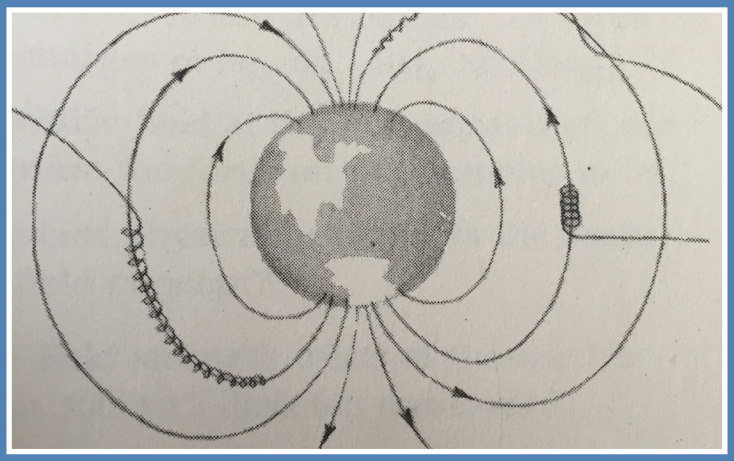
# A Waldorf High School Physics Program

with Appendices



Robert C. Oelhaf

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*A Waldorf High School Physics Program*
*with Appendices*

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# Introduction

Since main subjects are taught in blocks, it is possible to design a program to meet the developing students' interests and needs. There are several ways to view the four high school years, ways which supplement and support each other and form the basis of the traditional approach to organizing physics and other subjects. We have in addition several general objectives for a physics program, namely, to provide a foundation for understanding fundamental physics concepts and procedures and to do this in a Goethean or phenomenological style. Time limitations place restrictions on the total material and/or depth of the coverage.

# The Question of Breadth

The original Waldorf School in Stuttgart, Germany, ran six days a week and had a six week summer vacation in contrast to our five days per week (Today German schools also have only five.) and a summer holiday of some 12 weeks. Altogether American schools have perhaps 36 weeks, not all of them full due to various holidays. Main lessons also may run only two 45-minute periods or 1½ hours total. In general we have each year one three-week main lesson block, giving us 2 x 15 = 30 classroom hours per year in contrast to perhaps 36 in the original school. Some schools have tried using extra main lesson time, mathematics skills classes or art blocks in the afternoon to bolster the schedule. At least one school has extended the school day to produce two main lessons a day. However most of us must make due with 30 hours a year or 120 over the high school program. In contrast, public schools or prep schools generally have one period a day for a whole year, or a total time of 5 x 37 weeks = 185 classroom hours (somewhat less for prep schools). I taught in a prep school which allocated 7 hours per week to chemistry, allowing two full laboratory periods per week for a total of some 259 class hours. Today public schools also may expand the weekly classroom hours allocated to their science offerings.

How can we overcome this gap in technical education? Naturally we strive for depth, to present material so that it sticks, more likely in a block system than in daily lessons. Rudolf Steiner expected the teachers to be efficient, so that more could be learned and digested in a shorter time, allowing us to reach state expectations with fewer classroom hours. Still, it is difficult to match a conventional course, nor do we want to do this. We are teaching all students, not only those with an interest in science or college. The solution which I have used is to offer extra physics lessons to interested students. We have done this on Saturday mornings (the most effective), in electives and in after school club settings. These courses generally emphasize theory and calculations, the main things we cannot push too far with general students in a Goethean context.

## Goethean Physics

In a Goethean approach to physics, we begin with observations and a clear review of these observations. Students are allowed to reflect on these things during the night. The following morning on Day 2 the observations are reviewed and implications are drawn out, implications which generally lead to further experimentation, and so the process continues. On the third day ideally students will participate in their own investigations, verifying or exploring the area being studied. This threefold main lesson is an extremely efficient and powerful method of penetrating a subject. It is also quite difficult to put into practice, given limitations in time to carry out real laboratory investigations and often also limitations of student equipment and laboratory space. To the extent it can be approximated, however, considerable efficiency in learning can be accomplished.

Clearly, for students to undertake their own laboratory investigations they need space and a science laboratory designed for this purpose. The Waldorf school with the best designed laboratory that I am familiar with is at Kimberton Waldorf School. Each student pair has a complete set of equipment in their desk for experimentation, with adjoining sink and gas. There are two labs, one for physics and chemistry, one for biology and geology. They share a generously sized preparation and storage room.

When the time comes for a school to remodel or build, it is certainly worthwhile to include generously proportioned and equipped science rooms.

# 9th Grade Physics

The content of the 9th Grade Physics block is perhaps the most controversial among the Waldorf science blocks. Naturally we hope that all high school teachers are to some extent specialists in their teaching fields, so that some university study would be expected. While lower school teachers are generalists, high school teachers were expected by Rudolf Steiner to be specialists. So physics teachers would have had at least some exposure to university-level physics. Thus they know that the major branches of physics are mechanics, electricity and magnetism, optics and thermodynamics. We teach mechanics in 10th Grade, electricity and magnetism in 11th Grade and optics in 12th. So it is natural to think that thermodynamics should be the subject of the 9th Grade block. It is not totally out of place there. However there are too many reasons for avoiding the thinking of conventional physics programing.

## Communication and Transportation, not Thermodynamics

Let us think of the typical 9th Grader. These students have recently entered puberty. They are full of energy and full of themselves. They are very conscious of themselves as independent human beings. They want to make practical contact with the modern world. Put all together, and we receive a picture of young people who need to take control of themselves and guide their energy to useful purpose. They also need to find their way through the world and to others, to make positive connections. They are not interested in theory, but in practical matters: how engines work, how to build a shed, plant a garden, the latest cell phone...

Rudolf Steiner recommended meeting these needs through the topics of steam engines (locomotives) and the telephone. What is the significance of these technologies? They are the main transportation and communication technologies of the early 20th Century. A century later, they are that no longer.

Today they have been for the most part replaced by the automobile and the cell phone. This means the internal combustion engine, not the external combustion of steam. This replacement of external energy with internal energy corresponds to the emergence of the strong ego and independent spirit of the 20th Century. Furthermore, young people are rapidly leaving the old “land line” phones behind for their cell phones. The cell “phone” is, however, not really a phone in the traditional meaning, but a radio. So we come to the major themes for 9th Grade Physics in our time: the internal combustion engine and the cell phone (radio).

There are further considerations. 9th Graders are not so interested in theory, rather more in practical matters. This is good reason not to focus on the theory in thermodynamics, but rather how it is applied. Furthermore, the First Law is most easily seen in 10th Grade Physics (mechanics). And the Second Law is almost impossible to avoid in 10th Grade Chemistry, falling out visually and through the release of heat in a simple phase change, making it far easier and clearer to demonstrate and explain then. By 10th Grade students are also more mature and more ready for concepts and theories.

Not only are 9th Grade students constantly using their cell phones, they will also soon be driving. If they do not receive some understanding of how an automobile engine works, they feel short-changed. Many schools offer driver education in the 9th Grade, including some Waldorf schools. Rudolf Steiner urged us to learn the working principles of the machines we use, else we are wandering through life in a dream world we do not understand. In science classes we are constantly on the lookout for practical applications to enliven lessons and to help students orient in the modern world.

In Stuttgart, according to Stockmeyer, Waldorf schools were already bringing in internal combustion in 9th Grade in the 1940s. American schools need to catch up! For several years I was told by a leading Waldorf science teacher, that "we have no idea what to do in 9th Grade Physics." I hope that is no longer the case.

The practical side of thermodynamics is, however, an important part of the block. And certainly thermodynamics, discovered and founded by Carnot, was crucial in designing the internal combustion engine. Heat in all its aspects—including the gas laws of Charles and Boyle, expansion and phase change, absorption and transmission—is important in practical applications. The gas laws will be needed later in 11th Grade Chemistry. So these practical aspects should be thoroughly explored, to the extent that they were not already introduced in 8th Grade. In connection with Carnot, advanced students may wish to explore the theory of the Carnot cycle and heat engines.

## References


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Walker, Jearl. *The Flying Circus of Physics*, Wiley, 2007

## Recitation Suggestions

"Cargoes," John Masefield
"Clap! Snap! The black crack!" J.R.R. Tolkien, *The Hobbit*
"Smart, smirched Smiths"

## Industrial Tours

Private collections of classic steam engines or gasoline engines. Often can be demonstrated; large parts make viewing easier
Radio-TV station
Automobile or other assembly plant
Railroad diesel repair shop

## Course Outline

Atmospheric engines
Pressure
Steam engines
Experiment: Boyle's Law
Experiment: volume of air and temperature (air thermometer, Charles' Law)
Temperature scales
The internal combustion engine
    Sadi Carnot
    Rudolf Diesel
The four-stroke cycle engine
Engine components and their functions
Bernoulli's Principle and applications
Heat
The expansion of water
The expansion of solids
Heat capacity (optional)
Heat transfer
Phase changes, latent heat
Refrigerators
The electromagnetic spectrum
Radio communication
Cell phones

# Teaching Notes

**Opening Demonstration**
A simple and dramatic way to begin the block is with the crushing of a can with atmospheric pressure. The easiest way is to heat a large can with some water in the bottom, such as from maple syrup, until filled with steam, close the lid, cool with ice water, keeping fingers distant. If a large steel drum and an air pump are available, that would be even more impressive. It is also possible to crush soda cans.

Other possibilities: melt wax in a can, let it cool, leaving a hole in the center. Can students guess how you made the hole?

Simple magic with Bernoulli's Principle, e.g., throwing a curve with a styrofoam ball, balancing a ball on a soda straw.

**Atmospheric Engines**
No doubt steam engines have been covered in 8th Grade. It is worthwhile, nevertheless, to begin with a brief review of the engines of Newcomen and Watt. Often small scale models are available. The theme is overcoming practical difficulties through human ingenuity. A simple model of Hero's (first) steam powered "engine" is available from AstroMedia. The steam locomotive, steam power today running turbines in power plants.

**Pressure**
Calculation, measurement, units need to be explained. Simple Magdeburg hemispheres used to lift plate glass may be available. The various properties of pressure of fluids are easily demonstrated with water. Depth limits on pumps, types of pumps (force, suction, rotary). (Newcomen's engine ran a force pump, Savory's a suction pump.) Depth diving. Diving bell. Syphon.

Boyle's Law can be conveniently demonstrated using large syringes from Sargent-Welch. Students pile bricks on a wooden block mounted above the syringe. (Wrap bricks in brown paper.) Simple calculations and graph clearly show the relationship.

**Temperature**
Contrast human experience with thermometer (3 bucket experiment)
Engine design is also based on a knowledge of temperature effects on gases. A simple experiment demonstrates the relationship (Charles' Law). A dry flask is heated in a hot water bath to 100°C, then plunged into ice water. When the two volumes are graphed against temperature, an assumed linear relationship leads to absolute zero and the Law. Temperature scales and conversion follow directly.

## Internal Combustion Engines

The stories of Carnot and Diesel demonstrate the motivations behind technical developments. Carnot, of the French aristocracy, inventing thermodynamics in order to develop an engine to beat the Germans. But the Germans built it first (Otto). Diesel, as a child ostracized in France for being German, in Germany for having a French accent, seeking world peace through an engine running on any fuel. But the engine was used in World War I. The aristocrat and the hard-working engineer-salesman. Recent revival of Diesel: dirty and clean diesel.

Modern 4-stroke cycle (or 4-cycle) and 2-cycle engines should be explained. An old lawn mower engine is generally available to borrow or have donated. Most students enjoy tearing it apart. Those who do not can watch and sketch parts. Note character of each piece, name and how it functions.

The venturi should be visible, leading to a discussion of Bernoulli's Principle and applications in flight. Simple demonstrations: blowing over paper, putting spin on balls, sail boats. A glass venturi is available from Frey.

Jet engines and rockets also need to be addressed.

## Heat

Character and location: expansion, activity. Warm: earth core, equator, our interior, engines, computers. Cold: earth poles, our extremities. These qualitative observations in fact correspond to modern physical theory of molecular basis of heat, to be discussed in 11th Grade Chemistry.

Heat measurement

Heat transfer (Can be skipped or skimmed if detailed coverage in Lower School)

- >Conduction. Metal vs cloth. Various metal rods, glass, wood, held in candle or Bunsen burner
- >Convection. $KMnO_4$ in beaker of water, heated on one side; smoke in fish tank with 2 holes in cardboard cover, candle under one
- >Radiation. 1) Thermometers one under black paper, one under white, in sun or heat lamp. Temperature after several minutes
  2) Boiling water in two metal cans, one shiny, one blackened Temperatures after several minutes
- Practical applications

Coefficients of Expansion (Expansion of gases has already been covered.)

Solids: Expansion of solids can be measured by arranging 2 parallel meter sticks, one fixed, the other flexible, separated by the length of a metal rod a few cm above the fulcrum. The rod is hung in boiling water long enough to reach 100°C. The rod is then re-inserted between the sticks a few cm above the fulcrum. The expansion of the rod can be calculated and its expansion coefficient. Practical application in bridge design, bi-metal strips

Liquids: A 250 ml Erlenmeyer flask fitted with a one-hole stopper and a long glass tube inserted in the hole, immersed in a 1000 ml beaker over a Bunsen burner. As the beaker is heated, the water rises, and measurement of the water temperature allows estimates of how the expansion coefficient changes with the temperature.

Heat Capacity: If time permits, a comparison of heat capacity of water and corn oil can be made by heating small beakers of each, using identical Bunsen burner settings.

Phase Change, Latent Heat: Begin with 400 ml beaker of ice (Some water present to avoid cracking the glass), heat with stirring and temperature measurement until all melted, then to boiling point and then continue vaporizing as time permits. Calculate heat flow to beaker from rate of temperature rise of water. From this estimate latent heat of melting and boiling/vaporization.

Heat pump, refrigerator

Demonstration: boiling point and pressure
Boil water in flask, stopper with thermometer, cool

**Communication Systems**

Signals, vibrations, tin cans and string...

Telegraph, "land-line" telephone

Radio communication. Morse code

Electromagnetic spectrum, frequency allocation

Voice and music: Human ear and voice: requirement of carrier frequency and modulation
Compression and sound quality. Direct voice or music vs modern media

Radio transmitter and receiver: components, arrangement, function. Demonstration.
Actual functioning of components can wait for 11th Grade Physics.

Mobile phone. History. Cell phone system, functioning

Advances and possible dangers

## Appendices

**9-1** Masefield, "Cargoes" and "Smith's Prayer" from the Middle Ages
**9-2** Student Laboratory Desk
**9-3** The Engine House
**9-4** Engine Components and Their Purposes
**9-5** Internal Combustion Engine: History
**9-6** Rudolf Diesel
**9-7** Boyle's Law
**9-8** Charles' Law
**9-9** Experiment: Heat Capacity and Latent Heat

# Cargoes

Quinquireme of Nineveh from distant Ophir,
Rowing home to haven in sunny Palestine,
With a cargo of ivory,
And apes and peacocks,
Sandalwood, cedarwood, and sweet white wine.

Stately Spanish galleon coming from the Isthmus,
Dipping through the Tropics by the palm-green shores,
With a cargo of diamonds,
Emeralds, amethysts,
Topazes, and cinnamon, and gold moidores.

Dirty British coaster with a salt-caked smoke stack,
Butting through the Channel in the mad March days,
With a cargo of Tyne coal,
Road-rails, pig-lead,
Firewood, iron-ware, and cheap tin trays.

– John Masefield

*Quinquireme:* an ancient form of ship having five banks of oars.
*Ophir:* a region mentioned in the Old Testament as a source of gold.
*Spanish galleon:* sailing vessel with three or four decks, treasure ship in American commerce.
*The Isthmus:* the narrow land bridge between Atlantic and Pacific oceans, the Isthmus of Panama
*Moidore:* gold coin of Portugal and Brazil, worth about $10

# Smith's Prayer

*from the Middle Ages*

Smart smirched smiths smattered with smoke
Drive me to death with the din of their dents.
Such noise on nights men ne'er heard never,
Such clamoring of cries and clattering of knocks.
The craftsmen clamor for coal, coal, coal,
And blow their bellows their brains to burst.
They jostle and jangle; they jape and they jest.
They groove and they grind and they grumble together,
Hot with the heaving of heated hammers.
Stark strokes they strike on the steeled stack.
Well wrought, well wrought, well wrought!
Might daunt the devil such life they lead.
All armorers, founders, forge men,
Christ save them!

# Student Laboratory Desk

## Equipment List

250 ml Erlenmeyer flask
100 ml beaker
250 ml beaker
400 ml beaker
6 test tubes
Test tube rack
Watch glass
Glass plate
Stirring rod
Glass tube
Crucible and lid
Medicine dropper
Utility clamp with right angle clamp
Wire gauze
Test tube holder
Crucible tongs
Screw clamp
Matches
4" ring
Bunsen burner
Flame spreader
Clay triangle (pipestem triangle)
Apron
Goggles

## Check-in Procedure

1. Make sure all items are present and clean, neatly arranged.
2. Report any missing, dirty, messy or extra equipment.

Note: Large equipment should be in lower drawer/cabinet.

## Check-out Procedure

1. Make sure all equipment is present, neat and clean and that no extra equipment is present.
2. Clean desk top, sink and general work area.

**9-3**

# The Engine House

For over 20 years, the development and refinement of the steam engine occupied the hands and minds of engineers the world over. From its crude beginnings in the coal fields of England to its ultimate form as a high-speed, precision machine, the stationary steam engine was always in transition. The story of its inception and development has all the elements of a prize-winning novel; intrigue, luck, failure and fortune have all played their part in producing the stationary steam engine in its ultimate form. Or have we seen its ultimate form?

To try to compress the history of the steam engine into these columns would be an injustice to a fascinating story and would also take us away from our chief interest, the engineering aspects of stationary steam. However, having said that, it is important to appreciate the heritage of the steam engine in that later developments that we will look at will have their roots firmly in its history. In a later column, I will include a short list of books, presently available, that give an interesting account of the development of the steam engine.

Let's go back to the year 1699 and do a very fast overview of stationary engine development. In 1699 Capt. Savery used the principle of condensing steam to form a vacuum to drain a coal mine. The fact that mines usually flooded gave great impetus to the development of the steam engine and, for many years, almost all of the engines built were for pumping duty.

In 1705 Thomas Newcomen used the same vacuum principle to operate his Atmospheric Engine. As can be seen in Figure 1, the engine was non-rotative and so could be used only for pumping. In Newcomen's engine, the steam was introduced into the cylinder underneath the piston when the weight of the pump rod had lifted the piston to the top of its stroke. Cold water was then introduced into the cylinder, and this condensed the steam. The weight of the atmosphere pushed the piston down, raising the pump rod and thus lifting the mine water. As we can appreciate now, this continuous heating and cooling of the cylinder was highly inefficient; however, from the mine owner's point of view, the mine was being drained, and the coal he was using was legally unsaleable.

