute power of the radiation. Radiant energy outside the visible spectrum does not contribute to photometric quantities at all. For example a 1000 watt space heater may put out a great deal of **radiant flux** (1000 watts, in fact), but as a light source it puts out very few **lumens**, because most of the radiant energy is infrared, leaving only a dim red glow visible to the human eye.

Every quantity in one of these systems has an analogous quantity in the other system. Some examples of parallel quantities include:

Photometric	**Radiometric**
Luminance	Radiance
Luminous flux	Radiant flux
Luminous intensity	Radiant intensity

1. Luminous matter
    1. Luminous matter emits light.
2. Illuminated matter
    1. Illuminated matter reflects light.
3. Candela
    1. Luminous intensity, (I), measure by comparison to the international unit of the candela (text p290 sec 17:4)
4. Luminous Flux
    1. Measured in lumens (lm), Rate at which light is radiated (candelas/sec)
    2. Surface area of a sphere: $4\pi r^2$
    3. A point light source of 1 candela of luminous flux at the center of a sphere of radius 1m radiates 4π lumens on the surface of that sphere.
    4. Lumens are power units and are a measure of light energy per second (candelas/sec)
    5. 1 Candela is the equivalent of 1/683 Joules of energy per steradian, so 1 candela per second has 1/683 watts of power per steradian or $4 \times \pi \times \frac{1}{683}$ watts of power omni-directionally (this is a composite

definition from various Wikipedia definitions of SI units of luminance. http://en.wikipedia.org/wiki/Unit_conversion)

5. Illuminance (illumination of illuminated bodies)
    1. Illuminated bodies can absorb or reflect light
    2. Illuminance (E) is directly proportional to the # of candles and inversely proportional to the square of the distance between the candles and the illuminated surface. or
    3. Illuminance (illumination) is the rate E, measured in $\frac{lumens}{m^2}$, or $\frac{lm}{m^2}$, at which light falls on a unit area some distance from a light source.
    4. Unit of illuminance is lux (lx) where $1\frac{lm}{m^2} = 1lx$
    5. Surface area of a sphere is $4\pi\ r^2$
    6. A point light source of 1 candela of luminous flux at the center of a sphere of radius $1m$ radiates 4π lumens onto the 4π square meter surface of that sphere. Thus the sphere is uniformly illuminated with 1 lux, or 1 $\frac{lm}{m^2}$.
    7. A $2cd$ light source would emit 8π lumens, $3cd$ emits 12π, etc.
    8. 1 lumen is the amount of light that illuminates 1 sq meter of surface of a sphere of 1m radius with a 1 candela point source at its center.
    9. Illumination is measured in lumens per square meter, $\frac{lm}{m^2}$, abbreviated as lux (lx)

Term	**Abbreviation**	**Description**
Candela	cd	
Lumen	lm	
Luminous Intensity	I	
Illumination	E	
Unit of Illuminance	lux or lx	

Sources

- *Wikipedia, https://en.wikipedia.org/wiki/Photometry_(optics), 2023-04-23

Questions: The Nature of Light 1

1. What is the difference between luminous matter and illuminated matter? Give an example of each.

2. The textbook claims that light travels in a straight line. Do you think this is always true? Why?

3. Roemer discovered an error in his work while studying the moons of Jupiter. What was the cause of his error?

4. Michelson's octagonal mirror rotated 625 revolutions/second. How much time is required for one revolution?

Lab 2: Creek Walk

Purpose

We begin by examining images in nature, which are observable due to their differences in brightness (outlines). The relationships of these images will be examined geometrically-spatially. Usually, once we 'see' an object, we have a sense of where it is located in space and what it will feel like if we touch it. Our expectations concerning its texture hardness, roughness or size usually does not surprise us. But this is only because we have learned to interpret what we "see". The sense of sight is far more complex and mysterious than it at first appears. In this block we will explore some of this mystery.

Safety

1. Attendance list
2. Personal proscribed allergy medicine or EpiPen
3. Hiking shoes and appropriate clothes
4. Cell phone (for emergencies)

Materials

1. Lab Sheet
2. Our eyes
3. Local creek or pond
4. Sketch pad or unlined notebook page
5. Colored pencils

Procedures and Observations:

Reflections Near and Far

1. Find still water, stand at the water's edge, and look down at your reflected image. How large does your head appear (relative to your feet below you?
2. Do these images seem to move in accord with the laws of perspective? (Near is big; far is small; Left is left; right is right?)
3. Draw a sketch (#1) of the view at your feet including the reflection.
4. Look at the far side of the creek/pond. Where the water is very still, note the landscape beyond the opposite shore. How does the appearance of those objects compare in size and position to their reflection?
5. Walk a bit along the shore. What happens to your view of the far landscape as you move?
6. Carefully compare your view of the opposite shore with its reflection. Consider shapes, sizes, colors, tones, etc. How are the reflected colors and shapes similar or different from the originating scene?
7. Draw a sketch (#2) of the view of the far side of the creek or pond including the reflections in the creek/pond.
8. Crouch down so that your gaze is just skimming the water surface, and compare the far scene with the reflected scene in the nearby water. How are they similar and different to the reflections you saw when you were standing? Where is each portion of the image in the water, relative to its counterpart in the landscape?

Objects in the Water

1. Step closer to the water, crouch down and look into the water. Sight along a stick or reed as you slide it obliquely into the water. Find an object, such as a bright stone or leaf, in the shallow edge of the pond. Try to plunge the stick like an arrow or spear directly at the object. Can you hit the object on the first try?
   1. Sight along the stick. What's happening?
   2. Don't sight along the stick, hold it out and look at it from the side. What do you see?

   3. What is the difference in seeing something 'under' (or, through) water?
2. Compare the spatial relationships given by our visual-sense, and by our touch-sense. What can you conclude about 'visual space' and "tangible space"?

Refraction Measurements

1. Try crouching lower. How does this affect the degree of the "lifting" effect?

2. What are the limits in where we can see a lifted (refracted) image?

3. Can you see the lifting effect at all viewing angles 0° (viewed straight down) to near 90° (viewed from close to the water surface)?

4. Draw a sketch (#3) of what you saw using the submerged stick.
5. Look where trees are shadowing the water's surface. How do the shadows affect the quality of reflections and your ability to see into the water?
6. Look at the effect of ripples in the water on a distant objects's reflection. Describe the distortions created by the crests and troughs of the ripples.
7. Draw a sketch (#4) of an object in its rippled view.

Edges Underwater — Color Aspects

1. Consider the overall colors seen in the creek/pond. Note the color of the water. Is it different in the center than at the edges? If so, how is it different (faded, vivid, monochromatic)?
2. Look again at a bright stone or colored leaf on the shallow edge of the creek/pond. If it is in sunlight, what color(s) do you see at its edges?
3. Compare this to a dark stone on the light sandy bottom. Is it similar/different to the first object?

Quiz: 17:3 and 17:4

Choose True or False

1. (T | F) Incandescent lamps are more efficient at converting energy into light than fluorescent lamps.
2. (T | F) When you held your foot over the creek, it appeared half the size of your head's reflection.
3. (T | F) Reflections become dimmer as we look at them from closer to the water's surface.
4. (T | F) A stick can appear to bend at the point it enters water.
5. (T | F) Light contains light rays.
6. (T | F) The amount of illumination received by a source varies inversely to the square of it's distance from the source.
7. (T | F) The illuminance (E) of any surface is $E = \dfrac{1}{d^2}$.

Match terms and descriptions

- Candella (cd)
- Point light source
- Lumen (lm)
- Luminous flux
- $4\pi r^2$
- Iluminance (lux)

- The rate at which light energy falls on a unit area some distance from the source
- A unit of luminous flux
- A small light source that sends light energy out uniformly in all directions
- The rate at which light energy is emitted from a source
- Surface area of a sphere
- A measure of the rate at which energy is emitted, transmitted, or received

Review

1. Go over each observation question to build up to conclusion.
2. Clarify the comparative size of objects to their reflection on the water surface.
    1. Perspective applies.
    2. When you held your foot out it appeared to be twice the size of your head even though your foot is about as long as your head is tall.
    3. With you head appearing about as far into the water as it is above the water, the size of the reflection is smaller.

    4. Objects viewed on the distant shore and their reflections also obey perspective.
        1. The reflection appears as far below the surface as the object is above the surface.
        2. You are looking at a reflection on the surface that is nearer to you than the actual object.
        3. The size (width) of the reflection is actually smaller than the object.
        4. Object, reflection and observer are all in the same plane perpendicular to the water surface.
3. Note the quality of reflections as your viewpoint gets closer to the water's surface (more acute viewing angle).
    1. Reflection of treetops extends toward you.
    2. Color saturation is greater.
4. Lifting effect of stick. Consider moving your head lower than the stick so you sight down the stick that is within the water. This is the refracted angle of light originating from the stick under water.
5. Demonstration of red and blue edges of a black rock against a white background in aquarium when viewed underwater. This show the bending of light of different colors happening at different angles of refraction.
6. Example: Refraction using the aquarium
    1. When viewed from a perpendicular side view, there's not much to notice.
    2. When viewed from above the stick appears lifted.
    3. When viewed from the side at an angle, the stick begins to break.
7. Example: Geometry of the Inverse Square Law
    1. Demonstration of paper folded in quarters and comparison for size with a full sheet
    2. From a full sheet at 1m, put the $\frac{1}{4}$ sheet at 50cm and they will appear equal in size.
    3. Three candles lined up on a table. Sighting down all three at once they all appear to be of equal brightness although of different sizes.

Lab 3: Ray Tracing of Plane and Concave mirrors

Materials

- Light Box Kit
- 12V DC power supply
- Protractor
- Blank, white 8.5 x 11” Paper
- Sharp pencil

Preliminary

1. Review “Law of Symmetry in Mirrors”
2. The *normal angle* is an imaginary line *perpendicular* to the *plane of reflection* at the point of the reflected ray.
3. Prove that incident angle equals reflected angle in the first 2 exercises

Cautions 1. Use end with focus control knob 1. How to insert concave lens before doing “Experiment 2 Reflection of Divergent rays” 1. Explain “normal angle and how to measure the incident and reflected angles about the normal.
1. The normal angle (0 degrees) is labelled 90 degrees on the protractor.

Procedures

1. from copy…

Homework

1. Write up observations of Lab 3
2. Write up notes from class discussions

Conclusions

1. Review formulas and problems from Photometry Lab
2. Consider reflections off of ripples in a pond

Demo (2) – Plane Mirrors: Law of Symmetry in Reflections

Plane versus diffuse reflection (text 18:2)

Demo – Concave versus Convex mirrors

Geometric Optics and Derivation of the Mirror Equation

Math WS #1 assigned

Read chapter 19 for support (homework)

A. Reflection in Plane Mirrors (slide 1)

1) The normal line is defined as being a line perpendicular to the surface of the reflecting medium at the point of reflection.
2) The normal line is the 0 angle reference for measuring incident and reflected ray angles.
3) When a light ray is incident upon a plane mirror reflecting surface, the angle of reflection measured from the normal is equal to the angle of incidence measured from the normal.
4) The incident ray, reflected ray and the normal all lie in the same plane.

B. Demo 2 - Plane Mirrors and Law of Symmetry

C. The Law of Symmetry in Plane Mirrors (slide 2) (19:1 on page 317)

1) Reflected image in plane mirrors are the same size as the object and the same distance behind the mirror as the object is in front of the mirror. (note where in the text this is described.

D. Concave Spherical Mirror Reflection Conclusion (19:2 and 19:3 on pp317-320 1) Incident rays shining into a Concave mirror parallel to the principal axis reflect through the Focal Point & vice versa. 2) The focal point of a Concave mirror is at a point ½ the distance to the center of curvature. 3) Spherical aberration in a Concave mirror (spherical curve) causes parallel rays further from the principal axis to miss the focal point. 4) Spherical aberration in a Concave mirror can be eliminated or greatly reduced by using parabolic shaped mirrors 5) Demo parabolic mirror with tensor light being reflected onto wall E. Plane vs Diffuse reflection (18:2 on p301) 1) PP slide

1. Luminous intensity
    1. Luminious Flux is the rate at which candelas of light are radiated.
    2. Luminous flux is measured in lumens (lm).
        1. Lumens are units of power, and are a measure of light energy per second $\frac{candelas}{sec}$
    3. Surface area of a sphere is $4\pi\ r^2$
    4. A point light source of 1 candela of luminous flux at the center of a sphere of radius 1 meter radiates 4π lumens on the surface of that sphere.
2. Illuminance
    1. Illuminance (E) is directly proportional to the # of candles and inversely proportional to the square of the distance between the candles and the illuminated surface. or
    2. Illuminance (illumination) is the rate E (measured in lumens/m^2 or lu/m^2) at which light falls on a unit area some distance from a light source.
    3. Unit of illuminance is lux (lx) where 1 (lm/m^2) = 1 lx
    4. Surface area of a sphere is 4π r2
    5. A point light source of 1 candela of luminous flux at the center of a sphere of radius 1m radiates 4π lumens onto the 4π square meter surface of that sphere. Thus the sphere is uniformly illuminated with 1 lux (1lm/m^2)
3. For a given luminous intensity, the illuminance (lux) on a surface will decrease by a factor 4 for every doubling of the distance between the luminous source and the illuminated surface.
4. Comprehensive review of $E = \dfrac{I}{(d^2)}$
5. Included several example problems adapted from first test

Questions: Ray Tracing

1. Label the Source, Incident Angle and Reflective Angle.
2. What is the approximate degree of the incident angle?
3. What is the approximate degree of the reflective angle?
4. What is the degree of the Normal Angle?
5. Which of these angles always has the same degree?
6. Which two angles always have the same degree?

Study Guide: Reflection and Refraction

Reflection of Light

The Law of Reflection

1. **Light Reflections** occur when light bounces off a reflective surface. Most of what our eyes see in the world is reflected light.
2. **The Law of Reflection:** The *angle of reflection* is equal to the *angle of incidence* about the *normal line*.
3. **Angle of Incidence:** The angle at which a light ray reaches a reflective surface.
4. **Angle of Reflection:** The angle at which a light ray bounces off of a reflective surface.
5. **Normal Line:** An imaginary line perpendicular (0 degrees) to the surface of a reflective surface (at any one point). Think of the normal line as the 0 degree *base line* on which most reflection and refraction calculations are based.
6. The incident ray, reflective ray, and normal line are all on a plane. (*This is a great idea as keeping calculations within two dimensions simplifies the math.*)

Diffuse and Regular Reflection

1. **Diffuse** (or irregular) surfaces bounce light in many different directions. They do not produce recognizable images.
2. **Regular surfaces** produce **regular reflections**, in which light rays bounce in parallel directions. This produces recognizable images.
3. Each individual ray reflects according to the law of reflection.

Refraction of Light

1. Light travels at a different speed in different media.
2. Light changes direction (or bends) as it enters a new medium of a different density if it enters at an angle other than 0 degrees.
3. Optically dense matter slows light.
4. When light enters an optically denser medium (such as from air to water), it travels more slowly, bends **toward** the normal, and the angle of reflection is **less** than the angle of incidence.
5. Although in reflections, the incident and reflective angles are **always** equal, in refractions the angles are **usually not equal**.

Transition	**Δ of Speed**	**Bend**	**Diff. of Angles**
Lighter → Denser	Slower	→ Normal	Reflection is < Incidence
Air → Water	Slower	→ Normal	Reflection is < Incidence
Denser → Lighter	Faster	← Normal	Reflection is > Incidence
Water → Air	Faster	← Normal	Reflection is > Incidence

Snell's Law

Although the angle of incidence clearly affects the angle of refraction, the angle of refraction **does not vary directly** with the angle of incidence. (Note: A direct variance results in a linear equation, such as $y = 2x$. The relationship between incident and refractive angles is not that straightforward.)

The Dutch scientist Willebrord Snell (1591 – 1629) discovered the mathematical relationship now known as Snell's Law. The following equation applies to light traveling from a vacuum into a denser medium.

$$Index\ of\ refraction\ of\ the\ medium = \frac{sin\ of\ the\ angle\ of\ the\ incident\ ray}{sin\ of\ the\ angle\ of\ the\ refractive\ ray} \tag{1}$$

$$n = \frac{sin\ i}{sin\ r} \tag{2}$$

Where

- n = Index of refraction of the medium
- i = Incident ray
- r = Refractive ray

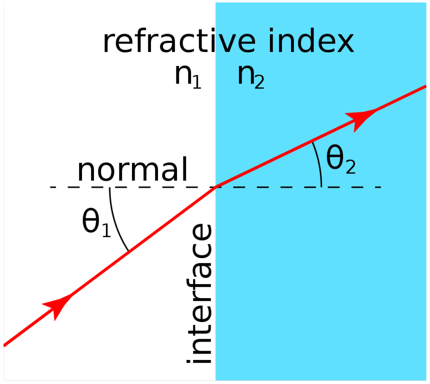
To apply the equation for light traveling from any medium into any other medium, we convert it to the following. If we have any three values, we can find the fouth.

$$n_1\ sin\ \theta_1 = n_2\ sin\ \theta_2$$

Where

- n_1 = Index of refraction of the first medium
- n_2 = Index of refraction of the second medium
- θ_1 = Angle of incidence
- θ_2 = Angle of refraction

Figure 2: Example of Refraction (Source: Wikipedia)



Example Indexes of Refraction

Every medium has an index of refraction. Vacuum has in index of 1. All other matter has a higher index. Here are some commonly used values.

Medium	Index of Refraction
Vacuum	1
Air	1.0003
Carbon dioxide	1.00045
Hydrogen	1.000139
Oxygen	1.000271
Water	1.333
Crown glass	1.517
Dense flint glass	1.655
Diamond	2.417

Example Angles

Angles (In Degrees)	0	30	45	60	90	180	270	360
Angles (In Radians)	0	$\pi/6$	$\pi/4$	$\pi/3$	$\pi/2$	π	$3\pi/2$	2π
sin	0	1/2	$1/\sqrt{2}$	$\sqrt{3}/2$	1	0	-1	0
approx. sin			1/1.414	1.732/2				

Trigonometry Functions

$$\begin{array}{ll} sin\ \theta = opp/hyp & csc\ \theta = 1/sin\ \theta = hyp/opp \\ cos\ \theta = adj/hyp & sec\ \theta = 1/cos\ \theta = hyp/adj \\ tan\ \theta = opp/adj & cot\ \theta = 1/tan\ \theta = adj/opp \end{array}$$

Example 1

A ray of light traveling through air is incident upon a sheet of crown glass at an angle of 30°. What is the angle of refraction? (Note that the refractive index of air is so close to that of a vacuum that we can round to 1.00.)

Given:

- Refractive index of air: $n_1 \approx 1.00$
- Refractive index of crown glass: $n_2 \approx 1.52$ (rounded to the nearest hundredth)
- Incident angle: $\theta_1 = 30.0°$
- Reflective angle: $\theta_2 = x°$

$$\begin{aligned}
n_1 \ sin\ \theta_1 &= n_2\ sin\ \theta_2 && \textit{Original equation} && (3)\\
sin\ \theta_2 &= \frac{n_1\ sin\ \theta_1}{n_2} && \textit{Isolate the unknown value} && (4)\\
&= \frac{1.00\ sin\ 30.0°}{1.52} && \textit{Replace known values} && (5)\\
&= \frac{0.5}{1.52} = 0.329 && \textit{Simplify numerator} && (6)\\
\theta_2 &= 19.2° && \textit{Find } \sin^{-1} \ \textit{of}\ 0.329 && (7)
\end{aligned}$$

Example 2

A ray of light traveling through air falls on the surface of a transparent glass slab. The ray makes an angle of 45° with the normal. Given that the refractive index of the glass is $\sqrt{2}$, find the angle made by the refracted ray within the slab.

$$\frac{\sin\ 45°}{sin\ r} = \sqrt{2} \tag{8}$$

$$sin\ r = \frac{1}{\sqrt{2}} \times 45° \tag{9}$$

$$= \frac{1}{\sqrt{2}} \times \frac{1}{\sqrt{2}} = \frac{1}{2} \tag{10}$$

$$\textit{Thus, as } \sin\ r = \frac{1}{2}, \textit{ the angle of refraction would be, } r = \sin^{-1}\left(\frac{1}{2}\right) = 30° \tag{11}$$

Practice: Snell's Law and Angles of Refraction

1) A ray of light traveling through water is incident upon a sheet of dense flint glass at an angle of 45°. What is the angle of refraction?