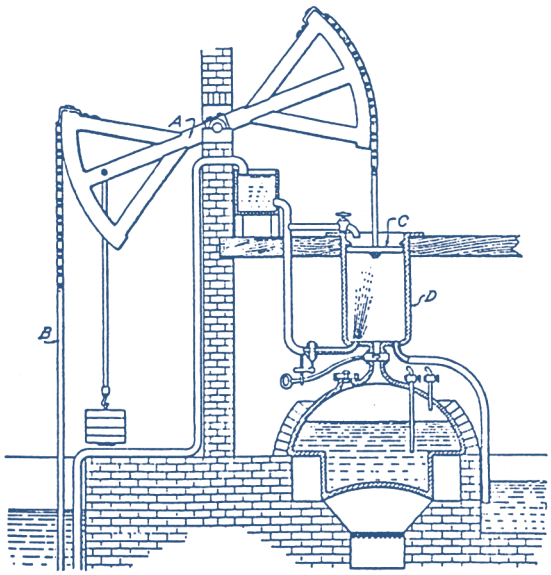
While repairing a model Newcomen engine, James Watt realized the inefficiencies inherent in the engine. Contrary to popular belief, Watt did not invent the steam engine; but he did make some profound changes—changes that would alter forever

the development of many branches of steam engineering. Watt invented the separate condenser. By carrying out the condensing in a separate vessel, Watt could keep the cylinder at a constant temperature, effecting a great increase in efficiency and a similar saving at the coal pits.

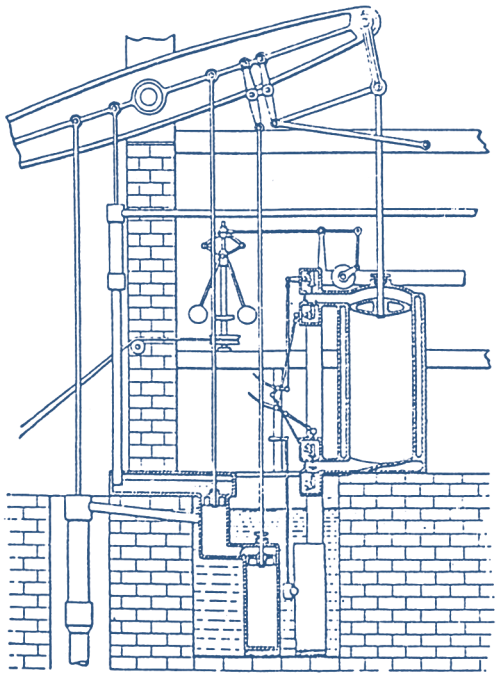
By 1768, a Watt engine could produce the same power as a Newcomen engine on approximately one-quarter the fuel. As this formerly unsaleable coal was now legally saleable, the mine owner was saving boiler fuel and realizing extra profit. The drawing in Figure 2 shows the final form of Watt's pumping engine.

The introduction of the crank and flywheel enabled the beam engine to change its reciprocating motion to rotary motion, opening up a whole new field of uses. At about the same time, many engineers were experimenting with "high pressure steam"—that is, at pressures of 45 to 60 psi! Strangely enough, Watt, for all his scientific knowledge and enthusiasm, was not an advocate of higher pressures, and it was left to men like the American, Oliver Evans, and the Englishman, Richard Trevithick, to explore this new development.

As boiler materials improved and it was realized that substantial savings of fuel were possible with high pressure steam, further ways were investigated to utilize to the fullest the expansive power of this steam. Although both Woolf and Hornblower had developed




NEWCOMEN'S STEAM PUMPING ENGINE
FIGURE 1

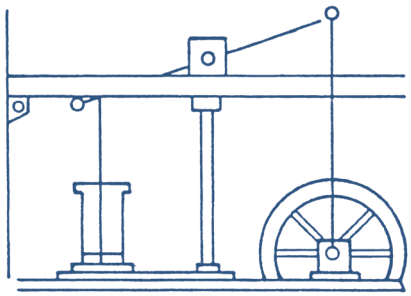


FINAL FORM OF
WATT'S STEAM PUMPING ENGINE
FIGURE 2

compound engines, it took the later increases in boiler pressure to make these—and their logical progression, the triple- and quadruple-expansion engines—viable power units. In spite of these developments in fuel economy, it is a sobering thought that the best combination of engine and boiler will only give an efficiency of around 15%, based on the theoretical energy of the fuel.

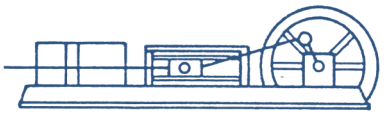
Stationary steam engines were developed to fulfill a variety of needs. Unlike the railway and marine engines, the stationary engine had to perform a wide range of powering tasks under a wide range of conditions. A study of even the main classes of engines will reveal a wide range of shapes, sizes and configurations.

In Figure 3, we can see the three main classes—the beam engine, the horizontal engine, and the vertical or inverted cylinder engine. These three styles were developed because of specific needs, and many later engines conformed to these styles with only minor changes.



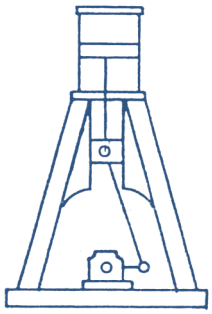
The original form of Beam Engine, as constructed by Watt, owed its existence to the fact that most engines were used to pump water and the Beam was convenient to hang pump rods on.

BEAM ENGINE



The Horizontal Engine – a general purpose engine – could be of any size and power and of one-, two-, three- or four-cylinder configuration.

HORIZONTAL ENGINE



DCR·ld

The Vertical Engine was a type used extensively for both small and large engines taking up little floor space, and used in one-, two-, three- or four-cylinder configurations.

VERTICAL ENGINE

TYPES OF STATIONARY
RECIPROCATING ENGINES
FIGURE 3

| Atmospheric Engine Savery 1700 | Low Pressure Engine Watt 1768 | High Pressure Engine Evans 1804 | Double Cyl. Engine Woolf 1804 | Compound Engine Elder 1850-1891 | Triple Expansion 1880-1891 |
|---|---|---|---|---|---|
| 31 | 8.8 | 6.7 | 4.5 | 2.25 | 1.76 |

COAL CONSUMPTION
In Pounds Per Horsepower Per Hour
From 'Handbook On The Steam Engine' 1902

FIGURE 4

# Engine Components and Their Purposes

**Cover.** An air shroud protects the engine (and the operator) and directs air over the cooling fins.

**Flywheel.** Its large mass keeps the crankshaft turning smoothly. The fan fins blow air over the cooling fins on the head and block.

A **magnet** induces a high voltage impulse in the coil.

**Governor.** It controls the throttle(or gas regulator) to maintain an even speed.

**Air Filter.** It filters the air.

**Choke.** It controls the air intake.

**Carburetor.** It mixes gas and air. The gas is sucked into the air stream by a Venturi, a narrowing of the air passage, which lowers the air pressure, causing the gasoline to enter and vaporize.

**Spark Plug**. Ceramically insulated, it extends into the combustion chamber, where it ends in a narrow gap, which must be kept clean and exactly the correct width.

**Coil**. The magnet on the flywheel causes a voltage in a primary coil of about 200 turns, which is multiplied by a secondary coil of 20,000 turns. A circuit breaker induces a voltage surge in the secondary of about 25,000 volts, producing a spark in the spark plug, which ignites the fuel.

**Cam and Camshaft**. The camshaft gear is twice the diameter (and thus also twice the circumference) of the crankshaft gear. Thus the camshaft makes one rotation for each two rotations of the crankshaft. The cam pushes up the push pin, which pushes up the rocker arm, which pushes down the spring, thus opening a valve.

**9-5**

# Internal Combustion Engine: History

1680 First proposed, using gunpowder

17th C. Gaseous products are used to pump. Watt develops packings and piston rings.

1800 Henry Maudstay develops the lathe, making possible precision parts

1820 Hydrogen-air mixture tried. The apparatus exploded.

1824 Sadi Carnot (1796–1830), French physicist, writes pamphlet, "Reflections on the Motive Power of Heat"

> Develops the theory of the internal combustion engine

> New idea: Driving force from pressure of combustion of fuels, gases compressed before burning

> Thermodynamics founded, the physics of heat, the basis of the internal combustion engine and of refrigeration

> Carnot's motivation: Win the next war with Germany. He came from a prominent French family; his father was the War Minister.

> Problem: The engine did not work.

1860 Etienne Lenoir, French, built the first successful engine, but had only a 4% efficiency.

1862 Alphonse Beau de Rochas (1815–1893), French engineer, proposed a 4-stroke cycle engine with the compression of the fuel-air mixture before ignition, in order to raise the temperature. He received a patent in 1862. The principles are:

1. Maximize cylinder volume with minimum cooling surface
2. Maximize the rapidity of expansion (thus less heat loss)
3. Maximize the compression ratio
4. Maximize the pressure of the ignited charge

However, he did not build the engine. The Germans did.

**Nikolaus Otto (1832–1891)**

1864 Began engine manufacture

1876 Patent on successful 4-stroke cycle engine, used in a motorcycle

1878 Manufacture in the US begun

1876 A 2-stroke cycle engine developed, more powerful per stroke, but less efficient in clearing waste gases

1886 Karl Benz. First gas-fueled car

1897 First successful Diesel engine, using high pressure and compression ignition

1898 US manufacture begun

# Rudolf Diesel (1858–1913)

Born in Paris, 1858, 18 March. Father was a leather craftsman, mother a language tutor.

As a child lived in Paris during threatened war with Germany. Diesel ostracized as German, called "pretty little German pig." Won scholastic honors, spent free time sketching technical exhibitions in Paris museums.

1870. Franco-Prussian War began. Family, as "undesirable aliens," shipped by police to London. Diesel again studied technical exhibits in museums.

A cousin, professor in Augsburg, invites Diesel to live with him and enter school. Now Diesel ostracized as French because of accent. Again top honors in school. Scholarship to Technische Hochschule (= university), Munich. Most brilliant in history of University. One of his professors had developed refrigeration. Diesel worked for him and became manager of a factory manufacturing refrigerators.

Two years studying mechanical design at famous Sulzer Machine Works, Winterthür, Switzerland.

Diesel's idea, while still a student: Develop a more efficient engine using local sources of fuel. Why? Social revolutionary idea: Enable local craftspeople to obtain power on their own from local sources, thus competing with large firms. (Note similar movement today.) Fuel from shale oil, coal, palm oil, butter

Diesel was seeking social justice and balance in society and economy. He believed the result would be World Peace. Diesel became a pacifist.

Contrast Diesel's motivation with Carnot's, also their radically different lives, though in the end neither achieved his goal.

| | |
|---|---|
| 1885 | Working as refrigerator salesman in Paris, began work on new engine. It took 13 years. |
| 1888 | Ammonia engine exploded, almost killed Diesel. He switched to petroleum oil. |
| 1892 | Moved to Berlin with 12 trunks of drawings. Found financing |
| 1893 | First working engine. p = 80 atm, highest ever achieved. Engine exploded. |
| 1896 | Working model with efficiency of 75% |
| 1897 | First successful engine. High pressure, compression ignition (Note warmth when pump up bicycle tire) |
| 1898 | First commercial engine, at Busch Brewery in St. Louis |

*Diesel engine characteristics:*
The heat from high compression ignites the fuel.
Thus a very high compression ratio
Heavy construction necessary
Slower speeds
Cheaper to run because uses less-refined fuel-air
4-stroke cycle engine

Though millionaire, Diesel mismanaged wealth, also depressed as saw world war approaching. On Sept 27, 1913, took ferry to England, mission was peace in Europe. He disappeared. Germans believed foul play by British agents, but family believes suicide. His engine for peace used for war.

# Boyle's Law The Relationship Between Pressure and Volume of a Gas

**Purpose:** to find the relationship of pressure and volume of a gas

**Equipment:** syringe with stand, bricks, scale, ruler

**Background:** According to Boyle's Law, the volume of a gas varies inversely with the pressure.

**Approach:** We will use a sample of air trapped in the syringe. Pressure is varied by setting bricks on top of the syringe. The total pressure is atmospheric pressure plus the pressure exerted by the bricks. Volume and pressure can then be compared, their product calculated, and a graph made showing volume as a function of pressure.

**Procedure:**
Measure the diameter of the syringe and find its area.
Weigh a brick with the scale (in pounds). Note: 2.2 lb = 1 kg
Assemble the syringe and stand. Be sure that the syringe is air-tight.
Record the height of the syringe plunger/piston.
Place half and full bricks, one at a time, on top of the syringe, measuring the height in the tube after each addition.
Calculate the total pressure in the cylinder.
Calculate pressure times volume, pV.
Plot volume as a function of pressure on graph paper.

**Calculations:**

Area of piston = $\pi d^2/4$
Pressure of brick ($lb/in^2$) = weight of brick/area of piston
Total pressure in the cylinder = $p_{air} + p_{bricks}$

**Data:** Include your data and that of all classmates:

| V (cm ) | # bricks | p of bricks | Total p | pV |
|---|---|---|---|---|

**Graph:** Graph volume as a function of total pressure.

**Conclusions:** Describe the appearance of your graph. How do the values of pV compare? Is this product approximately constant? What is this relationship called in mathematics? Do your graph and your data confirm Boyle's Law? Explain. What errors could influence your results. Are you still convinced of the validity of the Law? Why?

**9-8**

# Charles' Law **An Air Thermometer**

**Purpose:** To understand temperature scales and the behavior of gases when their temperature is changed.

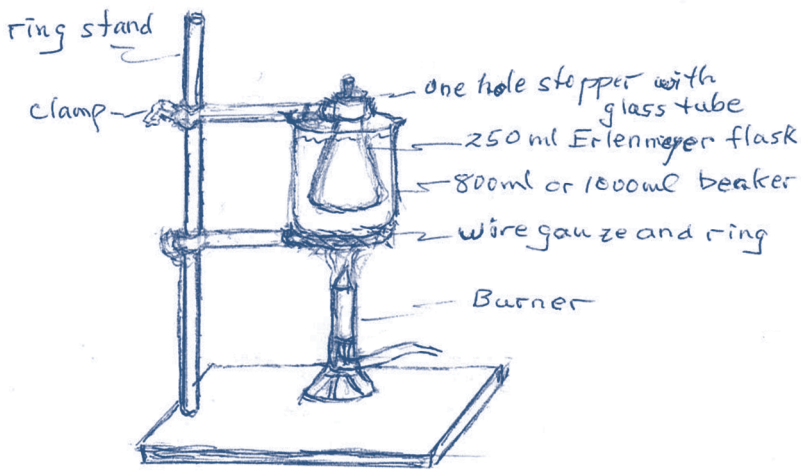
**Method:** In this experiment, a flask of air will be heated to the boiling point, which we call 100°C. After waiting for the air in the flask to also rise to this temperature, it will be plunged into ice water, water which has come to equilibrium with the ice and thus has a temperature of the freezing point, which we call 0°C. To do this without losing or gaining air, a finger will be kept tightly over the top of the glass tube. The clamp will be removed from the ring stand, and clamp, flask and stopper with tube will all be plunged into the ice water. The finger can then be removed, allowing ice water to flow into the flask as the air contracts.

Comparing the original volume of air in the flask with the new volume, we can see how much the air contracted. Suppose that we cooled the air further? If we assume that the air continues to contract by the same amount for each degree Celsius that the temperature declines, we can calculate the temperature when the volume would shrink to zero. This temperature is known as "Absolute Zero," a temperature considerably lower than 0°C. We can estimate this temperature by graphing the Volume of air in the flask as a function of Temperature.

**Procedure:**

1. Prepare an ice bath by filling a pneumatic trough or other container with ice and adding enough water to cover the ice.

2. Using a dry Erlenmeyer flask, insert a short glass tube into a rubber stopper to fit the flask, and insert the stopper into the flask.




3. Place a ring and wire gauze on a ring stand, an 800 or 1000 ml beaker on the gauze, and lower the 250 ml flask into the beaker, holding it in place with a clamp attached to the ring stand. The flask must not touch the beaker. (Why?) Then fill the beaker with water to the neck of the flask.

4. Heat the water to boiling with a Bunsen burner and continue heating for at least 5 minutes to assure that the air in the flask has reached the temperature of the boiling water, which we call 100°C.

5. Make sure that the stopper is held tightly in the flask.

6. Now place your finger firmly over the end of the glass tube and plunge the flask, tube down, into the ice-water bath. Remove your finger and observe. Leave the flask in the bath for several minutes. What is happening inside the flask? Why?

7. When the flask is ice-cold, adjust the water level in the flask to that in the ice water, keeping the tube end under water at all times. This equalizes the pressure inside and outside the flask. Why is this important?

8. Now place your finger over the end of the tube and turn the flask right side up on the table. Remove the stopper and measure the water with a graduated cylinder. Call the temperature of the ice water 0°C.

9. A "250 ml" flask is only approximately 250 ml in volume. Furthermore, there was a stopper in the top of the flask. To determine the actual original volume of air in the flask, fill the flask with water, insert the stopper, remove the stopper, and empty the remaining water into a graduated cylinder. (If you are using a 100 ml graduated cylinder, you will have to pour in only about 1/3 of the water at a time, then add them together to find the total.)

**Data:** Record all data and observations in your notebook.

**Calculations:** Calculate the volume of air in the flask at the freezing point.

**Graph:** Plot your results for the volume and temperature of air on graph paper, allowing room on the graph to show the temperature at which the volume of air would become zero. You will need a horizontal axis which includes values of temperature (°C) from about -300 to +100. Place your vertical axis at 0°C and let the units run from 0 ml at the x axis up to 300 ml. Plot your values for the volume of air at 0°C and at 100°C. Connect your two data points with a straight line and extend the line to the left to lower temperatures until the line intersects (meets) the Temperature (x) axis. This value of the temperature is known as "Absolute Zero" or 0°Kelvin.

**Questions:**

1. According to your graph, what should be the volume of air in your flask at room temperature of about 20°C? Explain how this apparatus could be used as a thermometer. What are the disadvantages of such a thermometer?
2. What temperature is absolute zero on your graph? How close are you to the accepted value of approximately -273°C (0°K)?
3. State Charles' Law in °C and in °K.

**9-9**

# Experiment: Heat Capacity and Latent Heat

**Purpose:** To compare the heat required to produce phase changes in water with the heat required to increase its temperature.