2) A ray of light traveling through air is incident upon water at an angle of 0°. What is the angle of refraction?

3) A ray of light traveling through air falls on the surface of a transparent glass slab. The ray makes an angle of 60° with the normal. Given that the refractive index of the glass is 1.517, find the angle made by the refracted ray within the slab of glass.

4) A light beam makes an angle of 60 degrees to the normal as it strikes a transparent substance with a partially reflective surface. Part of the beam is reflected from the surface into the air and part is refracted through the substance. The reflected and refracted beams make an angle of 90 degrees with each other. What is the index of refraction of the substance? (Use the back side of this page to make a diagram and show your calculations.)

Lab 4: Snell's Law

Introduction

When we look into a pool or lake, the position of the bottom is changed. This shifting is called refraction, and occurs in all sorts of media and many different types of waves–light, sound, radio, and even mechanical vibrations (earthquake waves).

The principles of refraction are applied in a wide variety of optical devices: eyeglasses, microscopes, cameras and binoculars.

Purpose

Measure the refraction of a light in water and recreate the analysis that led to what is called Snell's Law.

Materials and Equipment

- Darkened room
- Plastic D-Tank
- Water
- Custom 360° protractor
- Foam core board
- Quilting pins
- Pencil and notepaper

Procedures

1. Set up D-tank
    1. Place the protractor on the foam core board.
    2. Place the D-tank on the protractor.
    3. Adjust the D-tank so its long straight edge lays over the base line of the protractor and the curved edge is concentric to and equally distant from the protractor angle measurements.
    4. Check: The 0 (zero) line of the protractor should bisect the D-tank when you have it set up correctly.
    5. Fill the D-tank about half full with water. (You should not need to move the D-tank again once the water is added.)
2. Set up light box
    1. Position the light box with the single slit card such that it can shine toward the straight edge side of the D-tank at various angles, as measured from the normal (0 degree angle line on the flat side), but always meets and "enters" the D-tank at the center of the protractor.
    2. Depending on the angle that the incident light enters the flat side of the D-tank, the refracted light will exit the curved side of the D-tank at a different refracted angle, as measured from the 0 angle reference line on the curved side of the D-tank. There is one incident angle where the incident and refracted angles are equal. Can you tell which angle that is?
3. Measure various angles
    1. Be prepared to mark each pair of incident and corresponding refracted angle using pins of the same color.

2. Move the light box and repeat for several different angles, using pins of the same color for each set of angles. Take pairs of readings for:
    1. 1 incident angle less than 20 degrees,
    2. 2 incident angles between 20 and 50 degrees, and
    3. 1 incident angle greater than 50 degrees.
3. With each test, verify the refraction effect for yourself by looking from the incident angle marking pin, through the water and toward the center of the flat side of the D-tank to the corresponding refracted angle pin. Then raise your viewpoint slightly to view from above the waterline.
4. Calculate the sin value for each angle.
5. Compute each ratio of $\frac{sin\ i}{sin\ r}$.

Data

Position	Pin Color	θ_i	θ_r	$sin\ i$	$sin\ r$	$\frac{sin\ i}{sin\ r}$
1	Red	22	16.5	0.3746	0.2840	1.32
2	Blue	32	23.5	0.5299	0.3987	1.33
3						
4						
5						
6						
7						
8						
9						
10						

Observations

Lab: Snell's Law Conclusions

1. After computing the sines and ratios, for each experiment, compare the ratios. How consistent are they? If Snell was correct, all the ratios should come out nearly the same (within experimental error).
2. What were your sources of error?

Observing Refraction

When we looked into the creek and tried to touch a stone with a relatively straight stick we experienced the bottom as 'lifted'. We can study the ratio of the apparent depth of the visible (refracted) bottom, and the depth of the tangible bottom. As seen in the side view of the tank (right), these are the depths OA ('visible'), and OB ('tangible'). However, the relationship of the two depths is not a simple arithmetic difference; the difference grows as the point of view approaches horizontal.

Snell's Discovery

The actual relationship or law of refraction was first worked out in 1621 by Dutch mathematician Willebrord van Roijen Snell (1591-1626). Snell noticed that the ratio of depths seemed constant for a given pair of media. (Strictly, this is true only for vertical view.) He finally realized that if we use their 'visible length', then that ratio was a constant (equivalent to the index of refraction). Using a water tank, we could also measure the length SB to the lower (tangible) point B, compared to the 'sight-line' length SA, seen from the entrance point S to the upper ('lifted') point A.

Snell's Law in Modern Form

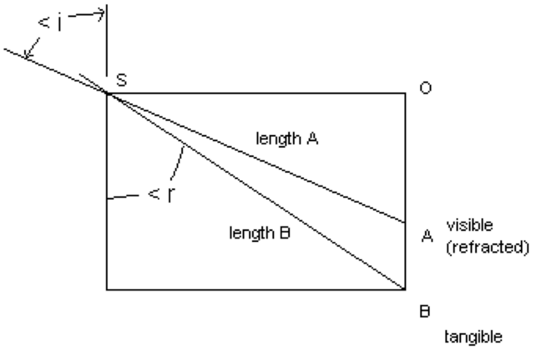
Since these "path length" are difficult to measure in practice, simply measure the angle, and use trigonometry to compare this ratio. If i is the incident angle to the *surface normal* in the upper media of light entering the lower media, and r is the *refracted angle* of the light in the lower media relative to the normal, then the refractive index n is the ratio of:

$$\text{(index of refraction of the medium with incident beam)} : \text{(index of refraction of the medium with refracted beam)}$$

Thus, our tangible position B in the tank diagram corresponds to P on the r beam, since our direction of view is shifted or refracted downwards within the water; while the direction to the visible lifted position is called the i beam, since this is the direction we look initially to see the apparently lifted object.

So, in general, Snell's law implies that when tracing the pathway into a denser medium (air into water for example), the direction of light is bent toward the *surface normal*, while tracing it the other way, entering a less dense medium (from water into air), the beam is bent away from the *normal*.

Note: We disregard as negligible any additional refraction that occurs as a result of light passing through the plastic of the D-tank between water and the air.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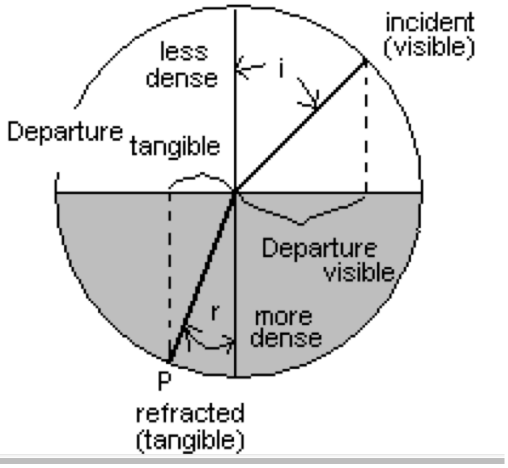
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(tangible)

Mirrors and Lenses

Study Guide: Mirrors

Shadows

1. Do shadows exist? Explain your reasoning.

2. Can shadows travel faster than the speed of light? Explain your reasoning.

One of the earliest studies of light was of shadows. It was from observing shadows that people first determined that light travels in a straight line. One interesting aspect of shadows is that they don't exactly exist. They are not "things"; they are simply the lack of light. For example, shadows can appear to move faster than the speed of light, but this is only because nothing ("no thing") is actually moving. Only the situation of where light falls is changing.

Shadows on the moon are black, and have sharp edges. In fact, it can be dangerous to step into your own shadow on the moon because you could easily step into a deep hole. Shadows on earth are not totally black and usually have fuzzy edges. This is because light scatters in atmosphere. Most shadowy regions are made up of multiple overlapping shadows. The **umbra** is darkest part of a shadow, where all shadows overlap. Surrounding the umbra is the **penumbra**, which is where only some of the individual shadows overlap.

Plane Mirrors

1. One wall of a room is covered with a plane mirror, how much larger will the room appear to be? Explain your reasoning.

2. Is is possible for a plane mirror to reflect an object that is NOT directly in front of it? If so, how is this possible?

3. If we arrange two mirrors at 90° and place a small object in front of them, how many images of the object will we see? Explain your reasoning.

4. If we move the mirrors to be arranged at 60°, how many images of the object will we see? Explain your reasoning.

Retroreflectors

A retroreflector is an arrangement of three mirrors arranged at 90° and perpendicular to each other to create a corner. Any ray that enters this set of mirrors will be reflected back toward itself in a parallel path. Retroreflectors are used for bicycle reflectors to reflect a car's headlight beams back towards the car. This alerts the driver while not blinding others. The same technique is used in cloth reflectors and many other situations.

Curved Spherical Mirrors

Curved mirrors are either **convex** (curving out) or **concave** (curving in). **Spherical** mirrors are uniformly rounded in three dimensions. Light rays are reversible; the Law of Reflection works the same in either direction. Therefore, the same shape that can focus rays to a point can take rays from a point and send them out in parallel rays (flashlight).

Terms	**Description**
C	Center of curve
M	Center of mirror
Optic axis	A line passing through C and M
F	Focal point. Light rays parallel to the Optic Access are reflected back through a common point.
f	Focal length. Exactly half way between C and M (1/2 the radius).

Convex Mirrors

Convex mirrors produce smaller images but have a larger field of view. (Example: rearview mirrors) *"Images in the mirror may be closer than you think!"* The focal point (F) and the the center of the sphere (c) are at the back side of the mirror. The focal point (F) is still half way between C and M. Rays parallel to the optic axis are reflected *as if they came from the focal point behind the mirror.* Convex mirrors ALWAYS produce images that are **erect** (right side up) and smaller than the object.

Concave Mirrors

The images produced by concave mirrors are more complex than those of convex mirrors. Concave mirrors form two different images depending on how close the object is to the mirror. When objects are further away, the mirror produces an image that is **inverted** and reduced in size. This image is formed by light from the object converging to form an image in front of the mirror. This is known as a **real image**.

When an object is closer to the mirror than the **central point**, the image behaves like a plane mirror, but the image produced is magnified. In this case, there is no light at the point of the image because the image is formed behind the mirror. This is known as a **virtual image**.

The essential different between real and virtual images is whether the light actually comes from the image location or only appears to. If the rays **diverge** upon reflecting, they can never come together to form a real image. Real images can be seen on a piece of paper placed at the image location, but virtual images can not be seen in this way because there is no light reflected onto this location.

Locating Images in Space

There are an infinity of light rays reflecting off of objects and mirrors, but we only need three rays to model how curved mirrors work.

1. The easiest ray to draw travels along any radius of the sphere. It strikes the mirror normal and is reflected back to itself.
2. The second ray approaches the mirror parallel to the **optic axis**, and is reflected back through the **focal point**.
3. The third ray is a reverse of the second ray. In this case, light travels through the **focal point**, and is reflected back parallel to the **optic axis**.

Ray	Incident Ray	Reflective Ray
1	Along radius	Back on itself
2	Parallel to optic axis	Through focal point
3	Through focal point	Parallel to optic axis

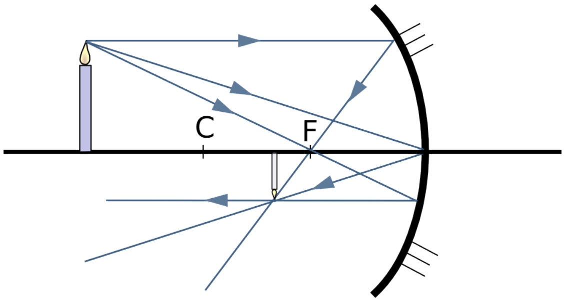

Figure 4: Object to M > 2f

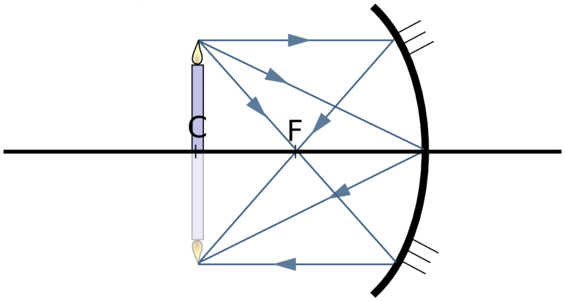

Figure 5: Object to M = 2f

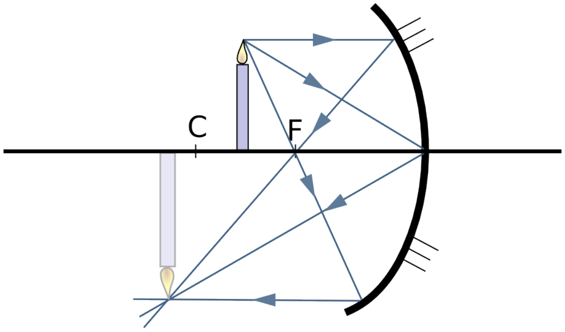

Figure 6: C > Object to M > f

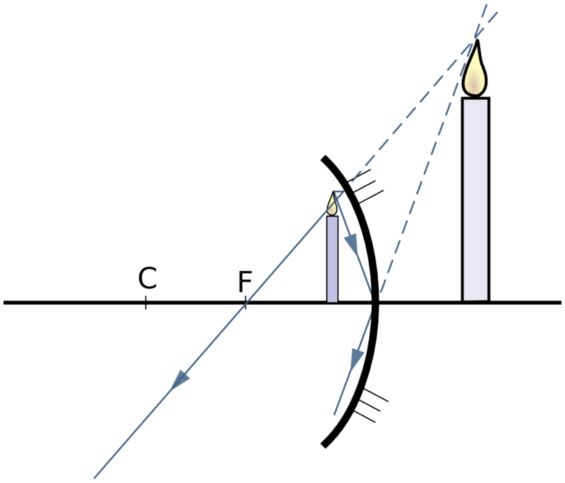

Figure 7: Object to M <> f

Study Guide: Lenses

TK

Study Guide: Total Internal Reflection and Albedo

Term	**Description**
Refractive Index	The ratio of the speed of light in a vacuum to its speed in a particular substance.
Total Internal Reflection (TiR)	The complete reflection of a ray of light within a medium such as water or glass from the surrounding surfaces back into the medium.
Critical Angle	The critical angle is the smallest angle of incidence that yields total reflection, or equivalently the largest angle for which a refracted ray exists.
Mirage	The deceptive appearance of distant objects caused by the bending of light rays (refraction) in layers of air of varying density.
Albedo	A non-dimensional, unitless quantity between 0 and 1 that indicates how well a surface reflects light energy, with 0 meaning a ”perfect absorber” that absorbs all incoming energy, and 1 meaning a ”perfect reflector” that reflects all incoming energy.

Total Internal Reflection

Total Internal Reflection occurs if the **angle of incidence** is greater than a certain limiting angle, called the **critical angle**. In general, total internal reflection takes place at the boundary between two transparent media when a ray of light in a **medium of higher index of refraction** approaches the other medium at an angle of incidence greater than the critical angle.

For a water-air surface the critical angle is 48.5°. Because indices of refraction depend on wavelength, the critical angle (and hence the angle of total internal reflection) will vary slightly with wavelength and, therefore, with color. At all angles less than the critical angle, both refraction and reflection occur in varying proportions.

Both refraction and reflection can occur at the same time if the angle of incidences is less than the critical angle for a particular medium.

Critical Angle

The critical angle is the smallest angle of incidence that yields total reflection, or equivalently the largest angle for which a refracted ray exists. For light waves incident from an “internal” medium with a single refractive index n_1, to an “external” medium with a single refractive index n_2, the critical angle is given by $\theta_c = arcsin\frac{n_2}{n_1}$, and is defined if $n_2 \leq n_1$.

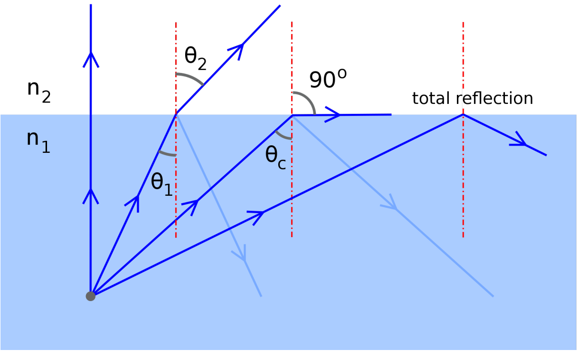

Figure 8: Total Internal Reflection Angles

TiR in a Mirage

Under certain conditions, such as over a stretch of hot pavement or desert air heated by intense sunshine, the air rapidly cools with elevation and therefore increases in density and refractive power.

Sunlight reflected downward from the upper portion of an object——for example, the top of a camel in the desert——will be directed through the cool air in the normal way. Although the light would not be seen ordinarily because of the angle, it curves upward after it enters the rarefied hot air near the ground, thus being refracted to the observer's eye as though it originated below the heated surface.

A direct image of the camel is also seen because some of the reflected rays enter the eye in a straight line without being refracted. The double image seems to be that of the camel and its upside-down reflection in water. When the sky is the object of the mirage, the land can be mistaken for a lake or sheet of water.

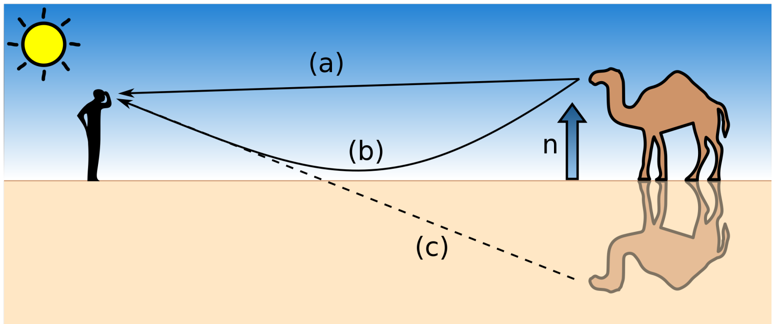

Figure 9: Total Internal Reflection in a Mirage

TiR in a Looming

Sometimes, as over a body of water, a cool, dense layer of air underlies a heated layer. An opposite phenomenon will then prevail, in which light rays will reach the eye that were originally directed above the line of sight. Thus, an object ordinarily out of view, like a boat below the horizon, will be apparently lifted into the sky. This phenomenon is called looming.

Figure 10: Total Internal Reflection on the Sea

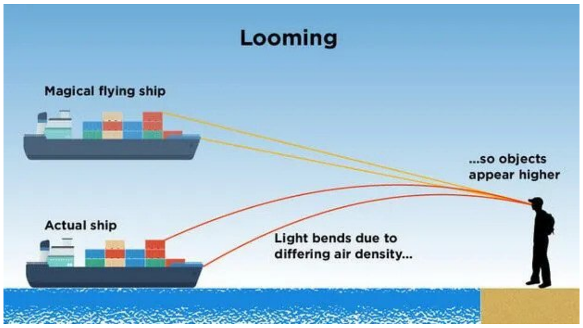

Figure 11: Total Internal Reflection in Looming

TiR in a Cut Diamond

Diamonds (with a high refractive index of about 2.42) are often cut so that as light penetrates, it is subjected to TiR on multiple faces (or facets). The critical angle of diamond to air is 24°. When the angle of incidence at any face is less than 24 degrees, light shines through again, making the diamond on that face seem more brilliant.

Tir in Optical Fibers

The design of optical fibers makes use TiR. An optical fibre is made up of an inner core (glass or plastic) with a high refractive index, and an outer cladding (glass or plastic) with a lower refractive index.