**Method:** We will heat a known mass of ice slush until it melts and then continue heating it until some vaporizes (boils off). We can find the heat flow supplied by the Bunsen burner by measuring the temperature change of the water in a given time interval. If we divide the total heat absorbed by the water by the period of time, we can find the heat flow, the calories supplied by the burner per minute. (H = Q/t, where H = Heat flow in calories per minute.) Once we know the heat supplied by the burner, we can use this to calculate the heat used in melting ice and in making water vapor.

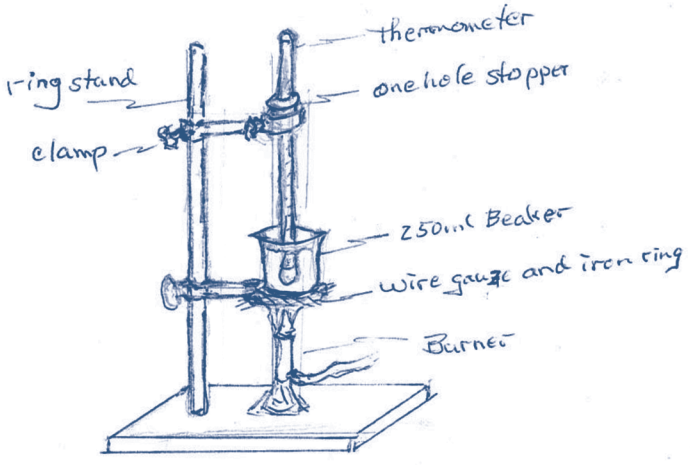
We cannot start out with a beaker full of ice, for the beaker would break as it was heated, air being a poor conductor. Therefore we start with crushed ice or snow in equilibrium with ice water at approximately 0°C.

**Equipment and Materials:** Ice, water, 400 ml beaker, ring stand, ring and wire gauze, thermometer, test tube clamp, rubber stopper, timepiece, Bunsen burner, balance or scale

**Procedure:**

1. Prepare an ice-water mixture and stir until the ice ceases to melt. Check the temperature, which should be close to 0°C.

2. Assemble ring stand, ring and wire gauze. Insert thermometer into stopper (carefully! Be sure that stopper hole is well-lubricated with glycerin, the thermometer inserted gently with twisting, and hand covered with cloth. Stopper should not cover any of the temperature scale below about 110°C.) and mount thermometer and stopper in the test tube clamp.




3. Weigh a 400 ml beaker and submerge it in the ice-water bath, allowing its temperature to adjust to the freezing point.

4. Fill the beaker with crushed ice or snow from the ice-water mixture and weigh again.

5. Add a small measured amount of water from the ice-water mixture. We will assume that this water is at the freezing point.

6. Place the beaker with the ice on the wire gauze. Prepare to measure time. Turn on the burner and adjust to give a hot (efficient) flame. **Do not adjust the burner during the experiment.** (Why?)

7. Begin heating and record time and temperature every minute or two. As you heat, stir and continue stirring until all ice is melted. Continue to heat with the same flame, recording time and temperature until the water reaches the boiling point (a "full" or "rolling" boil). What are the little bubbles that form and come off as you begin to heat the water? How do these bubbles differ from those which form at the boiling point?

8. Continue to heat for 5 to 10 minutes or until a noticeable amount of water has boiled off. Then record time and turn off the burner.

9. When the beaker has cooled sufficiently to handle, weigh beaker and water. From this you can find out how much water has boiled off.

**Graph:** Make a graph showing how the temperature of your water varied with time. Plot time along the horizontal axis and temperature along the vertical axis. Use a whole page of graph paper.

**Calculations:**
1. Mass of ice (grams)

2. Mass of water heated from 0° to 100° C (grams)

3. Water vapor generated

4. Heat flow from burner. This is the quantity of heat (calories) supplied per minute. Since the heat capacity of water is 1 cal/gram-C°, the heat input to raise its temperature by an amount $\Delta T$ is $mc\Delta T$. Pick a section of the graph which is straight, for example, from 20°C to 80°C. $\Delta T$ is then 60 C°. The heat supplied is $Q = mc\Delta T$ where c = 1cal/g C°. The heat flow is this amount divided by the time needed to raise the temperature.

5. Now that we know the heat flow, calories/minute, we can calculate how much heat went into melting the ice and how much into vaporizing the water which boiled off.

6. The Latent Heat of melting or freezing is the heat required per gram to cause the phase change, that is, the heat required per gram to melt the ice or boil off the water. We take the heat flow in calories per minute, multiply by the time required for the phase change and divide by the mass.

$$L = \frac{H\Delta t}{m}$$

**Questions:**

1. Compare the values you calculated for the latent heat of ice and water vapor with the accepted values of 80 cal/g and 540 cal/g respectively. Can you offer explanations for any differences between your values and the accepted values?
2. How does the heat capacity of water compare with the values of the heat required for phase changes?

# 10th Grade Physics

After the energy and the difficulty in controlling it of 9th Grade, 10th Grade students are looking for a balance. This is the year of the water or fluid element, which adjusts to its environment and brings a balance between extremes, a major theme in the Chemistry block. In history, there is a return to classical times, the time of the foundation of human logic, and the clear logic of plane geometry is a focus of math this year. Students should gain a confidence in the power of human thinking for mastering difficult challenges. Mechanics is the ideal realm for both finding balance and applying thought to understand the physical world. Mechanics requires mathematics, in particular, algebra, for which it is dependent on the main element of the 9th Grade math program. From lower school classes most students are familiar with levers and simple machines. Now mechanics moves on to kinematics and dynamics. Many students need support in gaining a clear understanding of motion: constant and accelerated, linear and circular. Only then can the action of forces be made clear. The subject is broad, and choices must be made. It would be sad not to introduce satellites and gyroscopes. Time should be allowed for at least a limited introduction.

Since the block requires some mathematics for even a limited understanding, teachers are faced at the start with resistance or non-interest on the part of many general students who are not particularly interested in math or physics. This can be overcome through entering into the historical struggle of pioneers like Galileo and the extraordinary personality and achievements of Isaac Newton. Also interest is enlivened through surprising demonstrations and students' own experiments.

## References

Galileo. *Two New Sciences*
*Project Physics: Text, Handbook, Resource Book*
Walker, Jearl. *The Flying Circus of Physics*

## Block Outline

Aristotle's life and teachings
Describing motion
Galileo's life and work, Galileo's ramp
Measurement of the acceleration of gravity (2 ways)
Free fall
Inertia, projectiles

Newton's life and work
Newton's First Law
Components of forces
Experiment: The sum of forces
Newton's Second Law
Measuring force: Pound and Newton
Universal gravitation and tides
Newton's Third Law
Conservation of momentum
Conservation of energy
Elastic and inelastic collisions
Rotational motion, satellites
Centripetal acceleration. Experiment
Angular momentum and gyroscopes

## Poem

Gerard Manley Hopkins, "God's Grandeur"

## Quotations

Isaac Newton:

*If I have been able to see farther than others, it is only because I was standing on the shoulders of giants.*

*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 by now and then finding a smoother pebble or a prettier shell than ordinary, while the great ocean of truth lay all undiscovered before me.*

Alexander Pope:

*Nature and Nature's Laws lay hid in night.*
*God said, 'Let Newton be,' and all was light!*

## Problems

*Project Physics* chapters 1–4, 6, 9–11 (selected)

## Introductory Demonstrations

Spin on superball, let bounce back and forth.
Let small superball rest on large one, bounce them together.
Construct domino set with ratios l.5 between all 3 dimensions, starting with 1/8" thickness (plywood), arrange in series from smallest to largest. Push over smallest and impulse travels until largest also tips over.

## Teaching Notes

**Aristotle's life and teaching on science**
Elements, quintessence, free fall, natural and violent motion, use of mathematics vs direct observation. Rediscovery, Church doctrine.

**Measurement of motion**
Speed, velocity, acceleration, average and instantaneous, vectors and scalers

**Galileo**
Life, character, relations with Church and colleagues
Discovery of the law of the pendulum
Galileo's Inertia Principle. Galilean Relativity. Demonstrations, e.g., weight hanging on thread, second thread beneath. Pull second slowly, breaks above; quickly, below; stack of wooden blocks, knock out lowest; coin on cardboard over glass, pull quickly
Freely falling bodies, difficulty measuring.
Galileo's ramp. This is simple to set up, with a long molding from a lumber yard, marked at equal intervals with colored masking tape. Galileo's problem timing, even on ramp, water clock, stop watch. Resort to some algebra makes measurement of acceleration possible and comparison for different lengths, using Galileo's formula, $d = \frac{1}{2} at^2$, confirming his hypothesis of constant acceleration. (Note high friction case: Did Aristotle think of this situation, where speed was slowed down by friction? and speed is proportional to mass at terminal velocity.)
Free fall: measurement of acceleration of gravity.

1) Pendulum formula (relationship discovered by Galileo)
2) Water drops. Attach rubber tube to faucet spout, clamp so that drop interval can be controlled. Place aluminum pie tin to catch drips, adjust drip rate so that drip hits pan as next one starts its fall. Measure time for many drips, estimate time for one drip, measure height of fall. Use Galileo's formula to calculate acceleration of gravity.

Tie heavy washers to strings, one string using equal spacing, another using ratios of 1, 3, 5 ,7. Drop from high window onto aluminum pie pan.

Independence of vertical and horizontal motion: Demonstration with ball rolling down incline on table (or hotwheels car), along table, then off end. Measure distance and time on table during trial run, catching the ball or car, and calculate its speed. Calculate where object should land, place x on paper cup there and try it. (During one class, when the car hit the money, a disengaged young lady screamed, "Oh, my God, I don't believe it!" This is what we are striving for.)

**Projectile motion**

Derive formula showing parabolic form. Derive formula for height as a function of time in the air. Contest: highest throw. Tennis ball machine can demonstrate maximum range as a function of angle.

**Independence of horizontal and vertical directions of motion**

Use apparatus from Sargent-Welch, "Collisions in Two Dimensions."

**Astronomical discoveries, sun-centered system**

Dialog of the Two Great World Systems. Church reaction, Galileo's confinement, writing of *Two New Sciences* made possible by house arrest.

**Newton**

Life. Christmas birth, father dies, mother leaves, absent-minded farmer, practical gadgets,
School: worst student until second-worst kicks in stomach. Newton beat up, then went to top
Trinity College, Cambridge U. closed for plague, back to farm where thought out major ideas: gravity, calculus, optics
Professor at 27
Character: morbidly suspicious, hot temper, but generous
Optics: lens hobby, prism and color, critique by Hooke, withdrawal and end to publishing
Haley asked Newton about planets' motion, suggested inverse square law. Newton had proof.
Haley: If you don't publish soon, someone else will. Three years wrote *Principia*
*Principia*. Major contents: definitions, three laws and vectors, rules of reasoning, Universal gravitation and Kepler's laws
Significance. Unity of laws for earth and heavens
Kinematics to Dynamics (description to causes)
New details of planetary system
Power of mathematics
Newton's First Law. Forces, vectors. Experiment with spring balances, adding forces to resultant zero. Resolving into components, crane, inclined plane
Newton's Second Law. Cart pulled by string over pulley, variable weights on cart, variable masses on string. Weight and mass. Pounds and kilograms

Newton's Third Law. Car at constant speed, tractor pulling log, person standing on earth, standing on dollies, push off wall, each other.

**Conservation Laws**

Conservation of Momentum. Implication of Newton's Second Law. Examples, using carts and bricks, steel balls. Question: (Elastic) collisions of steel balls, carts, many ways to conserve momentum, but always same result. Discovery of

Conservation of Energy. Experiment with carts and also balls on track, e.g., horizontal molding.

Kinetic Energy. Formula easily derived by using free fall formula $d = \frac{1}{2} at^2$.

Elastic and inelastic collisions

**Rotational Motion**

Conservation of angular momentum. Experience: swivel chair and dumbbells

Centripetal acceleration. Demonstration, e.g., bucket of water

Derivation of centripetal force formula: Object attempts to go straight, falls toward center.

Student experiment: centripetal force

Geosynchronous satellite

Gyroscopes. Precession

## Appendices

**10-1** Psalm 8
**10-2** Superball Demonstration
**10-3** Aristotle and the Medieval Church
**10-4** Galileo's Method: Mathematics and Experiment
**10-5** Measuring the Acceleration of Gravity
**10-6** Freely Falling Bodies
**10-7** Galileo Galilei
**10-8** Projectile Motion
**10-9** Isaac Newton
Importance of Newton
Newton and Pounds
**10-10** Resolving Forces into Their Components
**10-11** Newton's First Law
**10-12** Newton's Second Law
**10-13** Newton's Third Law
**10-14** Experiment: Vectors and Forces
**10-15** Experiment: Forces in an Inclined Plane
**10-16** Experiment: Newton's Second Law
**10-17** Experiment: Momentum Changes in an Explosion
**10-18** Experiment: A Collision in Two Dimensions
**10-19** Conservation of Momentum and Energy
**10-20** Centripetal Force
**10-21** Centripetal Acceleration and Force

**10-1**

# Psalm 8

O Lord, our Lord,
How excellent is Thy name in all the earth!
Whose glory is praised above the heavens,
Out of the mouths of babes and infants.

When I consider Thy heavens, the work of Thy fingers,
The moon and the stars, which Thou hast made,
What is man, that Thou art mindful of him?
And the son of man, that Thou dost care for him?

Yet Thou hast made him a little lower than the angels
And dost crown him with glory and honor.
Thou hast given him dominion over the works of Thy hands
Thou hast put all things under his feet.

All sheep and oxen, yes, and all the beasts of the field,
The birds of the air and the fish of the sea.
O Lord, our Lord,
How excellent is Thy name in all the earth!

– King James, RSV and NEB versions,
cast in Hebrew poetry form

# Superball Problem

G. Stroink, Dept Physics, Dalhousie U, Halifax, Nova Scotia, Canada
In *The Physics Teacher* (October 1983)

If one puts a small superball on top of a big super ball and then releases this combination from a height, h, dramatic things happen as soon as this combination strikes the floor.

The small ball will take off and can reach a height nine times as high as h. Why? Just after the combination hits the floor, the big ball moves up with a velocity v, whereas the small ball is still moving down with a velocity v. This velocity v is given by $\frac{1}{2}mv^2 + mgh$.

Now place yourself on the big ball and try to anticipate what will happen.

For an observer on the big ball, the small ball is approaching you with a velocity of 2v.

Assuming the collision is elastic, then the velocity of the small ball after the collision between big and small superballs is again 2v, but now in the opposite direction. The small ball moves away from the big ball with a velocity 2v, but don't forget the big ball moved up with a velocity v relative to the floor. So the small ball moves up with a velocity 3v relative to the floor.

The small ball would have gone up with a velocity v if it had just hit the floor, but now it takes off with a velocity 3v.

However how high it goes depends on $v^2$ ($mgh = \frac{1}{2}mv^2$). A 3 times larger take-off velocity means that it goes 9 times as high.

**Application:** If a satellite with a velocity v manages to have an "elastic collision" with a big planet with velocity V, by swinging around it, then its velocity after the collision, at the same distance away from the planet, will be v + V (the relative velocity of the two objects) plus V, the velocity of the big object. This illustrates the "sling shot" effect which is employed for space probes.

**10-3**

# ARISTOTLE AND THE MEDIEVAL CHURCH: TEACHINGS ON MOTION

1. There are two kinds of motion: Natural motion takes a body to its natural place, according to the balance of the four elements (earth, water, air, fire) in it. Violent motion takes a body away from its natural place, and thus requires a force.



2. Constant motion requires a force. An arrow continues to fly through the air because the air pushes it along.



3. Celestial bodies are composed of a fifth element, quintessence. Unlike earthly bodies, they are perfect and they can move forever without an applied force.
4. The earth is the center of their circular motion.



5. Freely falling bodies fall at a constant speed. The heavier the object, the faster it falls: the speed is directly proportional to the weight.



6. Trust your direct experience of the world, not complicated mathematics and experiments.



# Galileo's Method: Mathematics and Experiment

Aristotle taught that heavier things fall faster than lighter ones. For example, a rock falls faster than a feather, a ball faster than a balloon. This is true when friction is comparatively large, when objects reach terminal velocity (Stokes' formula). But Galileo was sure that in air all normal objects (no feathers, balloons...) would fall at the same rate. But he had no way to measure time accurately. He did two things to make a test possible.

1) Galileo developed a formula relating acceleration to distance, which could be easily measured.

For uniform or constant acceleration, average velocity is distance divided by time and it is also equal to one half of the final velocity:

$$v_a = d/t \text{ and also } v_a = \tfrac{1}{2}v$$

Further, $v = at$. Substituting, Galileo obtained the relationship:

$$\frac{d}{t} = \tfrac{1}{2}at$$

$$\text{or } d = \tfrac{1}{2}at^2$$

This is a formula relating distance to total time for the fall.

2) Unfortunately, objects still fell too fast for him to measure time accurately enough for objects in free fall. Galileo's solution was to slow the motion down with a ramp.

**10-5**

# Measuring the Acceleration of Gravity

**Method I:** A direct measurement of the acceleration. Fit a short length of rubber tubing to a spigot and attach a pinch clamp over the tube. Place a metal pie pan on the floor under the tube so that water leaving it will fall on the pan. Measure the distance of fall, d, from the tube to the pan. Adjust the water and pinch clamp so that when a drop hits the pan, the next drop appears and begins to fall. Prepare to measure time. Measure the time for a series of drops, say 50 or 60, to hit the pan. Dividing the total time by the number of drops yields the time of fall for one drop. The acceleration of gravity can now be found using Galileo's formula:

Solve for a: $a = \frac{2d}{t^2}$

and substitute the measured values of d and t.

**Method II:** Using the formula for the period of a pendulum
Bored in church, Galileo watched the great lamp in the center of the ceiling slowly swing back and forth. He timed the swings with his pulse and developed the relationships between the period and the length, namely, that the period is directly proportional to the square root of the length. The complete formula is

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where T is the period, $l$ is the length of the pendulum, and g is the acceleration of gravity.