TiR in Water

When standing beside an aquarium with our eyes below the water level, we are likely to see fish or submerged objects reflected in the water-air barrier. The brightness of the reflected image—often just as bright as the “direct” view—can be startling.

A similar effect can be observed by opening our eyes while swimming just below the water’s surface. If the water is calm, the surface outside the critical angle (measured from the vertical) appears mirror-like, reflecting objects below.

At such angles, the region above the waterline cannot be seen, where the hemispherical field of view is compressed into a conical field known as **Snell’s Window**, whose angular diameter is twice the critical angle.

The field of view above the water is theoretically 180° across, but seems less because as we look closer to the horizon, the vertical dimension is more strongly compressed by the refraction; e.g., by Eq. (3), for air-to-water incident angles of 90°, 80°, and 70°, the corresponding angles of refraction are 48.6° (cr in Fig. 6), 47.6°, and 44.8°, indicating that the image of a point 20° above the horizon is 3.8° from the edge of Snell's window while the image of a point 10° above the horizon is only 1° from the edge.[13]

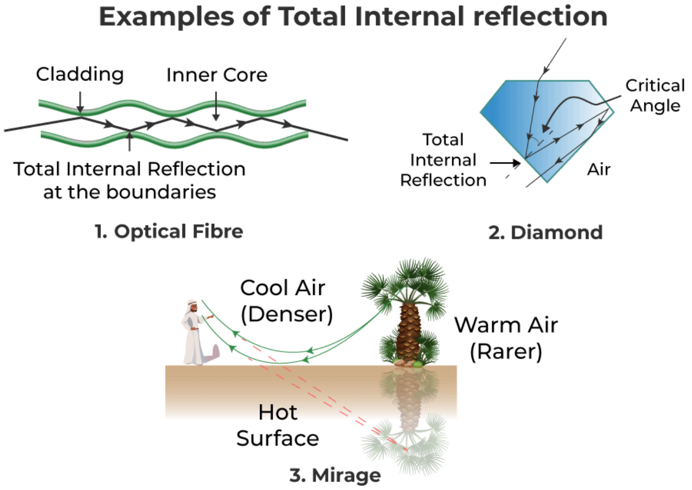

Figure 12: Examples of Total Internal Reflection

Earth's albedo

Albedo is usually differentiated into two general types: **normal albedo** and **Bond albedo**.

Normal albedo

Normal albedo (also called normal reflectance), is a measure of a surface's relative brightness when illuminated and observed vertically. The normal albedo of snow, for example, is nearly 1.0, whereas that of charcoal is about 0.04. Albedo generally refers to visible light, although it may involve some infrared. than concrete because the black surface absorbs more energy and reflects very little energy.

When sunlight reaches the Earth's surface, some is absorbed and some reflected. A surface with a high albedo will reflect more sunlight than a surface with low albedo. Surfaces with high albedos include sand, snow and ice, and some urban surfaces, such as concrete or light-colored stone. Surfaces with low albedos include forests, the ocean, and some urban surfaces, such as asphalt.

Albedo generally applies to visible light, although it may involve some of the infrared region of the electromagnetic spectrum. You understand the concept of low albedo intuitively when you avoid walking barefoot on blacktop on a hot summer day. Blacktop has a much lower albedo than concrete because the black surface absorbs more energy and reflects very little energy.

Albedo is important to Earth scientists because it plays a significant role in our planet's average surface temperature. When a surface reflects incoming sunlight, it sends the energy back to space, where it doesn't affect temperature or climate.

Bond albedo

Bond albedo is defined as the fraction of the total incident solar radiation reflected by a planet back to space. It is a measure of the planet's energy balance. (It is named for the American astronomer George P. Bond, who in 1861 published a comparison of the brightness of the Sun, the Moon, and Jupiter.)

The value of Bond albedo depends on the spectrum of the incident radiation because such albedo is defined over the entire range of wavelengths. Earth-orbiting satellites have been used to measure Earth's Bond albedo. The most recent values obtained are approximately 0.29. The Moon, which has a very tenuous atmosphere and no clouds, has an albedo of 0.12. By contrast, that of Venus, which is covered by dense clouds, is 0.75.

Albedo and Astronomy

Measurements of albedo are commonly used in astronomy to describe the reflective properties of planets, satellites, and asteroids. Investigators often rely on observations of normal albedo to determine the surface compositions of satellites and asteroids. The albedo, diameter, and distance of such objects together determine their brightness.

If the asteroids Ceres and Vesta, for example, could be observed at the same distance, Vesta would be the brighter of the two by roughly 10 percent. Though Vesta's diameter measures less than half that of Ceres, Vesta appears brighter because its albedo is about 0.35, whereas that of Ceres is only 0.09.

Albedo and Climatology

The Earth's albedo plays a significant role in our planet's average surface temperature. When sunlight reaches the Earth's surface, some of it is absorbed and some is reflected. The relative amount (ratio) of light that a surface reflects compared to the total incoming sunlight is called albedo. A surface with a high albedo will reflect more sunlight than a surface with low albedo. Surfaces with high albedos include sand, snow and ice, concrete and light-colored stone. Surfaces with low albedos include forests, the ocean, and asphalt. When a surface reflects incoming sunlight, it sends the energy back to space, where it has little direct affect on surface temperatures or climate.

Changes in the Earth's **global albedo** can affect the global climate. Sea-ice loss in the Arctic since the end of the 20th century has lowered the region's albedo, decreasing the region's ability to reflect incoming sunlight while increasing its ability to absorb energy from sunlight. Researchers note that the Arctic's falling albedo is producing a **positive temperature feedback loop**——in which greater energy absorption at the surface leads to increases in available heat, which in turn melt additional ice, thereby further decreasing the region's albedo...

Some Practical Applications

1. **Optical Instruments:** The development of specially shaped glass prisms to produce total internal reflection in binoculars, periscopes, telescopes, and other optical instruments.
2. **Fiber Optics:** The development of low-consumption and near speed of light communications using long, twisted paths of glass or plastic rods or fibers that allow rays of light tn travel by **multiple total internal reflection**.
3. **Climatology:** Research into the effects of a changing planetary surface on global climate patterns.
4. **Astronomy:** Research into the makeup of distant planets.

Questions

1. What is the difference between Normal and Bond albedo?
2. What causes a mirage?
3. Does the open ocean have a low or high albedo?
4. Does asphalt have a low or high albedo?
5. Do ice and snow have a low or high albedo?
6. Do clouds have a low or high albedo?
7. How can observations of the albedo of distant planets help us understand their surface composition?
8. When analyzing a planet's brightness, why is it important to know it's size, distance from Earth and albedo?
9. How does melting snow and ice at the poles affect global climate patterns?

Sources

- Wikipedia: https://en.wikipedia.org/wiki/Total_internal_reflection
- Wikipedia: https://en.wikipedia.org/wiki/Mirage
- Britannica: https://www.britannica.com/science/total-internal-reflection
- Britannica: https://www.britannica.com/topic/mirage-optical-illusion

Study Guide: Light and Climate

Term	Description
Refractive Index	The ratio of the speed of light in a vacuum to its speed in a particular substance.
Total Internal Reflection	The complete reflection of a ray of light within a medium such as water or glass from the surrounding surfaces back into the medium.
Critical Angle	The greatest angle that a ray of light, traveling in one transparent medium, can strike the boundary between that medium and a second medium of lower refractive index without being totally reflected within the first medium.
Albedo	The fraction of light that is reflected by a body or surface when viewed vertically (at 90 degrees).

Overview

The Arctic is often referred to as the Earth's icebox, helping cool the planet and shaping its jet stream. Warming in the Arctic influences conditions elsewhere around the globe—–what happens in the Arctic does not stay in the Arctic.

The Arctic is not just a geographic region but also a system—–physical, biological, chemical, and climatological. The region encompassing the north polar region (the area north of the Arctic Circle) is largely an ocean surrounded by land. On the surface of the ocean, sea ice grows throughout the autumn and winter, and melts throughout the spring and summer. On the sea ice and on land, snow accumulates during the autumn and winter, and melts away over the summer. In the far north, seasonal snow retreat over land exposes tundra, which greens and blooms in the warmest months of the year. Moving southward, tundra slowly transitions to forest, which also sees significant seasonal snow accumulation.

Although the Arctic may seem far removed from the rest of the globe, Arctic climate and weather are closely linked with climate and weather elsewhere. Cold conditions in both the Arctic and Antarctic play key roles in global circulation patterns in the atmosphere and ocean. In other words, weather phenomena at lower latitudes, such as heat waves, cold snaps, storms, floods, and droughts, can be strongly shaped by what is happening in the Arctic. At the same time, the Arctic's location and configuration creates northern phenomena rarely found elsewhere.

What is the Arctic?

Definitions of the Arctic

This map shows the main definitions currently in use to describe the Arctic. — Credit: Arctic Portal

The region surrounding the North Pole consists of a large ocean surrounded by land. This ocean, called the Arctic Ocean, is like no other ocean on Earth, and because of its special location and climate, the lands that surround it are unique.

A common boundary used to define the Arctic is the region above the Arctic Circle, an imaginary line that circles the globe at approximately 66° 33' N (dashed blue circle in the map above). The Arctic Circle marks the latitude above which the sun does not set on the summer solstice, on or about June 21, and does not rise on the winter solstice, on or about December 21. At the North Pole, the sun rises once each year and sets once each year: there are six months of continuous daylight and six months of continuous night. At lower latitudes, but north of the Arctic Circle, the number of days of continuous light and dark is intermediate.

Some scientists define the Arctic as the area north of the Arctic tree line (green line in map above), where the landscape is frozen and dotted with shrubs and lichens. The tree line broadly corresponds to where the average July summer temperature does not rise above 10 °C (50 °F). In some areas, trees grow well to the north of the Arctic circle.

What is the difference between weather and climate?