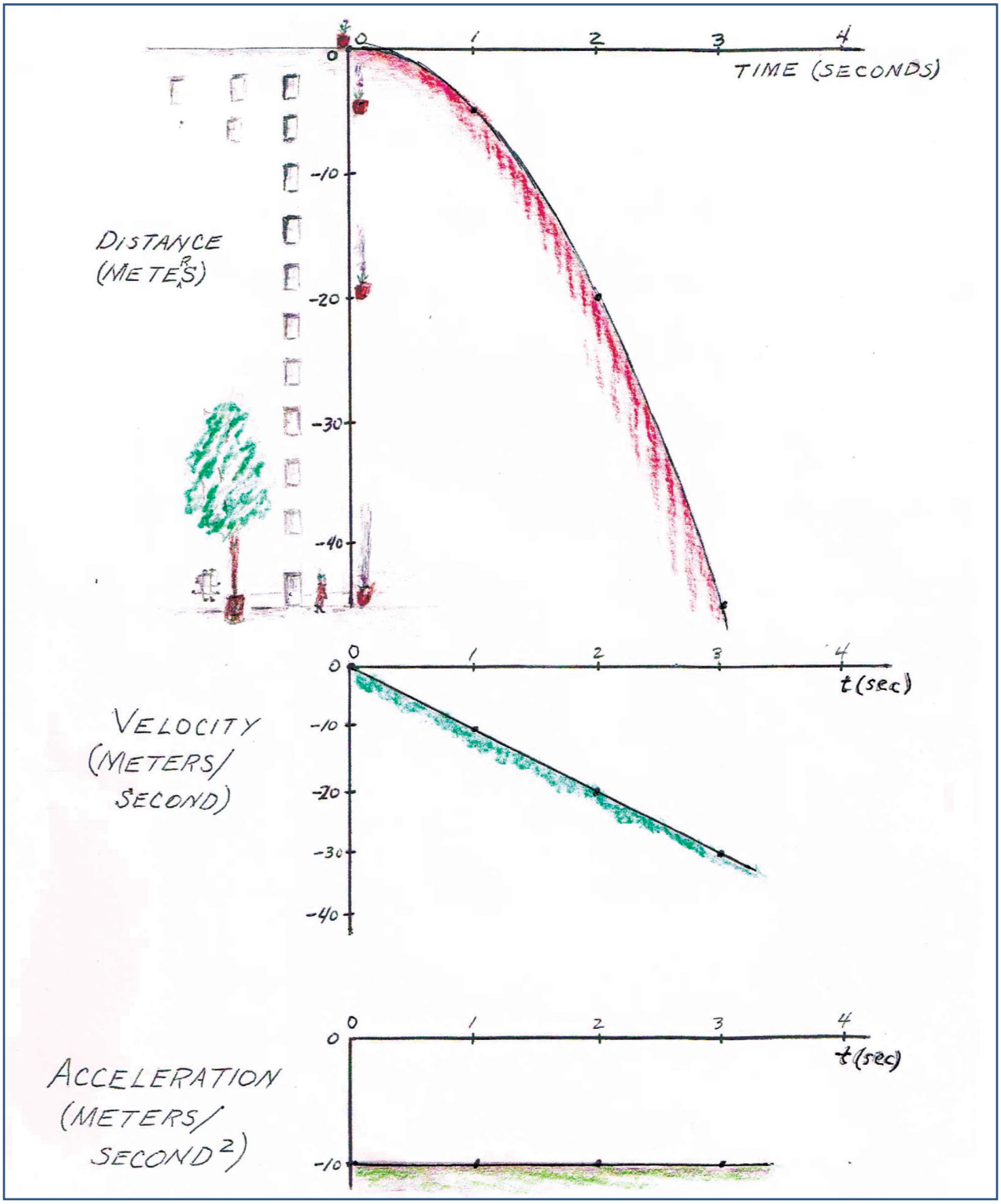
Solving for g:

$$g = \frac{4\pi^2 l}{t^2}$$

A simple pendulum of a length of string and a weight can be allowed to swing, the average time for several swings measured, and the acceleration of gravity calculated.

The values for g generally come out very close to the accepted value of 9.8m/sec$^2$

# Freely Falling Bodies



**10-7**

# Galileo Galilei

Born 1564, Florence, Italy, noble family. Died 1642
Education: classics, medicine at university at age 17
Interests: poetry, music, classics, Greek science, but major interests = math and physics

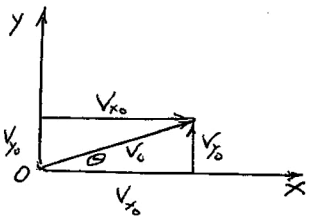
| | |
|---|---|
| 1590 | age 26, Professor of mathematics at University of Pisa<br>Experimented. Invented a thermometer, discovered theory of pendulum<br>Lectured in Italian. Was witty, novel and often wrong, tangled with Aristotle's theories |
| 1592 | Professor of astronomy at Padua, where authorities were more open-minded<br>Taught sun-centered universe, enemies among professors, experimented with motion |
| 1608 | Began to write up results of motion experiments |
| 1609 | Falling bodies, inclined ramp experiments |
| 1604 | Kepler had discovered a new star, showing that the heavens were not eternal. |
| 1609 | Telescope invented in Holland. Galileo made and sold better ones.<br>He discovered the optical principles of lenses.<br>He saw the moon was not smooth, had mountains and valleys, thus not perfect.<br>The Milky Way a mass of stars |
| 1610 | Noted imperfections in the sun (sun spots). He was not first, but claimed he was.<br>Saw Jupiter's moons, thus not everything goes around the sun.<br>Published *Message from the Stars* or *The Starry Messenger*, sun-centered universe.<br>Thus enemies. |
| 1611 | To Rome to show telescope and discoveries. Feted as hero. Top Church astronomers all convinced, made more discoveries. However still viewed world as earth-centered. |
| 1616 | Church declares Copernican theory against Scripture, only allowed as hypothesis |
| 1623 | New pope, open-minded. Galileo began to write. |
| 1632 | *Dialog on the Two Great World Systems*: heliocentric vs earth-centered<br>Three characters discus theories: Sagredo, open-minded, eager to learn; Salviati, the clever one = Galileo; Simplicio, the fool, modeled on the Pope<br>The pope was not amused. Galileo summoned to the Inquisition. Forced to recant |

Sentence: perpetual prison, commuted to house-arrest (in his villa in Florence!)
Thus Galileo forced to return to mechanics = his real contribution and foundation for Newton; the acceleration of gravity and the inertia principle.

1638 *Discourse and Mathematical Demonstrations Concerning Two New Sciences Pertaining to Mechanics and Local Motion*. Short title: *Two New Sciences*
Same three characters. Includes acceleration of gravity and principle of inertia

Although the censorship of Galileo and his recantation to avoid death were great scandals for the Catholic Church (Galileo was rehabilitated in 1984.) and a disservice to science, without Galileo's confinement to his villa, he never would have written up his really significant discoveries in physics. Many others were making the same discoveries in astronomy.

# Projectile Motion




$x = V_{x_0} t$ or $t = \frac{x}{V_{x_0}}$

$y = V_{y_0} t - \frac{1}{2} g t^2$

Substituting $t = \frac{x}{V_{x_0}}$

$$y = \frac{V_{y_0} x}{V_{x_0}} - \frac{g}{2} \cdot \frac{x^2}{V_{x_0}^2}$$

$$= \frac{V_{y_0}}{V_{x_0}} x - \frac{g}{2V_{x_0}^2} x^2$$

This the formala for a parabola.

This parabola intersects the x axis when $y = 0$:

$$0 = \frac{V_{y_0}}{V_{x_0}} x - \frac{g}{2V_{x_0}^2} x^2$$

The two solutions are:

1) $x = 0$ (the origin)

2) $\frac{V_{y_0} x}{V_{x_0}} = \frac{g x^2}{2V_{x_0}^2}$

$x = \frac{2V_{x_0} V_{y_0}}{g}$ This is the Range

To find the maximum Range conditions, rewrite using trigonometry.

$R = \frac{2V_{x_0} V_{y_0}}{g}$

$= \frac{2V^2 \cos\theta \sin\theta}{g}$

$= \frac{V^2}{g} \sin 2\theta$ which has a maximum when $\theta = 45°$. ($\sin 90° = 1.0$)

# Isaac Newton

(1642–1727)

Birth: Christmas Day in the year Galileo died. Premature, weak, needed collar to hold head up
Folk belief: Christmas birth means future success, supernatural healing power
Childhood: Father farmer, died 3 months before Isaac's birth

Age 3: Mother remarries at age 30, husband 63, a "wild, weak, extravagant man"
Isaac left with grandmother in grief, lonely impersonal life

Age 11: Stepfather dies, mother returns with three new siblings

Age 12: Isaac was worst in class at Grantham School, passive, phlegmatic
A classmate, second lowest in class, kicked Isaac in the stomach. Fully enraged, Isaac beat him up in churchyard, rubbing ears and nose into a wall. To add insult to injury, Isaac decided to also beat him at school, and quickly rose to the top.

Age 16 Mother calls Isaac home to manage farm. Disastrous. Many stories, e.g.,
Sheep, cattle ran loose.
Leads horse up hill, forgets to remount.
Horse slips bridle, doesn't notice.
Isaac reads and tinkers, makes kites, windmills (Mouse as miller milled own grain), water clocks, sundials, always asking why things worked.
One year was sufficient to decide to send him back to school.

Age 18 Entered Trinity College, Cambridge
Poor boy, had to serve rich classmates, wait on tables, run errands, Isaac envious

Age 23 College closes for two years due to the Plague. For Isaac, it's back to the farm.
During this time Newton developed his major theories:
>Gravitation, force and motion
>Calculus: relations of distance, velocity and acceleration
Infinitesimals, slopes, infinite series'
>Optics

Age 27 1669. Professor Barrow resigns and turns over his chair to Newton.
Newton's character: morbidly suspicious, hot temper when privacy threatened, yet generous with money, ready to help younger colleagues

**Major work**

Light and optics. Hobby grinding and polishing lenses

Noted colored fringes at edges, distortion

Invented reflecting telescope using a concave mirror instead of a lens

Inducted into Royal Society in 1672, age 30

Prism experiments: Some colors bent more than others

Colored rays do not split further in second prism.

Second prism can reunite colors into white light.

Published results with theory of white light as mixture of colors

Critique: Famous physicist, Robert Hooke and others argued that prism *made* the colors. Newton withdrew, hurt, refused to publish further.

"I was so persecuted with discussions arising from the publication of my theory of light that I blamed my own imprudence for parting with so substantial a blessing as my quiet, to run after a shadow."

Age 42 1684. Edmund Haley, famous astronomer (Haley's Comet) asked Newton about the motion of the planets. Haley thought there was an inverse square law of attraction and that planets moved in ellipses. Others had also made similar suggestions. Newton told Haley that he had a proof. Haley warned Newton that he had better publish promptly, else another would do so and gain the credit.

Three years later, 1687, Newton published the results of his reflections on the farm over 20 years earlier: *Philosophiae Naturalis Principia Mathematica,* which included:

1. Definitions of mass = F/a, momentum, velocity...
2. The three laws of motion and the rules governing vectors
3. Rules of Reasoning
   - >Nature is simple. Parsimony in hypotheses: "I make no hypotheses."
   - >For same results, assign the same causes.
   - >What applies to bodies we can test must apply to *all*: The Unity of Earth and Heaven. (Contra Aristotle: There are no "ethereal bodies" in the heavens.)
   - >Trust logic and reason. Accept generalizations based on experience until new experience forces a change or revision.
4. Universal Gravitation
   - >A body moving under central force satisfies Kepler's law of areas (= areas for = times)
   - >Elliptical motion implies an inverse square law and vice versa. (Kepler's law of elliptical motion with the sun at one focal point)
   - >An inverse square force implies Kepler's law of areas. ($T^2 = kR_a^3$, $R_a$ = average radius)
   - >Calculation for the acceleration of the moon indicates that gravity holds the moon to the earth, the same force as holds us to the earth.
   - >Universal Law of Gravitation

Master of the Mint, 1669 to death. Supervised new coins with ridges around the edge—milling lines—to foil "coin clipping" = shaving gold or silver from the edges

Alchemist. Experimented with mercury and probably was seriously poisoned.

Member of Parliament, 1689–1690, 1701

## Importance of Newton

1. Newtonian Synthesis: The extension of terrestrial mechanics to celestial bodies. The Unity of Earth and Sky. All other explanations gone.
2. From Kinematics (Galileo) to Dynamics, from Description to Explanation
   But: What is Gravity? How does it relate to other forces?
3. New details of planetary orbits, predict new planets, deduct the shape of the earth...
4. Demonstrated the power of mathematics, mathematical models in discovering workings of the universe.

**Limits?**

1. Fails in structure of galaxies: They should spin apart, but they do not. Why? "Dark Matter" has been proposed.
2. At the smallest scale, electricity and magnetism, nuclear and weak forces, quantum mechanics... determine, not gravity.
3. "Classical" physics must give way to special relativity at high speeds, and to general relativity when the gravitational field is extremely high.
4. What *is* Gravity? How does it relate to the other forces in the universe?

### Influence on Social Thinking

John Locke (1632–1704)

Reason is the ultimate judge.
Natural law is working in religion.
Seek rational laws of society
Society is composed of atoms, not an organic whole. Mechanical forces rule.
Government is there to protect the individual.

James Wilson (1742–1798)

The American Constitution produces a Balance of Forces = Good Government

# Newtons and Pounds

One Newton is the force needed to accelerate one kilogram one meter per second per second, or

$1\ N = 1\ kg\text{-}m/sec^2$
$1\ N = 10^5\ dynes$
$1\ dyne = 1\ gram\text{-}cm/sec^2$

2.2 pounds or lb = 1 kg (on earth). This means that a force of 2.2 pounds will accelerate 1 kg at $9.8 m/sec^2$, the acceleration of gravity on earth. Therefore:

On earth 1 kg corresponds to 9.8 Newtons, since

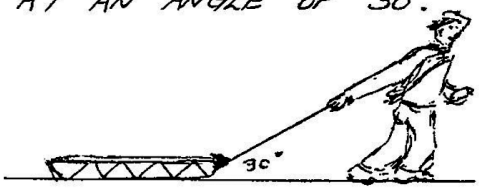
$$\text{Weight (Newtons)} = ma = 1\ kg \cdot 9.8 m/sec^2 = 9.8\ N \text{ or about } 10N$$

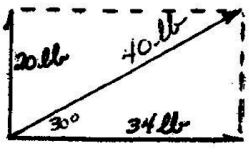
Using the English system of pounds for force, 2.2 lbs is necessary to lift 1 kg.
Thus 2.2 lb = 9.8 Newtons (or about 10)

and 1 lb = 4.4N
or 0.22 lb = 1 Newton

# RESOLVING FORCES INTO THEIR COMPONENTS

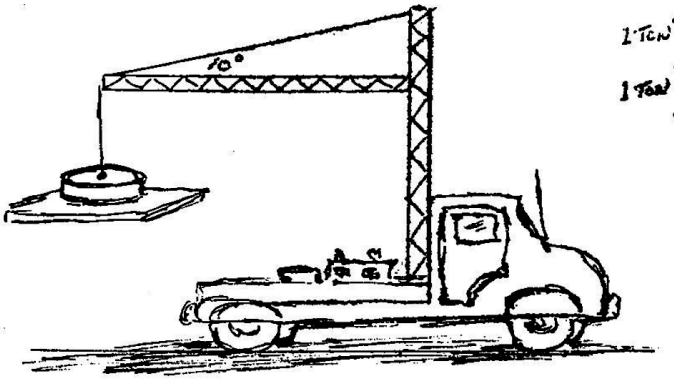
A BOY PULLS A SLED WITH A FORCE OF 40 POUNDS AT AN ANGLE OF 30°.

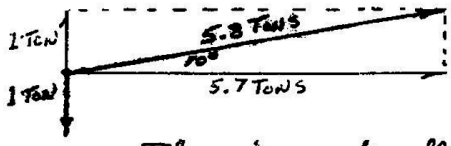



The horizontal component is 34 lb.
The vertical component is 20 lb.

A CRANE IS DESIGNED TO LIFT 1 TON; THE WIRE MAKES AN ANGLE OF 10° WITH THE STRUT.




The wire must pull up with a force of 1 ton. A pull of 5.8 tons in the wire has a vertical component of 1 ton. The horizontal component is 5.7 tons. This is the stress on the strut.

**10-11**

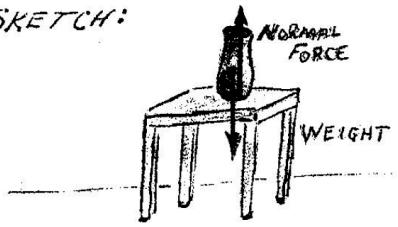
# NEWTON'S FIRST LAW

A body at rest or moving with uniform velocity will continue in its state of rest or uniform motion unless acted upon by an unbalanced force. Or:

For a body at rest or in uniform motion, the sum of all forces acting on the body is zero.

## VASE ON A TABLE

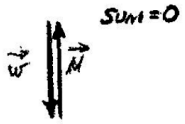
SKETCH:




FORCE DIAGRAM:

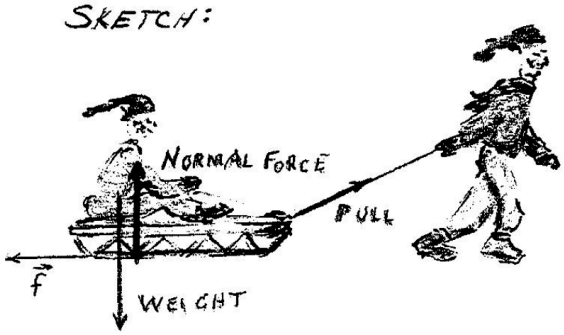



VECTOR SUM:

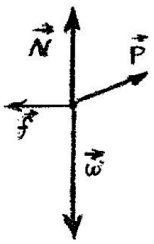



## BOY PULLING A SLED AT CONSTANT SPEED

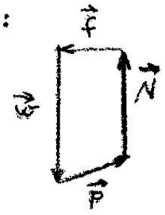
SKETCH:




FORCE DIAGRAM:




VECTOR SUM:

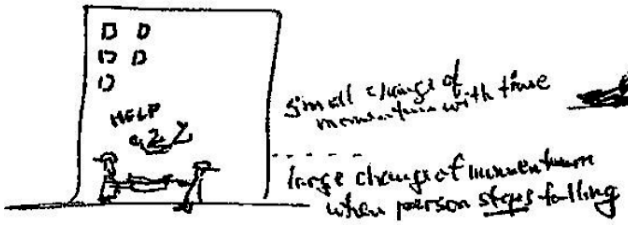


# NEWTON'S SECOND LAW

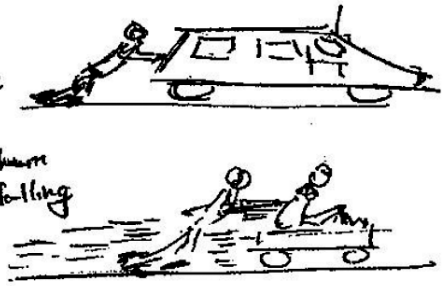
The time rate of change of momentum is directly proportional to the net (unbalanced) force and in the direction of that force.

The acceleration of a body is directly proportional to the net (unbalanced) force acting on a body and inversely proportional to its mass; the direction of acceleration is the same as that of the net force.

MOMENTUM CHANGES SLOWLY WHEN FORCE IS SMALL:



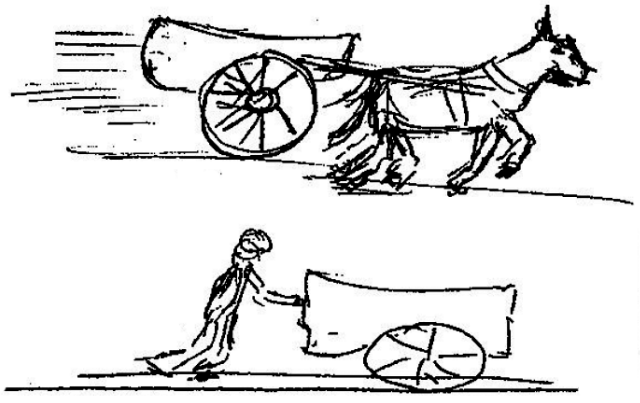

ACCELERATION IS LARGE WHEN MASS IS SMALL



MOMENTUM CHANGES FAST AND FORCE IS LARGE:



ACCELERATION IS LARGER WHEN FORCE IS LARGE.



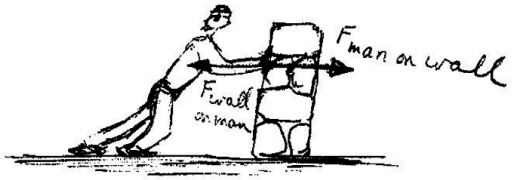
**10-13**

# Newton's Third Law

For every action there is an equal and opposite reaction.

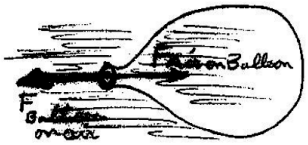
If one body exerts a force on another, the second body exerts a force on the first, which is equal in magnitude and opposite in direction.





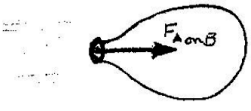


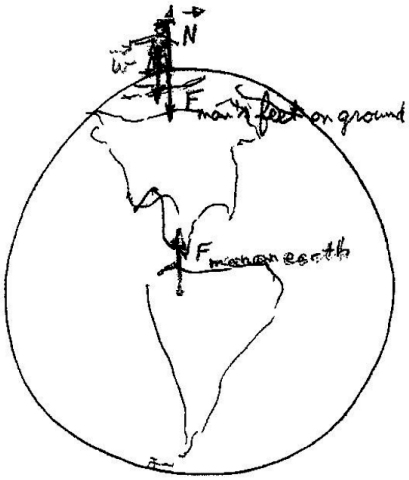



FORCE ON AIR:

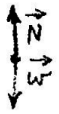



FORCE ON BALLOON:

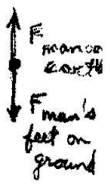



FORCES ON MAN:




FORCES ON EARTH:



# Experiment: Vectors and Forces

**Purpose:** To understand static equilibrium and vector addition

**Equipment:** Spring balances, protractor, ruler, pulleys and supports, ring stands, weights, string.

**Procedure:**
1. Work in pairs.

2. Connect two balances as in the figure below and pull apart. Record the directions and forces. Repeat for different forces. Jiggle the balances and note that the needle sticks in this horizontal position. How accurate are the balances when used this way?

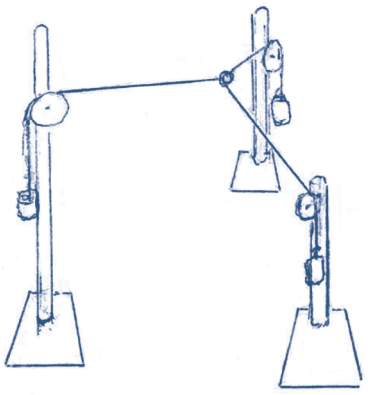
3. Draw a force diagram. Use a convenient scale such as 1cm = 100 grams. (Note: A gram is not a unit of force.)

4. Add the forces as vectors. If the resultant is not zero, explain.

5. Repeat using three scales. Record the directions and magnitudes on paper.

6. Add the forces as vectors.

7. Set up a pulley and weight system as in the illustration. Spring balances are not very accurate. A more accurate method of measuring forces is with weights and pulleys. The pulleys change the direction of the downward force of the weights into horizontal forces. Note that the length of the string has nothing to do with the magnitude of the forces. The string gives the direction; the weight gives the force (pull).



Draw the forces as vectors and add them.

8. Show that the sum of two of the forces in step 7 equals the negative of the third. Why does this make sense?

**10-15**

# Experiment: Forces in an Inclined Plane

**Procedure:**
1. Weigh a cart and, if your scale does not read in Newtons, find its weight in Newtons.

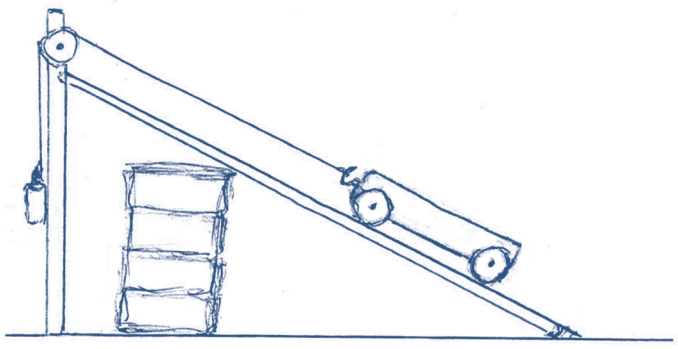
2. Set up the apparatus shown in the figure below. Hang a 100 g or 1N weight on the string over the pulley. Adjust the angle of the ramp until the forces acting on the cart balance. (Note that because of friction, there is a small range of angles.)

3. Place your notebook behind the ramp and draw a line showing the inclined plane. Sketch in the cart and show the forces acting on the cart by arrows. The force of the weight acts along the string. The weight of the cart acts vertically downward.

4. Resolve the weight into two components, one perpendicular to the inclined plane and one acting along it. Draw the components in light arrows. The plane must push back on the cart with a "normal force" perpendicular to the ramp. Its magnitude equals the component of the weight perpendicular to the plane. Attach a spring balance to the cart and measure the normal force by pulling outward on the cart, perpendicular to the plane. Add this force to your diagram.

5. Add the forces acting on the cart in a separate force diagram, head to tail. Is the sum zero?

6. As time allows, try other weights on the end of the string and see how the angle varies.



# Experiment: Newton's Second Law

## Part I. Experiencing the Second Law

1. Obtain a cart, dolly or other low-friction vehicle, and a meter stick. Also assemble several broken rubber bands, tied together end to end. You will use the rubber band chain to pull the cart. The force you exert will then be approximately proportional to the length of the rubber band chain, which can be determined from the meter stick. Rest the meter stick on the cart or attach it if convenient.

2. Pull with the least force necessary to move the cart at a constant speed, to find the frictional force.

3. Now pull with slightly more force than the frictional force and note the motion of the cart. Try to keep your hand the same distance from the cart, so that you are pulling with the same force. Record your observations.

4. Try other forces, that is, pull harder on the same rubber band chain. What is the relationship between force and acceleration?

5. Try pulling the cart at a steeper angle with the same force (same length of rubber bands). Keep changing the angle until the rubber band is vertical. Observe and explain.

6. Try other forces in the initial configuration, that is, pulling approximately horizontally. What is the relationship between force and acceleration?

7. Try other masses on the cart. How does the acceleration depend on the mass?

## Part II. Measured Acceleration of a Cart

1. The apparatus is shown in the figure on the next page. You should make a sketch in your notebook. Show the forces acting on the cart. Label each part of the apparatus.

2. Measure the mass of the cart and also of any bricks that you may wish to add to the cart.

3. Find the frictional force acting to retard the cart's motion. To do this, gradually increase the mass on the end of the string until the cart will just begin to move at approximately

constant speed. Record the force, which is an estimate of the frictional force. Since there is no acceleration, all forces on the cart are balanced.

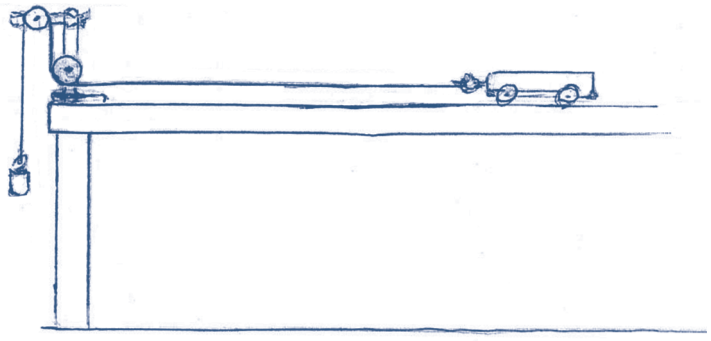
4. Place more weight on the string, holding the cart in place. Place a meter stick alongside the cart and prepare to measure time with a stopwatch.

5. Release the cart and record the time for it to go a known distance, say, 1 meter. Repeat the experiment and average your times.

6. Calculate the acceleration from the relation $d = \frac{1}{2}at^2$. Also calculate the net force by subtracting the frictional force.

7. Does F = ma? Do you believe that errors in measurement account for any differences? Explain.

If time permits, try other forces and/or masses on the cart and repeat steps 4–7.



# Experiment: Momentum Changes in an Explosion

**Equipment:** Two wooden blocks clamped one to two meters apart on a smooth table; meter stick; two carts, one outfitted with a spring, which can be compressed and released suddenly

**Procedure:** Two carts are pushed apart from rest as the result of a sudden force—an "explosion"—acting between them. How do the momenta of the carts change? To apply the sudden force, we can use a spring which we compress and suddenly release.

Place a second cart next to the first one so that the spring will push against the second cart when released. What happens now as you release the spring? Do this with various loads on the carts. Qualitatively, what would you say about the velocities of the two carts as you load them with different masses? How do you think the momenta of the two carts compare after the explosion?

To make this experiment quantitative, we need to measure the velocities and the masses of the two carts. But we do not have to know their velocities in meters per second; any unit will do. It is possible to find their velocities in terms of the distances both carts move during the same time interval. Suppose we release the carts just halfway between two wooden bumpers and they go at the same speed. We shall hear just one sound as they hit the bumpers. If one goes faster, it will hit earlier, and we will hear two distinct sounds instead of one. We can, however, move the starting point so the faster cart has to travel a longer distance. After several trials we can find a position from which the carts will take the same time to travel to the bumpers. Call the distances traveled by the carts $x_1$ and $x_2$. The carts travel these distances in the same time interval, t, and, if they move at constant velocity, a reasonable assumption, as they travel such short distances, we can write for their velocities:

$$v_1 = \frac{x_1}{t} \qquad v_2 = \frac{x_2}{t} \qquad \frac{v_1}{v_2} = \frac{x_1}{x_2}$$

In other words, the velocities are directly proportional to the distances.

Using this method of moving the starting point to give equal times, determine the ratio of the momenta of your carts after the explosion. What is the change in momentum of each cart as a result of the explosion? Try this with different combinations of masses on the carts. How does the total momentum of the system after the explosion compare with the total momentum beforehand?

**10-18**

# Experiment: A Collision in Two Dimensions

**Equipment:** Collision in two dimensions apparatus from Sargent-Welch, C-clamp, meter stick, carbon paper

**Background:** What if the colliding objects, balls in this case, go off in different directions after colliding? Will momentum still be conserved?

Because of the independence of vertical and horizontal components of motion, balls falling from the same height will strike the floor at equal times. The horizontal component of their velocities will simply be proportional to the horizontal distance they traveled. By comparing these distances we can find the horizontal velocity component.

**Procedure:**
1. Clamp the apparatus to the edge of a table using the C-clamp. Adjust the support for the stationary ball so that a ball rolling down the ramp will produce a glancing blow.

Prepare four sheets of carbon paper taped together to form a large single sheet and four sheets of tracing paper to cover them, also taped together, but not overlapping. Set the tracing paper on top of the carbon paper and place them on the floor in front of the ramp, so that both balls will land on the paper. Make a few trial runs in order to make sure that the balls land near enough to the table so that their landing locations will fall on the paper. Use the plumb bob to adjust the paper so that the center of the shorter side lies directly under the set screw holding the stationary ball. Mark the spot where the plumb bob hits the paper.

2. Mark a spot about 25 cm from the base of the ramp and release a steel ball from this spot several times, circling the distribution of points on the paper. How repeatable (or uncertain) are the initial velocities?

3. With a steel ball balanced on the set screw, try several collisions, releasing the incident ball from the same point as before. To change the point of collision, turn the arm supporting the target ball through a small angle. Place a numbered circle around each impact on the paper.

4. Draw on the paper the vectors that represent the velocities of the balls after collision.

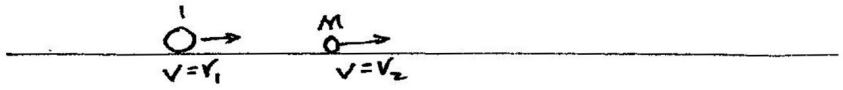
5. Since the masses of the balls are equal, the velocity vectors represent the momenta of the balls. Add the two momentum vectors graphically on your paper, placing the tail of the momentum vector of the target ball at the head of the momentum vector of the incident ball.

6. How does the vector sum of the two final momenta compare with the initial momentum of the incident ball? Is momentum conserved? How does the arithmetic sum of the two magnitudes of the momenta after the collision compare with the magnitude of the initial momentum of the incident ball?

# Conservation of Momentum and Energy

Two balls or carts collide elastically. There is no loss of energy to heat

Before: 


After: 


| | Before | | After | |
|---|---|---|---|---|
| Total momentum | 1 | = | $V_1 + mV_2$ | (1) |
| Energy · 2 | 1 | = | $V_1^2 + mV_2^2$ | (2) |

---

We have two equations in two unknowns, namely $V_1$ and $V_2$:

Solve equation 1 for $V_1$:

$$V_1 = 1 - mV_2$$

Substitute into equation 2:

$$1 = (1 - mV_2)^2 + mV_2^2$$

$$1 = 1 - 2mV_2^2 + m^2V_2^2 + mV_2^2$$

$$0 = -2V_2 + mV_2^2 + V_2^2$$

$$0 = V_2(V_2 + mV_2 - 2) = 0$$

There are two possibilities:

Either $V_2 = 0$ (no collision!)

or $V_2 + mV_2 - 2 = 0$ (collision)

Solve for $V_2$:

$$V_2 + mV_2 = 2$$

$$V_2(1+m) = 2$$

$$\boxed{V_2 = \frac{2}{m+1}}$$

Solving for $V_1$:

$$V_1 = 1 - mV_2$$

$$= 1 - \frac{2m}{m+1}$$

$$\boxed{V_1 = \frac{1-m}{1+m}}$$

Sample values

| m | $V_1$ | $V_2$ | |
|---|---|---|---|
| 1 | 0 | 1 | (masses equal) |
| 2 | $-\frac{1}{3}$ | $\frac{2}{3}$ | |
| $\frac{1}{2}$ | $\frac{1}{3}$ | $\frac{4}{3}$ | |
| → 0 | → 1 | → 2 | ! |
| 9 | $-\frac{4}{5}$ | $\frac{1}{5}$ | |
| → ∞ | −1 | 0 | |

# Centripetal Force

**Purpose:** To experience centripetal force and also to measure its dependence on speed and radius.

**Equipment:** Glass tube about 1cm OD, 15cm long, fire polished ends, wrapped with two layers of cellulose tape, about 1.5m braided nylon casting line, alligator clip, steel washers, paper clip, #4 2-hole rubber stopper

**Procedure:**
1. Assemble apparatus as shown in the diagram on the next page.

2. Investigate qualitatively how centripetal force is related to speed, mass and radius of the circle through which the stopper is moving. With one washer on the string to keep it from puling up through the glass tube, whirl the stopper over your head. Change the speed and observe if you need to change the force puling down on the string. Then try keeping the frequency or period about the same and change the radius.

3. While the stopper is whirling at a convenient speed and radius, suddenly pull in (downward) on the string. What happens to the frequency of rotation? the speed? Repeat, this time letting string out.

4. Join a partner. With one standing on a table or chair and viewing the stopper from above, the partner should whirl the stopper and then let go. Which direction does it go as it flies off? Explain.

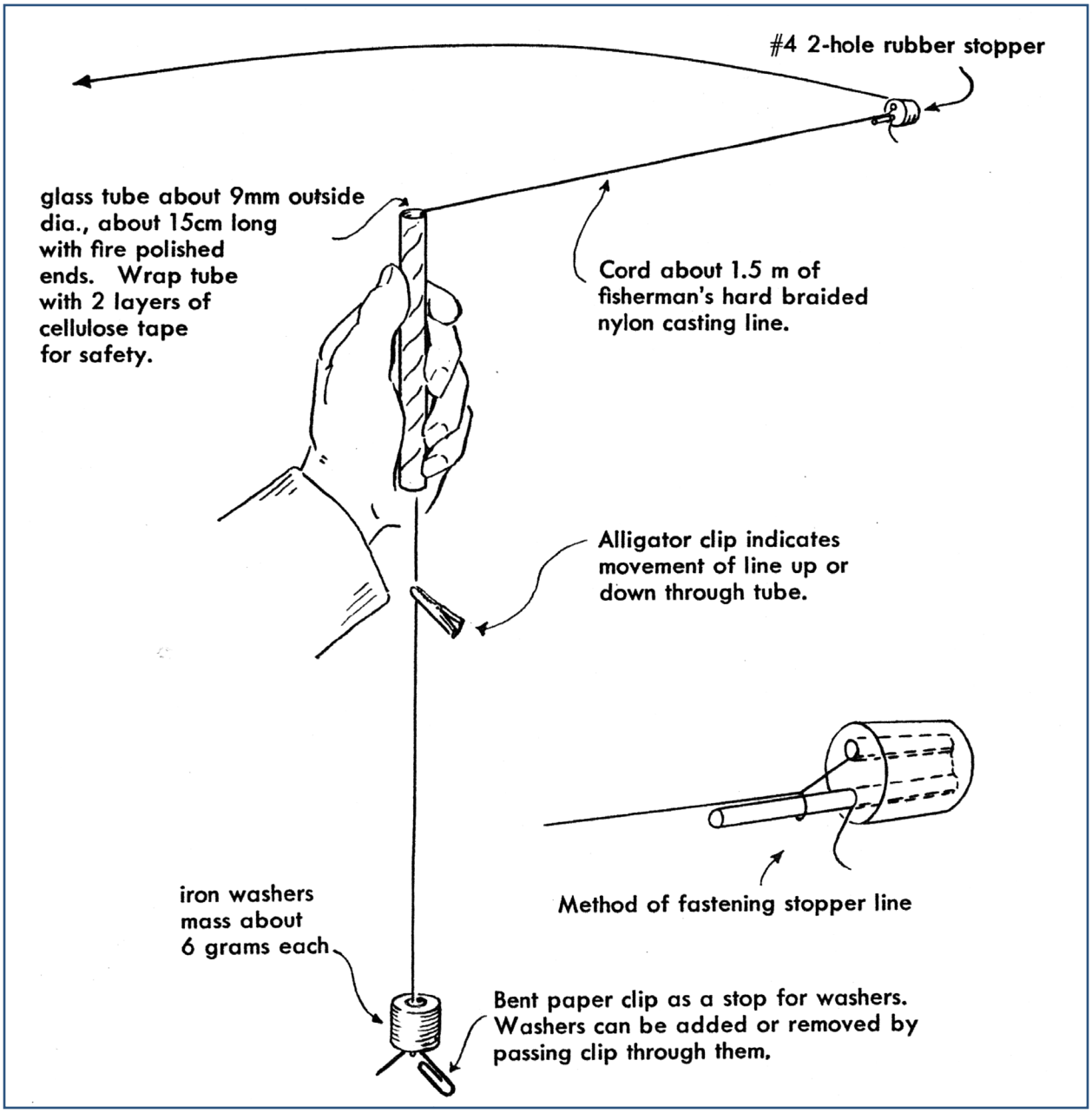
**Quantitative Investigations:**
5. Pull enough string through the tube so that the stopper will whirl in a circle of about 100cm=1m radius. Attach an alligator clip to the string just below the tube to serve as a marker so that you can keep the radius constant while whirling the stopper. Hang 4 or 6 washers on the end of the string.