Summer in Ilulissat, Greenland

This bustling harbor in Ilulissat, Greenland, is filled with various kinds of water vessels. Summers in Greenland turn Greenland green. — Credit: Twila Moon, NSIDC

Weather is the day-to-day state of the atmosphere, and its short-term variation in minutes to weeks. People generally think of weather as the combination of temperature, humidity, precipitation, cloudiness, visibility, and wind. We talk about changes in weather in terms of the near future such as: How hot is it right now? What will it be like today? Or, will we get a snowstorm this week?

Climate is the weather of a place averaged over a period of time, often 30 years. Climate information includes the statistical weather information that tells us about typical weather, as well as the range of weather extremes for a location.

We talk about climate change in terms of years, decades, centuries, even millions of years. Scientists study climate to look for trends or cycles of variability, such as the changes in wind patterns, ocean surface temperatures, and precipitation, to determine the causes of these variations and trends.

Colorful homes in Kangaamiut, Greenland, in winter

Colorful homes in Kangaamiut, Greenland, stand out against its snowy landscape in winter. — Credit: Mads Pihl, Visit Greenland/Flickr

What is Arctic climate?

Like other places on Earth, the weather in the Arctic varies from day to day, from month to month, and from place to place. But the Arctic is a unique place for weather and climate because of the special factors that influence it. Sunlight is perhaps the most important of those factors. Above the Arctic Circle, there is little or no solar energy in the winter, leaving the region dark and cold. What sunlight does reach the region in the winter comes in at a low angle. In summers, the sun shines for many hours or around the clock, bringing warmth and light. The Arctic experiences frequent temperature inversions. Inversions occur when cold air settles close to the ground, with warm air on top of it. Inversions separate the air into two layers, like oil and water, tending to limit the mixing of air. Over cities, inversions can trap pollutants, creating smoggy conditions that last until the inversion clears.

Scientists separate the Arctic into two major climate types. Near the ocean, a maritime climate prevails. In coastal Alaska, along with Iceland, northern Russia, and Scandinavia, the winters are stormy and wet, with snow and rainfall reaching 60 centimeters (24 inches) to 125 centimeters (49 inches) each year. Summers in the coastal regions tend to be cool and cloudy; average temperatures hover around 10 °C (50 °F).

Away from the coasts, the interior regions of the Arctic lands have a continental climate. The weather is drier, with less snow in the winter and sunny summer days. Some areas get scant precipitation and are classified as polar deserts. Winter weather can be severe, with frigid temperatures well below freezing. In some regions of Siberia, average January temperatures are lower than -40 °C (-40 °F). In the summer, the long days of sunshine thaw the top layer of frozen ground and bring average temperatures above 10 °C (50 °F). At some weather stations in the interior, summer temperatures can reach 30 °C (86 °F) or more.

Sources

- National Snow and Ice Data Center: https://nsidc.org/learn/parts-cryosphere/arctic-weather-and-climate

Study Guide: Issac Newton (1643 – 1727 CE)

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

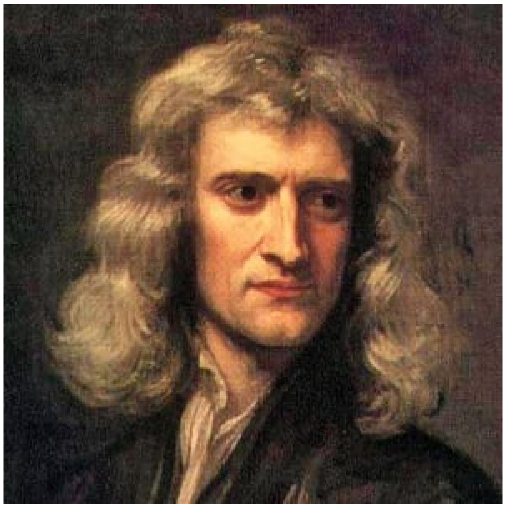

Figure 13: Issac Newton

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 14: 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 15: 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)

Relativity

Study Guide: The Four Fundamental Forces

Einstein

- Full name: Hans Albert Einstein.
- Born: 14 March 1879, in Ulm, Germany
- Died: 18 April 1955, in Princeton, US
- Very imaginative and dreamy as a child.
- Was considered a poor and disobedient student in school because he asked too many questions.
- Loved learning math.
- Studied in Milan, Italy, where his curiosity and questions were welcome.
- Wrote several scientific papers at an early age, but they were ignored due to his youth.
- In 1905, a year sometimes described as his *annus mirabilis* (‘miracle year’), Einstein published four groundbreaking papers.
- Moved to Switzerland, where he was very happy and met his first wife.
- Always enjoyed spending time alone, hiking in the woods, and thinking.
- Enjoyed playing the violin.
- Had an odd appearance because he did not care what others thought of appearances. Did not comb his hair; often forgot his keys; often forgot to eat.
- Moved to Germany where he met his second wife, Ilse.
- Developed the Theory of Relativity, $E = mc^2$, which unified our understanding of energy, matter and light.
- Moved to the US due to threats on his life by the Nazis.
- Helped develop the atomic bomb because although he opposed militarism, he felt it would be even worse if the Nazis developed it first.
- Supported the creation of Israel as a homeland for Jews, but came to oppose Zionism due to the treatment of Palestinians.
- Was happily married for many years to Ilse, and until her death.
- In later years, lived quietly alone in Princeton, and continued to play his violin.
- Died quietly while working on an equation.

The Four Fundamental Forces

The familiar force of gravity pulls us down toward the Earth’s center. We feel it as weight. Why don’t we fall through the Earth—through matter? Another force, **electromagnetism**, holds all atoms together, preventing one atom from intruding into the space of another atom.

The remaining two forces exist at the subatomic level which—despite our being made of atoms—we can not directly sense. The **strong force** holds the **nucleus** together. The **weak force** is responsible for **radioactive decay**, specifically, $beta$-decay (beta decay), in which a neutron within the nucleus changes into a proton and an electron, and the electron is then ejected from the nucleus.

Strong Force

The strong nuclear force is the strongest of the four fundamental forces of nature. It is so strong that it can be thought of as glue (the universal glue). It’s 6 thousand trillion trillion trillion (39 zeroes after 6) times stronger than the force of gravity. It binds fundamental particles of matter together to form larger particles. The strong force works only when subatomic particles are extremely close to one another. They have to be somewhere within 10^{-15} meters from each other, or roughly within the diameter of a proton.

Reality is stranger than fiction, and the strong force is one of the strangest phenomenon. Unlike the other fundamental forces, it gets weaker as subatomic particles move closer together. It actually reaches maximum strength when the particles are farthest away from each other. You may have heard the many strange names scientists give subatomic particles. This is their attempt to describe this strange behavior. Once within range, massless charged **bosons** called **gluons** transmit the strong force between **quarks** and keep them "glued" together. A tiny fraction of the strong force called the **residual strong force** acts between **protons** and **neutrons**. Protons in the nucleus repel one another because of their similar charge, but the residual strong force can overcome this repulsion, so the particles stay bound in an atom's nucleus.

Weak Force

The weak force is responsible for **particle decay**. This is the change of one type of **subatomic particle** into another. For example, a **neutrino** that strays close to a **neutron** can turn the neutron into a **proton** while the neutrino becomes an **electron**.

The weak force is critical for **nuclear fusion reactions** that power the sun and produce the energy used by most life forms on Earth. It's also why archaeologists can use **carbon-14** to date ancient bone, wood and other formerly living artifacts. Carbon-14 has six protons and eight neutrons; one of those neutrons decays into a proton to make **nitrogen-14**, which has seven protons and seven neutrons. This decay happens at a **predictable rate**, allowing scientists to determine how old such artifacts are.

Electromagnetic Force

The electromagnetic force, also called the **Lorentz force**, acts between charged particles, like negatively charged electrons and positively charged protons. Opposite charges attract one another, while like charges repel. The greater the charge, the greater the force. And much like gravity, this force can be felt from an infinite distance, but would be very small at great distances.

The electromagnetic force consists of two parts: the **electric force** and the **magnetic force**. At first, physicists described these forces as separate from one another, but researchers later realized that the two are aspects of a single force.

The **electromagnetic force** is responsible for some of the most commonly experienced phenomena: **friction**, **elasticity**, the **normal force** and the force holding **solids** together. It's even responsible for the drag that birds, planes and Superman experience while flying. These actions occur because of charged particles interacting with one another.

The **normal force** that keeps a book on top of a table (instead of gravity pulling the book through the table toward the center of the earth), is a consequence of electrons in the table's atoms repelling electrons in the book's atoms. Luckily for us, the same force allows us to stand on the earth.

Unified Field Theory

One of the biggest questions in science is about the four fundamental forces. Is it possible that they are actually different manifestations of a single great force of the universe? For example, can they be combined in the same way that the electric and magnetic forces have been theoretically unified? If so, each force should be able to merge with the others. Einstein believed there was such a force. He spent most of his life unsuccessfully trying to find it. There is already some evidence that such a force exists, but no one has yet been able to demonstrate it.

Physicists Sheldon Glashow and Steven Weinberg from Harvard University with Abdus Salam from Imperial College London won the Nobel Prize in Physics in 1979 for unifying the electromagnetic force with the weak force to form the concept of the **electroweak force**.

Physicists working to find a so-called grand unified theory aim to unite the **electroweak force** with the **strong force** to define an **electronuclear force**, which scientific models have predicted, but researchers have not yet been able to observe.

The final piece of the puzzle would then require unifying gravity with the electronuclear force to develop the so-called **theory of everything**, a theoretical framework that could explain the entire universe.

The Large and Small Of It

Physicists have found it especially difficult to merge what is known of the **microscopic world** (very small phenomenon) with what is known of the **macroscopic world** (very large phenomenon).

At **astronomical scales**, the force of gravity dominates and is best described by Einstein's **theory of general relativity**. But at the **molecular scale** (atomic or subatomic), **quantum mechanics** best describes the **natural world**. So far, no one has found a theory that can accurately describe both of these aspects of reality, although it seems obvious that they must be part of one universe.

Where are all the gravitons?

Physicists studying **quantum gravity** aim to describe the force in terms of the quantum world. Fundamental to that approach would be the discovery of **gravitons**, the theoretical **force-carrying boson** of the gravitational force. Gravity is the only fundamental force that physicists can currently describe without using force-carrying particles, but because descriptions of all the other fundamental forces require force-carrying particles, scientists expect that **gravitons** must exist at the subatomic level—they just haven't found them yet.