6. To find the rate of revolution of the stopper, have one partner whirl and count the number of revolutions while the other partner measures the time. From the time and number of revolutions, you can calculate the period and the frequency. Repeat the experiment with larger numbers of washers, for example, use 3, 6, 12 and 24 washers. Make at least 4 different runs using different centripetal forces (= the number of washers). The simplest way to measure frequency is to count revolutions for one minute. This is then the frequency in revolutions per minute, RPM.

7. Plot the number of washers, that is, the force, as a function of the frequency. Then plot the number of washers as a function of the frequency squared. How does the centripetal force depend on the frequency (that is, when other things are constant, e.g., revolving mass and radius)?

8. To investigate the dependence of force on revolving mass, try two rubber stoppers instead of one. How many washers do you need now for the same frequency? To investigate the dependency on the radius, try reducing the radius by half and see how many washers you need to maintain the frequency.

Source: Physical Science Study Committee, *Physics Laboratory Guide*



# Centripetal Acceleration and Force

The formula for centripetal acceleration is simply derived from consideration of a projectile sent initially parallel to the earth's surface. In time t it will fall a distance $h = \frac{1}{2}gt^2$. From the Pythagorean theorem,

$$(R + h)^2 = R^2 + d^2$$

or

$$R^2 + 2Rh + h^2 = R^2 + d^2.$$

Canceling $R^2$ and noting that R>h, this simplifies to

$$2Rh = d^2.$$

Since $h = \frac{1}{2}at^2$ and $d = vt$, we have by substituting,

$$2R(\tfrac{1}{2}at^2) = (vt)^2$$

and thus, $Ra = v^2$ and the centripetal acceleration is

$$a = v^2/R.$$

Since $F = ma$, the centripetal force is

$$F = mv^2/R.$$

In terms of frequency, since $v = d/t$ and, for a circle, $d = 2\pi R$, therefore

$$v = 2\,\pi R/T \text{ or } v = 2\,\pi Rf \text{ since } f = 1/T.$$

The force is thus

$$F = m(2\,\pi Rf)^2\,/R \text{ or } F = 4m\pi^2R^2f^2/R$$

Thus

$$F = 4m\pi^2f^2R \text{ or } F = 4m\pi^2R/T^2$$

# 11th Grade Physics

There are several reasons for teaching electricity and magnetism in the 11th Grade. At this age students awaken from the dreamy water-element of 10th Grade into the air element, into the social realm. The practicum may be a service week. *Parzival* and *Hamlet* are the literature choices. The history through art block is Music, the subject which reveals the hidden inner nature of substance through sound. Microscopes are introduced in biology. Projective Geometry addresses the mystery of the relation between center and periphery. Electricity and magnetism are everywhere: in nature, in technology, in us. We must be ready to see into ourselves as well as into nature. The forces themselves are more hidden, generally not readily perceivable. We must imaginatively project our consciousness into the depths of matter.

Students at this stage want to be clear about who they are and where they are going. Where do they fit into the nature of things? They want to get to the heart of the subject. They are ready to delve into the deepest questions of matter. In chemistry they will explore the nature of material structure: atoms, subatomic particles. These explorations require an understanding of electricity and magnetism. Most of the physics we have explored up to this point could be directly experienced: heat, mechanics and their practical applications. Electricity and magnetism are fundamental to our technology, but they are for the most part hidden, invisible. It is more difficult to penetrate their laws. Eleventh Graders are ready for this challenge. The block needs to review the fundamental character of each and their relationship. Their intimate connection to our world today, not to mention our own bodily chemistry, should be clear by the end of the block.

As Waldorf teachers, however, we are aware of the connection between these forces of electricity and magnetism and the world of "sub-nature," the world of Lucifer and Ahriman, as related by Rudolf Steiner. Steiner warns against imbuing the material world with the evil attributes of these forces. Though we are not called to teach anthroposophy, we can indicate the imprint of these forces and their hidden nature through their characteristics in the material world. The relationship to light is a sensitive matter. Steiner cautions us not to confuse Light with Christ as the Light of the World, with Lucifer and electrical waves. Nevertheless, it is a physical fact that Light expresses itself in the physical world as an electro-magnetic radiation, that is, flowing through space as these two interact in perfect balance. And this balance is Light. This seems to me a good picture with which to end the block.

## References

Hirshfeld, Alan. *The Electric Life of Michael Faraday*, Walker & Company, New York, 2006
*Harvard Project Physics*
Physical Science Study Committee, *Physics*
Francis, Keith. *Rudolf Steiner and the Atom*

## Poems

John Masefield, "Sea Fever"
Gerard Manley Hopkins, "God's Grandeur"
Psalm 8

## Block Outline

1. Magnetostatics
    - magnetic materials
    - compass, history of navigation
    - field of lodestone, magnet, earth
    - laws of magnets
2. Electrostatics
    - occurrence, kinds, materials
    - electroscope, electrostatic induction
    - flow
    - van de Graff generator, Wimshurst, Tesla
    - shielding, electric field, Coulomb's law
    - comparison of earth's electric and magnetic fields: character and direction
    - The power, the right angle relationship, are seen in the world at large.
3. Electric current
    - Ohm's law, power, watts
    - series and parallel circuits
4. Electromagnetism
    - magnetic field of wire and coil. motor
    - Faraday. transformers
5. Electromagnetic induction: electric field of moving magnets
    - force on charge moving in magnetic field
    - generators
    - Maxwell, electromagnetic radiation
6. Circuits. elements, resistor, capacitor, inductor, tank circuit, radio receiver,
    - vacuum tube, transistor, semiconductors, electronics, computers

## Industrial Tours

Pumped storage facility, nuclear power plant or other electricity-generating operation

## Problems

Project Physics cc 14, 15, 16

## Introductory Demonstration

Drop strong magnet down a copper tube. If a large diameter copper pipe is available, say 2", then students can watch the magnet rotate as it falls.
A Tesla coil could also serve if available.

## Teaching Notes

**Magnetism**
It is easier to begin with magnetism. Magnets have a steady field, the poles can be verified by hanging by a thread, and laws readily shown. The "north" pole of the magnet must be clearly distinguished from the so-called "north pole" of the earth, really a south pole, and separated from the earth's geographic north pole. Many students cannot read maps. It would be well if the gym teacher could run an orienteering exercise with the students at this time. Otherwise it will have to be part of the block.

The history of magnetic materials, kinds of magnetism, use in navigation, earth's magnetic field
Like and unlike poles, laws, permanent magnets, induced magnetism

Students can draw magnetic fields of single magnet using a large, strong magnet and a small mini-magnet to trace field lines. Then try two unlike poles and two like poles.

**Electrostatics**
Demonstrations: balloons (latex), scraps of paper, amber
History: Thales, Gilbert, Benjamin Franklin, Priestley, Coulomb
Earth's electric field, thunderstorms, lightning
Experiment with Scotch tape
Electroscope
Shielding
Leyden Jar, Wimshurst machine, electrophorus, capacitors
Van de Graaff generator (observe cautions), Faraday pail
Coulomb's Law

**Electricity and Magnetism Compared**
Laws of statics the same, yet the perpendicular quality already clear in the earth's fields: perpendicular to the surface for electricity, generally parallel (and thus perpendicular to the electric) for magnetism. There is a stability in the magnetic field, a protection for human life from solar radiation (aurora at the poles) and guide for the traveler. Electricity is dynamic and electrocutes the unwary traveler!

Note the contrast: On the one hand we have the earth's electric field, tightly bound to the earth's surface, everywhere vertical, bringing us wild and exciting electrical storms with potential destruction and death.

And on the other hand we have Magnetism, its field mostly horizontal (except of course at the poles), with its technical prowess, protecting the earth from electromagnetic radiation, supporting navigation, origin deep in the earth. A sketch of the earth's field appears as a giant, dark angel, brooding over the earth, great wings stretched to the sides.

**Current Electricity**
Cells and batteries, volts, electric potential
Circuits, series and parallel cells and resistors
DC and AC, Edison and Tesla
Power, household wiring

**Electromagnetism**
Oersted, Ampere, magnetic field of current-carrying wire. Coil, electromagnet
Faraday. Life and work. Motor. Magnetic induction, transformer
Motor and generator, AC and DC
Maxwell, equations, electromagnetic radiation: a perfect balance between electricity and magnetism, each producing the other and right angles, forming a cross.

**Electronics**
LC circuits, oscillators, antennas, receivers, radios
Vacuum tubes, TV
Transistors

## Appendices

**11-1** The Whole Armor of God
**11-2** Psalm 8
**11-3** Experiment: Magnetism
**11-4** Experiment: Electric Forces (Project Physics)
**11-5** Electricity and Magnetism Compared

**11-1**

# Whole Armor of God

Finally, be strong in the Lord
And in the strength of his might.

Put on the whole armor of God,
That you may stand against the wiles of the devil.

For we wrestle not against flesh and blood,
But against principalities, against powers,
Against the rulers of the present darkness,
Against the spiritual forces of wickedness in the heavenly places.

Take, therefore, the whole armor of God,
That you may withstand in the evil day,
And having done all, to stand firm.

Stand, therefore, having girded our loins with truth,
And having put on the breastplate of righteousness,

And your feet shod with the gospel of peace,
And above all, taking the shield of faith
With which you quench all the fiery darts of the wicked one.

And take the helmet of salvation
And the sword of the Spirit,
Which is the Word of God.

Paul's letter to the Ephesians 6:10–17 (written from Rome)
– Translation from King James, RSV, Moffatt and Phillips

# Psalm 8

O Lord, our Lord,
How excellent is Thy name in all the earth!
Whose glory is praised above the heavens,
Out of the mouths of babes and infants.

When I consider Thy heavens, the work of Thy fingers,
The moon and the stars, which Thou hast made,
What is man, that Thou art mindful of him?
And the son of man, that Thou dost care for him?

Yet Thou hast made him a little lower than the angels
And dost crown him with glory and honor.
Thou hast give him dominion over the works of Thy hands
Thou hast put all things under his feet.

All sheep and oxen, yes, and all the beasts of the field,
The birds of the air and the fish of the sea.
O Lord, our Lord,
How excellent is Thy name in all the earth!

– King James, RSV and NEB versions
set into Hebrew poetry form

**11-3**

# Experiment: Magnetism

**Purpose:** to explore the laws of magnetism

**Equipment and Materials:**

Magnets: iron, steel, neodymium…
Various objects
Ring stand, right angle clamp
Wooden rod
Compass
Cradle and string
Copper tubes

**Procedure:** Investigate

1. What materials are magnetic, that is, are influenced by a magnet? Which not?
2. How many different poles are there?
3. How do like and unlike poles of the magnets behave when brought near each other?
4. What happens when a magnet is broken? (Rather than breaking a magnet, take a series apart!)
5. Can you obtain a magnetic monopole? What happens when you try?
6. How does a magnet point when suspended freely? Which end points north? Why does this seem to be at odds with the laws of magnetic attraction and repulsion? What is the relationship between the earth's geographic north pole and the earth's magnetic north pole?
7. Can magnetism be induced from a magnet into other objects? What kind of object? Is the induced magnetism temporary or permanent?
8. Can you make a magnet?
9. Does the force between poles depend on the separation? How?
10. What happens when a magnet is dropped down a copper tube?

**Questions:** What questions remain to be investigated or answered?

# Experiment: Electric Forces (Project Physics)

**Equipment:** ring stand, right angle clamp, wooden rod

**Materials:** transparent ("magic" tape)

**Procedure:**
1. Stick an 8-inch length of transparent tape to the tabletop. Press the tape down well with your finger, leaving an inch or so loose as a handle. Carefully remove the tape from the table by pulling on this loose end, preventing the tape from curling up around your fingers.

2. To test whether or not the tape became electrically charged when you stripped it from the table, see if the non-sticky side will pick up a scrap of paper. Will the paper jump up to the tape? Is the tape charged? Is the paper charged?

3. Now investigate the effect of charged objects on other charged objects. Charge a piece of tape as you did before. Suspend the tape from a horizontal wood rod.

4. Charge another strip of tape in the same way and bring it close to the first one. (Have the two non-sticky sides facing.)

**Question A:** Do the two tapes affect each other? What kind of force is it—attractive or repulsive?

5. Hang the second tape a few inches away from the first one. Electrify a third piece of tape. Observe the reaction between this tape and your first two tapes. Record observations. Leave only the first tape hanging. Discard the other two tapes.

6. Stick down a new piece of tape on the table and stick another tape over it. Press them down well. Peel the stuck-together tapes from the table. To remove any net charge the pair will have picked up, run the non-sticky side of the pair over a water pipe or your lips. Check the pair with the original test strip to be sure the pair is electrically neutral. Now carefully pull the two tapes apart. As you separate the tapes, do you notice any interaction between them (other than that due to the adhesive)?

7. Hold one of these tapes in each hand and bring them slowly towards each other (non-sticky sides facing. What do yo observe?

8. Bring first one, then the other of the tapes near the original test strip. What happens?

9. Mount the two new tapes on the wooden rod to serve as test strips. Charge various objects (rods of glass, rubber, amber; comb, ruler, balloon) by rubbing on cloth or fur, and then bring them close to the two test tapes one at a time. Record your observations.

**Question B:** Classify the objects you have tested according to their behavior with the test tapes. Are your results consistent with the idea that there are only two kinds of electrified object (charges)? Summarize our results by stating the "Law of Charges."

**Question C:** How do charged bodies behave when near uncharged bodies? Explain why the force arises, and why it is the way it is. (Note: Negative charges are generally more mobile than positive.)

# Electricity and Magnetism Compared

**Similarities:**
There are two electric charges and two magnetic poles.
Like charges or poles repel, unlike attract.
The force, or field, decreases with distance (inverse square law).

**Differences:**

| Electricity | Magnetism |
|---|---|
| All substances exhibit electric properties. | Only a few materials respond (strongly) to magnets. |
| Electric charges flow. | Magnetic poles do not flow. |
| Separation of electric charges is possible. | There are no magnetic monopoles. |

The earth's magnetic field comes from the depths of the earth. The earth has two magnetic poles, north and south. The field's form is similar to that of a bar magnet. The field extends to great distances.

The earth's magnetic field protects us from the sun's radiation by deflecting cosmic radiation toward the poles, producing grand displays of light and color, the Aurora Borealis at the North Pole and the Aurora Australis at the South Pole. The magnetic field makes possible navigation with a magnetic compass. Except for near the magnetic poles, the earth's magnetic field is close to parallel to the earth's surface.

The earth's electric field is confined to a few miles above the earth's surface and is equally distributed across the globe. Its direction is perpendicular to the earth's surface at all points and thus generally perpendicular to the earth's magnetic field. The earth's electric field is highly dangerous. When one is caught out in a thunderstorm, you must avoid open fields, trees, hills. Lightning can also damage houses and explode planes.

# 12th Grade Physics

The capstone of twelve years of Waldorf education should address the major issues of the modern world. Thus we have economics, Faust, modern history, molecular biology, man and animal. Where does physics fit into this scheme? Why light?

First of all, it is our vision which primarily connects us with the outer world, whether directly in nature or through reading instruments. These observations are the basis for our knowledge and decisions. Optical devices, including new electronic ones, bring us the knowledge of the microscopic and macroscopic worlds. Light and color reveal the character of the world around us. And the art of seeing itself is far more complex than generally realized. Its study raises questions of consciousness and the spiritual nature of a human being. For all these reasons, optics is entirely appropriate for the 12th Grade.

Certainly we need to review the actual mystery of vision and the color theories of Newton and Goethe. However we dare not take too much time, else we short-change the analysis of modern optical instruments and receive Rudolf Steiner's admonishment of the first Waldorf physics teacher, who apparently never got around to microscopes and telescopes! And we must save some time for lasers, electron microscopes, modern telescopes.

Finally, it is perhaps appropriate to culminate with light, the representative in the physical world of the Light of the World, who brings into balance the adversary forces, as seen in Rudolf Steiner's sculpture and represented by the perfect balance in light of their representatives, electricity and magnetism.

## References


Greenler, Robert. *Rainbows, Halos, and Glories*
McBride, J. Michael. Yale Open Courses: Freshman Chemistry I
Minnaert, M. *The Nature of Light and Color in the Open Air*
Physical Science Study Committee, Physics
Rohan, Johannes W. *Functional Morphology*
Steiner, Rudolf. *Light Course*
Zajonc, Arthur. *Catching the Light: The Entwined History of Light and Mind*


## Poems

Wordsworth, "The Rainbow"
William Ernest Henley, "Invictus"

## Seminar Topics

The human eye and vision. Optical illusions
Black and white. Intensity and distance
How light travels. Speed.
Shadows. eclipses, umbra, penumbra
Colors. Sequential contrast. Color circle. Color mixing
Colored shadows. Simultaneous contrast
Plain mirrors. Parallax. Object and image. Real and virtual images
Concave and convex mirrors. Focal length. Image, distances, sizes
Prism. Newton vs Goethe
Refraction. Snell's Law
Lenses. Optical instruments
Waves and particles
Types of waves, character of waves, wavelength, frequency etc. rope, slinky, ripple tank
Interference. Diffraction
Lasers. Electron microscope

## Teaching Notes

**The eye and vision**

See Rohan. Active or passive? Examples, e.g., ability to recognize partially obstructed objects more easily than a computer

Optical illusions
Experiments with vision

Note: Are the colors of simultaneous contrast "really" there? Rudolf Steiner said, "yes," yet others, e.g., Goethe, said "no." Try looking through a tube at the colors. Try photographs, but note that commercial developing adjusts the colors for balance, hence red eyes with a blue dress. Check out the colored "optical illusions." See colorcube.com for striking examples, under Simultaneous Contrast and also Chromatic Adaptation.

Sequential Contrast: Let students explore with a collection of colored squares, produce the color circle. Are there correlates in nature? green in the summer, magenta (used by painters) in the winter, fall reds and yellows

**Mirrors, lenses, prisms**

Plain Mirrors: Simple mirrors, about 2" x 6" can be attached to small blocks of wood with a rubber band. Nails are the objects. It is often surprising how hard it is to understand object and image for a simple mirror! How tall a mirror do you need to see yourself, head to foot?

Concave mirrors, lenses: A simple optical bench can be made with adding machine tape and clay to hold the lenses. Use a small candle as object.
Is it possible to find the technical details without rays? We can demonstrate on a cardboard light passing through a lens, diverging and converging to a focus, also in a concave mirror. Rays are clearly an abstraction from this experience.

Prisms: Newton vs Goethe. A large plexiglas tank produces impressive results.
To reproduce Goethe's experiments, students must all look the same way through their prisms.

**Refraction, Snell's Law**
Simple plastic half-circle tanks are simple to use and produce good results.

**Optical Instruments**
Good cardboard models are available from AstroMedia.

**Waves vs Particles, Huygens vs Newton**
Let a ball roll down a series of two cardboard sheets at an angle. The "angle of refraction" is in the wrong direction. Contrast with a row of students marching on an angle across the border of solid earth and a swamp (imaginary).

**Spectra, Energy Levels, Lasers**

## Appendices

**12-1** The Rainbow, William Wordsworth
Light at the Creation: Genesis 1, John 1
**12-2** Optical Illusions
**12-3** The Eye and Seeing
**12-4** Vision Experiments
**12-5** "This Little Light of Mine"
**12-6** William Ernest Henley, "Invictus"
**12-7** "Dark as a Dungeon," Merle Travis
**12-8** Plain Mirror Cartoons
**12-9** Reflection in a Plane Mirror
**12-10** Concave Mirror
**12-11** Converging Lens
**12-12** Refraction

# My Heart Leaps Up When I Behold

**or *The Rainbow***

My heart leaps up when I behold
    A rainbow in the sky:
So was it when my life began;
So is it now I am a man:
So be it when I shall grow old,
    Or let me die!
The Child is father of the Man;
And I could wish my days to be
Bound each to each by natural piety.

– William Wordsworth

# Light at the Creation

In the beginning God created the heavens and the earth.
The earth was without form and void, and darkness was upon the face of the deep;
And the Spirit of God was moving over the face of the waters.
And God said, "Let there be light:" and there was light.
And God saw that the light was good; and God separated the light from the darkness.
God called the light Day, and the darkness He called Night.
And there was evening and there was morning, one day.

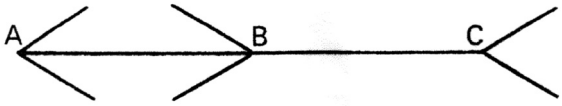
– Genesis 1:1–5

In the beginning was the Word, and the Word was with God, and the Word was God.
He was in the beginning with God;
All things were made through Him, and without Him was not anything made that was made.
In Him was life, and the life was the light of men.
The light shines in the darkness, and the darkness has not overcome it.

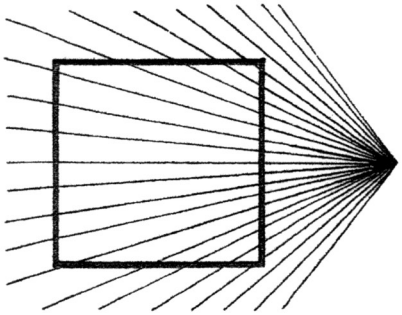
– John 1:1–5

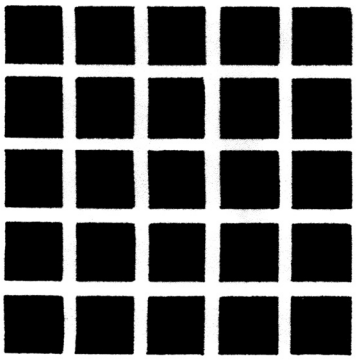
12-2

# Optical Illusions

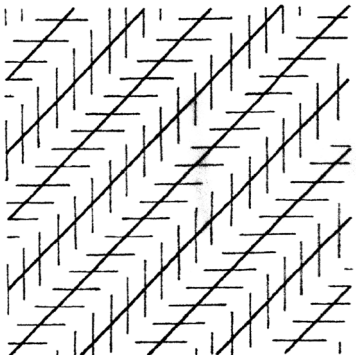



Has AB the same length as BC?

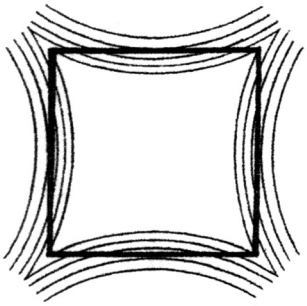


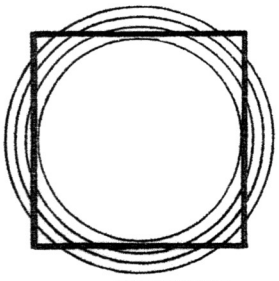


Dark points in the bright passageways

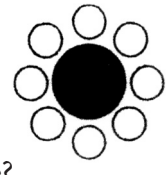


The "broken" line

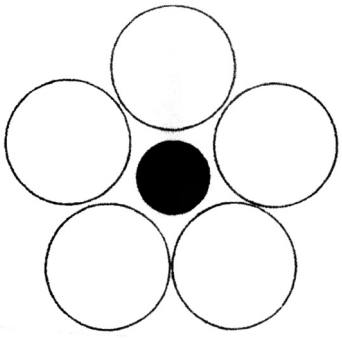


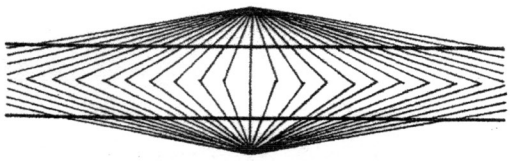


Really square or not?

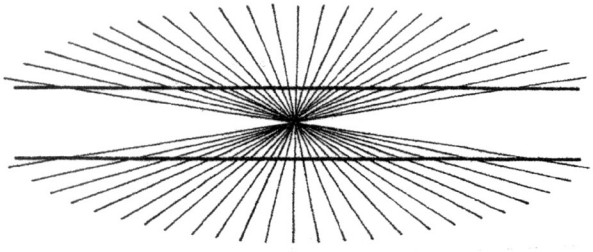


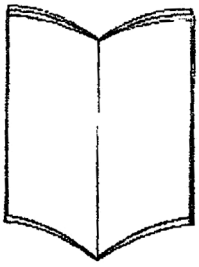
Are the dark areas the same size?





Are they really parallel?





Is the book face-down? or face-up?

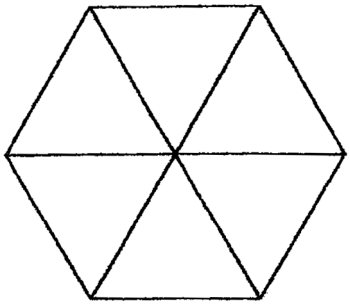


Do you see a musician or a girl's face?



A Native American profile?
Or an Eskimo entering a cave?



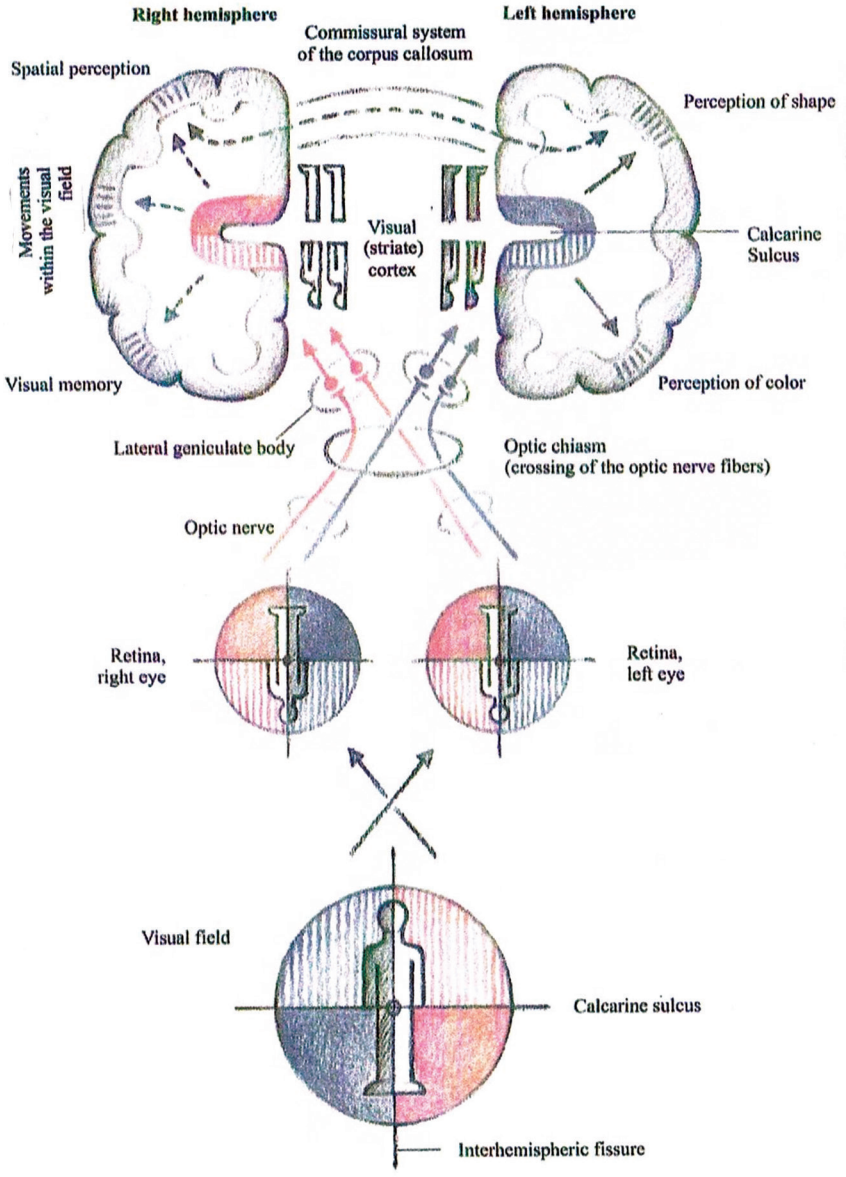


This hexagon can also be seen three-dimensionally as a pyramid with a hexagonal base, as a left-leaning cube, or as a right-leaning cube—a striking example of the active, conceptual components of sight.

**12-3**

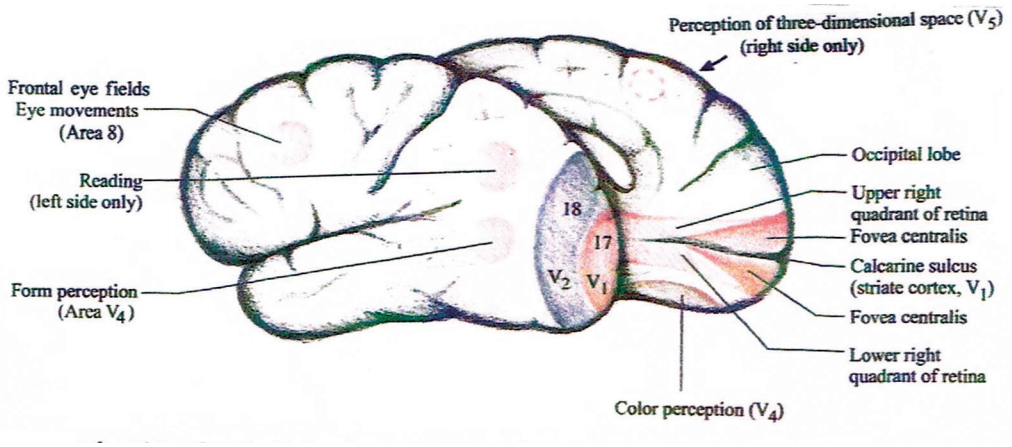
# The Eye and Seeing

**The optic tract and the process of seeing.** The image that appears in the visual field is reversed by the lens. Partial images from different quadrants are projected piece by piece onto the visual cortex in the occipital lobe of the brain hemispheres. From there, image fragments are distributed to different areas of the brain based on their functional values (shape, color, space movement). Brain centers for resynthesizing the image in its totality, as we experience, it, are largely unknown.



**Visual centers of the brain.** Impulses from both eyes stream into the interior of the occipital lobe in the so-called striate cortex (above and below the calcarine sulcus), of the primary cortical visual center. The greatest amount of space is taken up by projections from the fovea centralis (area of most acute vision). From there, they are distributed to different parts of the cortex (spatial separation of perceptions of color, shape, and movement). Area 18 contains the secondary cortical fields.

– Rohan, *Functional Morphology*



**12-4**

# Vision Experiments

**1. Left or right-eyed?** Make a circle of your index finger and thumb. With your arm stretched out in front and with both eyes open, look through this circle at some object on the other side of the room. Without moving your arm, close first one eye and then the other. With which eye do you see the object through the circle of your fingers now? Are you "left-eyed" or "right-eyed"? That is, which eye sees the same view as before?

**2. Judging distance.**
a) Have a classmate hold a pencil vertically with the tip upwards about two feet in front of your eyes. You take another pencil. Holding it with tip downward, and with one eye closed, try to lower it over your classmate's pencil so that you touch the tip of his/her pencil with the tip of yours. Try it a few times.
b) Then try it with both eyes open. Which way is more successful? Why?
c) Hold a small object at arm's length. Look at it first with one eye and then with the other. Are the two views the same? Explain.

**3. Accommodation.** The eye has the remarkable ability to adjust so that objects at different distances are seen clearly.
a) Place yourself about 3 feet from a window and concentrate your attention on the window itself. You will find that the window is seen very clearly, that the lines where the glass meets the frame are seen sharply, and that even such details as spots on the glass are apparent. Still concentrating your attention on the window, note the appearance of objects in the distance, outside. Are they sharp or fuzzy? Can you observe their details?
b) Next, concentrate your attention on the far-away objects until you see them sharply. Can you now see the details of the window clearly?

**4.** a) With one eye closed or covered, move this paper toward you. When the page has just reached the point at which the print blurs, have someone measure the distance of the book from your eye.
b) Repeat the experiment with the other eye. Are the two distances approximately equal?
c) Try this with a few people of different ages and record the results along with their ages. Is there a limit to the ability of the eye to adjust itself for clear vision? Is this limit the same for all people, or for the two eyes of any one person? Does it vary with the age of the person? Other factors? Compare your results with those of classmates.

**5. The iris.** a) While looking in a mirror at the pupil of your eye in a dimly lit room, suddenly turn on a light that is close to and shines directly into your eye. Describe what happens.
b) Punch a hole in a small square of cardboard or paper with a pin or paper clip. How does the size of the hole compare with the size of the pupil of your eye? Now, holding the cardboard close to your eye, see how close you can approach this printed page and still see the print clearly through the hole. Without moving your head, remove the cardboard. How far away must you now move your eye to see the print clearly? Why is high illumination needed for close, fine work? Why is it easier on the eyes to read in bright light?

**6. Rods and Cones.** Look directly at a dimly-lit object at night. Now look at it out of the corner of your eye. What is the difference? Why?

**7. The "Blind Spot."** With your left eye closed, look directly at the center of the cross below. While looking directly at the cross, you will be able to see the black spot at the right, out of the "corner of your eye." Now, while continuing to look directly at the cross, move the page slowly up toward your eye. At some critical distance, the black spot will disappear and then, as you continue to move the page toward you, the spot will reappear a few inches closer. While moving the page, be sure to look directly at the cross; do not shift your gaze to the black spot while moving the page. Where on the retina is the image of the spot falling when it disappears?



**12-5**

# This Little Light of Mine

"A song is to be sung. If it remains on the page, it is the same as a new automobile that is bought, placed in the garage and kept there.

"A song is to be sung. One's musical abilities may be limited, but there are no limitations to one's spirit. A musical note is a guide, but it alone does not make a song.

"A song is to be sung. One's musical abilities may be good for citizenship schools, mass meetings, etc. Some of the songs are to be shouted. Others are to be sung quietly, lived with and allowed to grow within you and with you. A song is to be sung."

– Julius Lester, Highlander song book

"I believe that throughout our southland and in other sections of the nation, too, we have been singing a song." – Septima Clark, *Echo in My Soul*



BRIDGE




Chorus:
This little light of mine, I'm gonna let it shine
This little light of mine, I'm gonna let it shine
This little light of mine, I'm gonna let it shine
Let it shine, let it shine, let it shine

Bridge
The light that shines is the light of love, lights the darkness from above
It shines on me and it shines on you, and shows what the power of love can do
I'm gonna shine my light both far and near, I'm gonna shine my light both bright and clear
Where there's a dark corner in this land, I'm gonna let my little light shine.

Bridge
On Monday he gave me the gift of love
Tuesday peace came from above
Wednesday he told me to have more faith
Thursday he gave me a little more grace
Friday he told me just to watch and pray
Saturday told me just what to say
Sunday he gave me the power divine -
To let my little light shine.

**12-6**

# William Ernest Henley

Henley was born in Glouchester in 1849. He attended the Crypt Grammar School in his native city and was fortunate to come under the influence there of the Manx poet, T.F. Brown, who was headmaster. Brown not only inspired his young pupil and directed his reading, but encouraged him at a time when he was most in need of encouragement. A tubercular disease necessitated the amputation of one of Henley's feet, and there was serious danger that he would lose the other foot. Fortunately, however, Dr. Joseph Lister, the great founder of modern antiseptic surgery, was practicing at that time in Edinburgh, and thither Henley went in 1873.

For twenty months he was under treatment in the Edinburgh Infirmary, and the ravages of the disease were checked. The hospital experience was by no means unprofitable to him. During a good deal of the time he wrote verse, and many of his poems appeared in *The Cornhill Magazine* during the period of his sickness. Furthermore, Leslie Stephen, then editor of *The Cornhill*, took to Henley's bedside another young contributor to the magazine; and thus Henley developed with Robert Louis Stevenson a close friendship which lasted until broken by an unhappy misunderstanding years later.