Dark Matter

Further complicating the story is the invisible realm of **dark matter** and **dark energy**, which seem to make up roughly 95% of the universe. It's unclear whether dark matter and energy consist of a single particle or a whole set of particles that have their own forces and **messenger bosons**. Dark matter can also be thought of as **Antimatter** because (Normal) Matter and Antimatter have complimentary properties:

- All particles have antiparticles!
- Antimatter has the same properties as matter, including the same mass, spin, and interactions, except that…
  - Matter and Antimatter have opposite electric charges.
  - Matter and antimatter can annihilate each other to create pure energy, or conversely, energy can create pairs of matter and antimatter. $E = mc^2$

The Fifth Fundamental Force

One messenger particle that currently interests scientists is the theoretical **dark photon**, which would mediate interactions between the visible and invisible universe. If dark photons exist, they'd be the key to detecting the invisible world of dark matter, and could lead to the discovery of a fifth fundamental force. So far, though, there's no evidence that dark photons exist, and some research provides strong evidence that they can not exist.

Study Guide: Einstein and the Theories of Relativity

Before Einstein

Before Einstein, scientists thought that motion occurred against a single reference frame called the “ether” and at particular points in time called “now”. Most astronomers understood the universe in terms of Isaac Newton’s three laws of motion:

1. **Law of Inertia:** Objects in motion or at rest remain in the same state unless an external force imposes change.
2. The force acting on an object is equal to the mass of the object multiplied by its acceleration.
3. For every action, there is an equal and opposite reaction.

Newton’s laws proved valid in nearly every application in physics, and for hundreds of years formed the basis for our understanding of mechanics and gravity. But some things couldn’t be explained, in particular light.

To explain the odd behavior of light, scientists in the 1800s supposed that light must be transmitted through some kind of medium, which they called the **“luminiferous ether”**. This hypothetical and undetectable ether had to be rigid enough to transfer light waves in the same way that a tight guitar string vibrates to transmit sound.

Researchers set about trying to detect the mysterious ether. In 1887, physicist Albert A. Michelson and chemist Edward Morley calculated how the Earth’s motion through the ether affected how the speed of light is measured, and unexpectedly found that the speed of light is the same no matter what Earth’s motion is. If, as their experiments showed, the speed of light doesn’t change no matter what the Earth’s movement is, there must be no such thing as ether to begin with. They concluding that somejhow light in space moves through a vacuum. That in turn meant that light couldn’t be explained by classical mechanics. Physics needed a new paradigm.

Theory of Special Relativity

The theory of relativity is actually two theories. One is called “special” relativity and the other “general” relativity. Two ideas are at the heart of Einstein’s Theory of Special Relativity.

1. **The principle of relativity:** The laws of physics are the same for any inertial reference frame.
2. **The principle of the speed of light:** The speed of light in a vacuum is the same for all observers, regardless of their relative motion or the motion of the source of the light.

Einstein claimed that the ether did not exist, and that all motion was “relative”. This meant that the measurement of motion depended on the relative velocity and position of the observer.

One example of relativity is to imagine two people on a train playing ping-pong. The train is traveling at around 30 m/s north. When the ball is hit back and forth between the two players, the ball appears to the players to move north at a speed of around 2 m/s and then south at the speed of 2 m/s.

Now imagine someone standing beside the railroad tracks watching the ping-pong game. When the ball is traveling north it will appear to travel at 32 m/s (30 m/s plus 2 m/s). When the ball is hit in the other direction, it still appears to travel north, but at a speed of 28 m/s (30 m/s minus the 2 m/s). To the observer by the side of the train, the ball always appears to be traveling north.

The result is that the observed speed of the ball depends on the “relative” position of the observer. It will be different for those on the train than for the those standing beside the tracks.

Einstein's 1905 theory of special relativity is one of the most important papers ever published in the field of physics. Special relativity is an explanation of how speed affects mass, time and space. The theory includes a way for the speed of light to define the relationship between energy and matter—small amounts of mass (m) can be interchangeable with enormous amounts of energy (E), as defined by the classic equation $E = mc^2$.

Einstein was at first not ready to add gravity to his theory. For this reason, special relativity applies only to "special" cases in which gravity is not considered,such as light moving through a vaccuum. In 1915, Einstein was able to combine Newton's Laws of Gravity with his theory of special relativity, to create has greatest acheivement, the General Theory or Relativity.

One of the results of the theory of special relativity is Einstein's famous equation $E = mc^2$, where E is energy, m is mass, and c is the constant speed of light in a vaccuum. This equation states that energy and mass are related. Any change in an object's energy requires a relative change in its mass.

Another interesting consequence of the theory is **length contraction**. Length contraction states that the faster objects move in relation to an observer, the shorter they will appear.

For example, if a spaceship 100 feet long flew by at 0.5 the speed of light, it would appear to be 87 feet long. If it sped up to 0.95 the speed of light, it would only appear to be 31 feet long. Of course, this is all relative. To people on board the space ship, it would always appear to be 100 feet long.

As an object approaches the speed of light, the object's mass becomes infinite and so does the energy required to move it. That means it is impossible for any matter to go faster than light travels. This cosmic speed limit inspires new realms of physics and science fiction, as people consider travel across vast distances.

According to Einstein, in his 1949 book "Autobiographical Notes", he began questioning the behavior of light when he was just 16 years old. In a **thought experiment** as a teenager, he wrote that he imagined chasing a beam of light.

Classical physics would imply that as the imaginary Einstein sped up to catch the light, the light wave would eventually come to a relative speed of zero—the man and the light would be moving at speed together, and he could see light as a frozen electromagnetic field. But, Einstein wrote, this contradicted work by another scientist, James Clerk Maxwell, whose equations required that electromagnetic waves always move at the same speed in a vacuum: 186,282 miles per second (300,000 kilometers per second).

If a person could, theoretically, catch up to a beam of light and see it frozen relative to their own motion, would physics as a whole have to change depending on a person's speed, and their vantage point? Instead, Einstein recounted, he sought a unified theory that would make the rules of physics the same for everyone, everywhere, at all times.

This, wrote the physicist, led to his eventual musings on the theory of special relativity, which he broke down into another thought experiment:

A person is standing next to a train track comparing observations of a lightning storm with a person inside the train. And because this is physics, of course, the train is moving nearly the speed of light.

Einstein imagined the train at a point on the track equally between two trees. If a bolt of lightning hit both trees at the same time, the person beside the track would see simultaneous strikes. But because they are moving toward one lightning bolt and away from the other, the person on the train would see the bolt ahead of the train first, and the bolt behind the train later.

Simultaneity

Einstein concluded that **simultaneity** is not absolute. In other words, simultaneous events as seen by one observer could occur at different times from the perspective of another. It's not lightspeed that changes, he realized, but time itself that is relative. Time moves differently for objects in motion than for objects at rest. Meanwhile, the speed of light, as observed by anyone anywhere in the universe, moving or not moving, is always the same.

E = mc^2, translates to "energy is equal to mass times the speed of light squared." In other words, energy (E) and mass (m) are interchangeable. They are different forms of the same thing.

But they are not easily exchanged. Because the speed of light is already an enormous number, and the equation demands that it be multiplied by itself (or squared) to become even larger, a small amount of mass contains a huge amount of energy. For example, if you could turn every one of the atoms in a paper clip into pure energy—leaving no mass whatsoever—the paper clip would yield the equivalent energy of 18 kilotons of TNT. That's roughly the size of the bomb that war criminals used to destroy the city of Hiroshima in 1945.

Time Dilation

One of the many implications of Einstein's special relativity work is that time moves relative to the observer. An object in motion experiences **time dilation**, meaning that when an object is moving very fast compared to an observer it experiences time more slowly than when it is at rest.

For example, when astronaut Scott Kelly spent nearly a year aboard the International Space Station starting in 2015, he was moving much faster than his twin brother, astronaut Mark Kelly, who spent the year on the planet's surface. Due to time dilation, Mark Kelly aged just a little faster than Scott—"five milliseconds," according to the earth-bound twin. Since Scott wasn't moving near lightspeed, the actual difference in aging due to time dilation was negligible. In fact, considering how much stress and radiation the airborne twin experienced aboard the ISS, some would argue Scott Kelly increased his rate of aging.

But at speeds approaching the speed of light, the effects of time dilation could be much more apparent. Imagine a 15-year-old student leaves school traveling at 99.5% of the speed of light for five years (from the student's perspective). When student returns to Earth, she would have aged those 5 years she spent traveling. Her classmates, however, would be 65 years old—50 years would have passed on the much slower-moving planet.

We don't have the technology to travel near that speed, but time dilation does affect precision instrumments in other ways.

GPS devices work by calculating a position based on communication with at least three satellites in distant Earth orbits. Those satellites have to keep track of incredibly precise time in order to pinpoint a location on the planet, so they work based on atomic clocks. But because those atomic clocks are on board satellites whizzing through space at about 8,700 mph (14,000 km/h), special relativity means that they tick an extra 7 microseconds, or 7 millionths of a second, each day. To remain synchronized with Earth clocks, atomic clocks on GPS satellites must subtract 7 microseconds/day.

With additional effects implied by general relativity (Einstein's follow-up theory incorporating the laws of gravity), clocks closer to the center of a large gravitational mass such as the Earth tick more slowly than those farther away. That effect adds microseconds to each day on a GPS atomic clock, so in the end engineers subtract 7 microseconds and add 45 more back on. GPS clocks don't tick over to the next day until they have run a total of 38 microseconds longer than comparable clocks on Earth.

Special Relativity and Quantum Mechanics

Special relativity and quantum mechanics are two of the most widely accepted models of the universe. But special relativity mostly pertains to extremely large distances, speeds and objects. Events in special (and general) relativity are continuous and deterministic, which means that every action results in a direct, specific and local consequence. That's different from quantum mechanics where events occur in jumps or "quantum leaps" that have probabilistic outcomes, not definite ones.

Researchers uniting special relativity and quantum mechanics—the smooth and the chunky, the very large and the very small—have developed new scientific fields, such as Relativistic Quantum Mechanics and Quantum Field Theory in an attempt to better explain subatomic particles and their interactions.

Researchers striving to connect quantum mechanics and general relativity, on the other hand, consider it to be one of the great unsolved problems in physics. For decades, many viewed string theory to be the most promising area of research into a unified theory of all physics. Now, a host of additional theories exist. One group proposes space-time loops to link the tiny, chunky quantum world with the wide relativistic universe. At this time, there is no known way to test such theories. One or all of them might be true, or all can be false. We have no way to test.

Sources

- https://www.space.com/36273-theory-special-relativity.html

Additional

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.

Optional Assignment: Kepler and the Witchcraft Trial

Directions

1. Read the article, *How Kepler Invented Science Fiction and Defended His Mother in a Witchcraft Trial While Revolutionizing Our Understanding of the Universe*, by Maria Popova
2. On separate paper, answer the below questions using full sentences and as much space as needed.

Questions

1. What was Kepler's personal motto?
2. How does Plutarch's metaphorical story of *The Ship of Theseus* relate to the idea of self-identity? What are your thoughts about this metaphor? Is it "true", useful, helpful, disturbing, hopeful…?
3. What did Lord Kelvin think about the state of scientific progress around the year 1900 CE? What do you think made him think this way?
4. What does Popova mean by the following selection. Do you think she is correct? If so why, or why not? *"Even the furthest seers can't bend their gaze beyond their era's horizon of possibility… We sieve the world through the mesh of these certitudes, tautened by nature and culture, but every once in a while — whether by accident or conscious effort — the wire loosens and the kernel of a revolution slips through."*
5. Through his research, Kepler came to disagreed with Dante that it was "love that moved the sun and stars". What did Kepler think was the single physical force that moved the stars and planets?
6. What was Kepler's primary duty while serving as royal mathematician and chief scientific advisor to the Holy Roman Empire?
7. Who wrote, *"It's part of the nature of of humans to start with romance and build to a reality,"*, and what did he mean by this?
8. What does Popova mean by, *"Which way the coin flips depends on the degree of courage, determined by some incalculable combination of nature, culture, and character."*? What do you think of this idea?
9. In Kepler's allegorical story, *The Dream*, what do the lunar denizens believe happens to "Volva"?
10. Why did Kepler write *The Dream*, and what literary techniques did he use to make his story more effective?
11. Why was Kepler's mother accused of witchcraft?
12. By whom and how did Kepler first become inspired to study the stars?
13. Popova writes that in an act of empathy, Kepler projected himself into the greatest work of art there is. What was this work of art, and who do you think was the artist?
14. What did Kepler believe was crucial and abiding about human psychology that prevented the scientifically illiterate from understanding scientific proofs, and what did he think would be more convincing? Do you think he was right? Why or why not?
15. How did the people of Kepler's home village react once they read a copy of *The Dream*? Why did they associate Kepler's mother with a character in the story?
16. Why did Ursula Reinhold accuse Katherine Kepler of witchcraft?
17. What specific accusations were made against Katherine Kepler in her trial for witchcraft?
18. What did Kepler think he did that caused his mother to be charged with Witchcraft?
19. What did Kepler believe was the clearest evidence of the gravitational relationship between the earth and the moon?

20. Kepler was far ahead of his time in his understanding of the differences and similarities between men and women. What did he think was the primary reason why his mother was accused of witchcraft while he was able to live a full and rich life as one of the leading scientists of his era. In what ways does society today place similar burdens on people?

Sources

- How Kepler Invented Science Fiction and Defended His Mother in a Witchcraft Trial While Revolutionizing Our Understanding of the Universe, by Maria Popova

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

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 $= 2^4 = 2 \times 2 \times 2 \times 2 = 16$.

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

Source: OpenStax College Physics (Accessed: 2023-05-08)

Glossary: Optics

aberration: a distortion in an image produced by a lens

additive color: A primary light color—red, blue, or green; these three colors produce white light when added together.

angle of incidence: The angle between a wave striking a barrier and the line perpendicular to the surface.

angle of incidence: the angle, with respect to the normal, at which a ray meets a boundary between media or a reflective surface

angle of reflection: The angle between a reflected wave and the normal to the barrier from which it is reflected.

angle of reflection: the angle, with respect to the normal, at which a ray leaves a reflective surface

angle of refraction: the angle between the normal and the refracted ray

angstrom: An angstrom is 1/100,000,000 of a centimeter.

central axis: a line perpendicular to the center of a lens or mirror extending in both directions

chromatic aberration: an aberration related to color

concave lens: A lens that is thinner in the middle than at the edges; used to correct nearsightedness.

concave lens: a lens that causes light rays to diverge from the central axis

concave mirror: a mirror with a reflective side that is curved inward

converging lens: a convex lens

convex lens: A lens that is thicker in the middle than at the edges; used to correct farsightedness.

convex lens: a lens that causes light rays to converge toward the central axis

convex mirror: a mirror with a reflective side that is curved outward

critical angle: an incident angle that produces an angle of refraction of 90°

diffraction grating: A piece of transparent or reflecting material, which contains many thousands of parallel lines per centimeter; used to produce a light spectrum by diffraction.

dispersion: separation of white light into its component wavelengths

diverging lens: a concave lens

electromagnetic spectrum: Transverse radiant energy waves, ranging from low frequency to very high frequency, which can travel at the speed of light.

electromagnetic wave: A wave that does not have to travel through matter in order to transfer energy.

element: A substance that cannot be broken down into simpler substances by ordinary means.

equilateral triangle: A triangle with three equal angles of 60 degrees and sides of equal length.

filter: A screen that allows only certain colors to pass through it; a transparent material that separates colors of light.

focal length: The distance between the principal focus of a lens or mirror and its optical center.

focal length: the distance from the focal point to the mirror

focal point: the point at which rays converge or appear to converge

focal point/focus: The point that all light rays from a mirror or lens pass through.

frequency: The number of waves that pass a point in a given unit of time.

gamma ray: High-energy wave of high frequency and with a wavelength shorter than an x ray; released in a nuclear reaction.

image: The reproduction of an object formed with lenses or mirrors.

in phase: When two or more light rays overlap exactly at the crest and the trough, they are said to be “in phase.”

incident ray: the incoming ray toward a medium boundary or a reflective surface

index of refraction: The amount that light is refracted when it enters a substance; given as the ratio of speed of light in a vacuum to its speed in a given substance.

index of refraction: the speed of light in a vacuum divided by the speed of light in a given material

infrared radiation: Invisible radiation with a longer wavelength than red light and next to red light in the electromagnetic spectrum; used in heat lamps, to detect heat loss from buildings, and to detect certain tumors.

interference: The addition by crossing wave patterns of a loss of energy in certain areas and reinforcement of energy in other areas.

kaleidoscope: A toy in which reflections from mirrors make patterns. It was invented in 1819 by David Brewster.

laser (light amplification by stimulated emission of radiation): A device that produces a highly concentrated, powerful beam of light which is all one frequency or color and travels only in one direction.

law of reflection: Angle of incidence equals the angle of reflection.

law of reflection: the law that indicates the angle of reflection equals the angle of incidence

law of refraction: the law that describes the relationship between refractive indices of materials on both sides of a boundary and the change in the path of light crossing the boundary, as given by the equation n1 sin $\omega 1 = n^2 sin\omega^2$

lens: A curved, transparent object; usually made of glass or clear plastic and used to direct light.

light: Light is a form of energy, traveling through the universe in waves. The wavelengths of visible light range from less than 4,000 angstroms to more than 7,000 angstroms.

normal: A line perpendicular to a surface.

opaque: Not transparent; no light passes through the material.

optical axis: The line straight out from the center of a parabolic mirror; straight line through the center of a lens.

optical fiber: A thin strand of glass that transmits light down its length.

optical telescope: A tube with magnifying lenses or mirrors that collect, transmit, and focus light.

out of phase: When the crest of one wave overlaps the trough of another they are said to be “out of phase.”

parabola: A curved line representing the path of a projectile; the shape of the surface of a parabolic mirror.

parabolic mirror: A curved mirror with a single focal point..

pigment: A material that absorbs certain colors of light and reflects other colors.

plane mirror: A mirror with a flat surface.

polarized light: Light in which all waves are vibrating in a single plane.

prism: A transparent material with two or more straight faces at an angle to each other.

ray: light traveling in a straight line

real image: An image that can be projected onto a screen; formed by a parabolic mirror or convex lens.

real image: an optical image formed when light rays converge and pass through the image, producing an image that can be projected onto a screen

reflecting telescope: A telescope in which magnification is produced by a parabolic mirror.

reflection: The light or image you see when light bounces off a surface; bouncing a wave or ray off a surface.

refracted ray: the light ray after it has been refracted

refraction: Bending of a wave or light ray caused by a change in speed as it passes at an angle from one substance into another.

scattering: The spreading out of light by intersecting objects, whose size is near the wavelength.

Snell’s law: the law of refraction expressed mathematically as 1sin 1= 2sin 2

spherical: Surface of a lens or mirror that is part of a sphere.

subtractive color: One of the three pure pigment colors—magenta, yellow, cyan; these pigment colors produce black when mixed.

total internal reflection: reflection of light traveling through a medium with a large refractive index at a boundary of a medium with a low refractive index under conditions such that refraction cannot occur

translucent: Semitransparent; a material that admits some light.

transparent: See-through; light can go through.

true image: A true image is the way other people see us. It is the opposite of the image that is seen in a mirror.

ultraviolet radiation: Radiation that has a shorter wavelength than visible light; next to violet light in the electromagnetic spectrum.

virtual image: An image formed by a mirror or lens that cannot be projected onto a surface.

virtual image: the point from which light rays appear to diverge without actually doing so

visible light spectrum: Band of visible colors produced by a prism when white light is passed through it.

wavelength: The total linear length of one wave crest and trough.

X-ray: Invisible electromagnetic radiation of great penetrating power.

Bibliography

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

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