Some of the most vivid of Henley's poems are those which grew out of his experiences in the Edinburgh Infirmary, and which be collected in 1888 under the title *In Hospital*. His best known lyric "Invictus" (written in 1875) was a defiant challenge to fate from his bed of pain.

Discharged from the hospital, he did hack-writing in Edinburgh for a short time, and in 1877, he went up to London to become editor of *London*, a short-lived magazine in which appeared Stevenson's *New Arabian Nights* and a series of poems modeled on old French verse forms by Henley himself. From 1882 to 1886 he was editor of *The Magazine of Art*. His most notable magazine connection was as editor of the *National Observer* in London. Under Henley's editorship this magazine became noted for its vigorous advocacy of British imperialism. True to its policy it published, along with other imperialistic items, Kipling's *Barrack-Room Ballads*.

In 1888, in addition to publishing *In Hospital*, he also issued *A Book of Verse*. A sheaf of his reviews and criticisms appeared in 1890 under the title *Views and Reviews*. Two years later three plays which he had written in collaboration with Stevenson—*Beau Austin*, *Deacon Brodie*, and *Admiral Guinea*—appeared; these found their way to the stage but were not notably successful. His own play *Macaire*, published in 1895, was also a failure. In 1893 another volume of poetry, *The Song of the Sword*, came out; it was called later *London*

*Voluntaries*. Five years afterwards a collection of his verses appeared under the simple title *Poems*, and in 1901 a second volume was published, entitled *Hawthorn and Lavender*. He died two years later.

Henley's marked individuality and independence of spirit emerge in his poetry. He advocated all things new, and had no fear of facing novelty himself. He engaged in various metrical experiments and was fond of imitating the artificial forms of French verse like the *rondeau* and the *ballade*, and of copying the lyrical devices of Heinrich Heine, the German romantic poet, who may perhaps have attracted Henley because he wrote verses while lying on a "mattress-grave."

The individuality of Henley's poetry comes from both content and form. Much of it is vividly impressionistic as are, for example, the startlingly modern poems in his volume of hospital verse. He was a master of the pictorial phrase, and his concrete sketches of persons and places are unforgettable. He worshiped speed, and the tempo of some of his poems is breathless. Finally, in his use of unrhymed rhythms—a form of verse which he employed very often—he is distinctly individual and modern. His poems without rimes have the rugged vigor of his boisterous personality; the technique is reminiscent of that of Walt Whitman, but though in them and in his other poems, Henley often echoes other poets, he succeeds, nevertheless, in retaining his individuality.

## Invictus

[The title means *Unconquered*.
Cf. Swinburne's Garden of Proserpine, ll. 81–85, p. 815.]

Out of the night that covers me,
    Black as the Pit from pole to pole,
I thank whatever gods may be
    For my unconquerable soul.

In the fell clutch of circumstance
    I have not winced nor cried aloud.
Under the bludgeonings of chance
    My head is bloody, but unbowed.

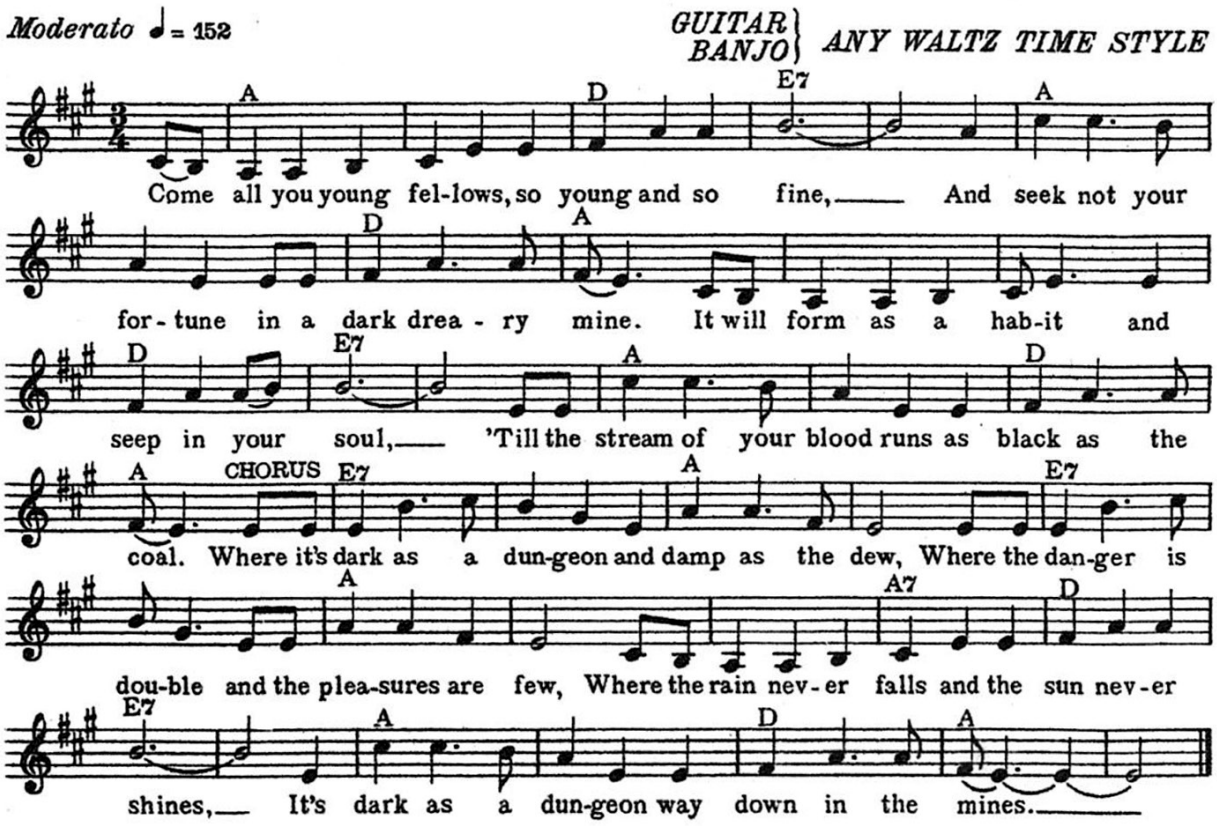
Beyond this place of wrath and tears
    Looms but the Horror of the shade,
And yet the menace of the years
    Finds, and shall find, me unafraid.

It matters not how strait the gate,
    How charged with punishments the scroll.
I am the master of my fate;
    I am the captain of my soul.

12-7

# Dark as a Dungeon

By Merle Travis; copyright 1947 American Music Inc., Hollywood. Used by permission of publisher and author.




1. Come all you young fellows, so young and so fine,
And seek not your fortune in a dark dreary mine.
It will form as a habit and seep in your soul,
'Till the stream of your blood runs as black as the coal.
CHORUS:
Where it's dark as a dungeon and damp as the dew,
Where the danger is double and the pleasures are few,
Where the rain never falls and the sun never shines,
It's dark as a dungeon way down in the mines.

2 It's many a man I have seen in my day,
Who lived just to labour his whole life away,
Like a fiend with his dope and a drunkard his wine,
A man will have lust for the lure of the mine. (CHO.)

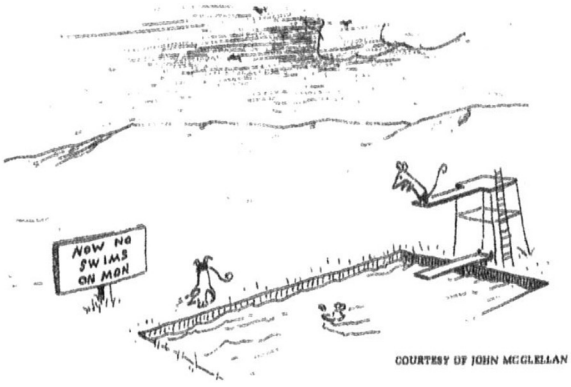
3 I hope when I'm dead and the ages shall roll
My body will blacken and turn into coal,
Then I'll look from the door of my heavenly home,
And pity the miner a-digging my bones. (CHO.)







The swimming pool in this cartoon is closed on Mondays. There is something rather remarkable in the picture other than the fact that there are mice swimming in the pool. What is it?



**12-9**

# Reflection in a Plane Mirror

**Apparatus:** Plane mirror, block of wood (About 2" by 6" by 1" is convenient), 2½" nails, rubber band, ruler, paper, cardboard, pins, pencils

**Procedure:**

1. Locating an object by parallax
Parallax is the apparent displacement (or difference in apparent direction) of an object, as seen from two different locations.

Hold a pencil vertically at arm's length. In your other hand hold a second pencil about 15 cm (6") closer than the first. Without moving the pencils, look at them while you move your head from side to side. Which way does the nearer pencil appear to move with respect to the one behind it when you move your head to the left?

Now move the pencils closer together and observe the apparent relative motion between them as you move your head.

Where must the pencils be if there is to be no apparent relative motion, that is, no "parallax," between them?

2. Locating an image by parallax
Now use the method of eliminating parallax to locate the image of a nail seen in a plane mirror. Support a plane mirror vertically on the table by fastening it to a wood block with a rubber band (wrapped horizontally). Stand a nail on its head about 10 cm in front of the mirror. Where do you think the image of the nail is?

Move your head from side to side while looking at the nail and the image of the nail. Is the image in front of, at the same location, or behind the real nail?

Locate the position of the image of the nail by moving a second nail around until there is no parallax between it and the image of the first nail. In this way locate the position of the image for several positions of the object. How do the distances of the image and object from the reflecting surface compare? Tabulate your results.

3. Locating an object by lines of sight (ray-tracing)
We can also locate the position of an object by drawing rays along several lines of sight to the object. Stick a pin vertically into a piece of paper resting on a sheet of soft cardboard. This will be the object pin. Establish the direction from your eye from the pin by sticking

two additional pins into the paper along the line of sight. Your eye should be at arm's length from the pins as you stick them in place, so that all three pins will be in clear focus simultaneously. Look at the object pin from several widely different directions and, with more pins, mark the new lines of sight to the object pin. Where do these lines intersect?

4. Location of the image of a plane mirror by lines of sight
We can use the above method to locate an image. Place the vertical mirror in the center of a fresh piece of paper on the cardboard. Locate the position of the image of a pin seen in the plane mirror by tracing at least three lines of sight (rays) from widely different directions. Mark the position of the mirror on the paper with a straight line before removing it. Use a sharp, hard lead pencil to draw the lines. Where do the lines of sight converge?

5. Angle of incidence and reflection
Draw rays showing the path of the light from the object pin to the points on the mirror where the light was reflected to your eye. What do you conclude about the angles formed between the mirror surface and the light paths?

6. Images of two mirrors at right angles
Arrange two mirrors at right angles on the paper with a nail as an object somewhere between them. Locate all the images by parallax. From what you have learned about reflection from plane mirrors and the images formed, show that these images are where you would expect to find them.

**Optional:**
7. Find images when your mirrors make other angles, e.g., 60°, 45°, 120°. Describe and explain. What of three mirrors?

**12-10**

# Experiment: Concave Mirror

**Purpose:** To investigate the images formed by a concave mirror.

**Equipment:** Concave mirror, meter stick, paper strip; modeling clay, small candle or light bulb in socket with battery.

**Procedure:**
Note: PLEASE USE CARE HANDLING THE MIRRORS.

1. Notice your own reflection in the concave mirror at different distances of your face from the mirror.

2. Set up the mirror on some modeling clay at the end of a strip of paper taped to the table top. Adjust the mirror until it is perpendicular to the table and the length of the tape.

2. Begin with the object (light bulb or candle) very close to the mirror. Compare the image with that of a plain mirror. Explain. Move the object gradually away from the mirror, noting how the image distance and size vary. Is the image real or virtual? Find the position of the image for a few object distances using parallax.

Confirm the locations found by parallax using ray-tracing.

3. About where does the principal focus (focal point) come? Examine the relations between object and image when the object is beyond the focus. Note
a) the object and image distances (How do they vary?)
b) the relative sizes of object and image.
c) whether the image is real or virtual.
Find the image position by parallax and/or with a sheet of paper. Which method can be used for any image? Why? Confirm results with ray diagrams.

4. Optional: Let $S_o$ be the distance of the object from the principal focus and $S_i$ the distance of the image from the principal focus. Plot $S_o$ in the x direction (horizontal) of a piece of graph paper and $S_i$ in the y direction (vertical). Also plot $1/S_i$ in the y direction. What do you conclude about their relationship?

# Experiment: Images Formed By a Converging Lens

**Equipment:** Converging lens, modeling clay, meter stick, paper strip, modeling clay, small candle or light bulb in socket with battery.

**Procedure:**
1. Look through a converging lens at an object. Is the image larger or smaller than the object? Is it right side up or upside down (inverted)? What happens to the size and position of the image when you move the lens with respect to the object?

2. Arrange lens and a light source on a long strip of paper. Place the lens near the middle of the paper strip. Start with the bulb at one end of the paper tape and locate its image by parallax. Is the image erect or inverted? Larger or smaller than the original?

3. Move the object gradually toward the lens, in small steps, marking and labeling the positions of both object and image as you go. Continue this until the image moves off the end of the tape and can no longer be recorded. How does the change in position of the image compare with that of the object?

4. Where would you expect the image to be when the object is at least several meters away? Try it. At this distance you may find it easier to find the image on a piece of paper. The location of the image when the object is very far away is the principal focus of the lens. How can you demonstrate that the lens has two principal foci, one on each side and at the same distance from the center?

5. Place the bulb as close to the lens as possible and again locate the image by parallax. Is it erect or inverted? Move the object away from the lens in small steps, marking and labeling the positions of object and image until the image is no longer on the tape.

6. Measure $S_o$ and $S_i$, the distance from the principal foci to the object and image, respectively, for the pairs of points and record in a table. (The distance $S_o$ is measured from the principal focus on the opposite side from the object.) Since $S_i$ clearly decreases when $S_o$ increases, try forming the product, $S_oS_i$. What can you conclude. As a check also graph $S_i$ as a function of $1/S_o$.

**Question:** Where would the image be if the object were placed at the principal focus? Try it. Can you find it?

**12-12**

# Refraction

**Purpose:** To explore the relationship between the angles of incidence and refraction for light passing from air to water

**Equipment:** clear plastic semi-circular box or tank, pins with round heads, cardboard, paper (It is convenient, though not necessary, to use circular graph paper.)

**Procedure:**

1. Use a pin to scratch a vertical line down the middle of the straight (flat) side of the semicircular plastic box.

2. Fill the box about half full of water.

3. Set the box on a piece of graph paper resting on soft cardboard. Make sure that the bottom of the vertical line on the box falls on the intersection of two lines on the paper, or, if using polar paper, at the center of the circles. For convenience the straight side should lie on one of the axes of the graph paper, although this is not absolutely necessary, as long as the position of the side is recorded on the paper.

4. Stick a pin on the line passing through the center of the straight side and perpendicular to it, a convenient distance away from the box, perhaps 4 to 5 cm. This pin must be vertical.

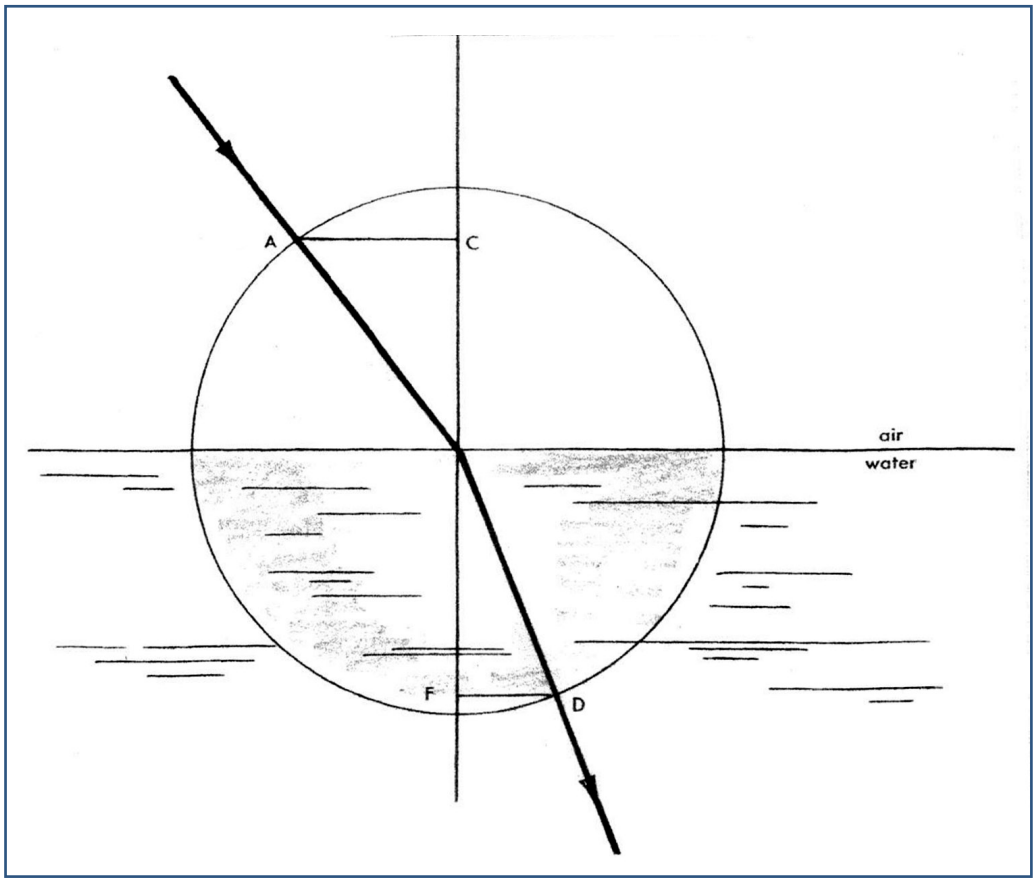
5. Now look at the pin through the water from the other side, the curved side, and move your head until the pin and vertical scratch on the box are in line. This means that the path of light from pin to your eye has traveled through the middle of the straight side. And the path to your eye goes from there through the tank on a path perpendicular to the curved edge of the tank.

6. What happens to light passing from air to water at an angle of incidence of 0°, that is, perpendicular to the surface? Is its path bent?

7. Change the position of the first pin to obtain an angle of incidence of about 10° to 15°. With the second pin mark the path of light going from the first pin to the vertical line on the box and through the water. Again, find the location outside the curved side where the pins and the vertical scratch line up and insert a pin outside the curved side of the box to mark the angle of refraction. Mark the pin locations for the incident light and the refracted.

8. Continue following the same procedure for other angles, about every 10° to 15°.

9. Make a table of angles of incidence and of refraction. Does anything remain constant? For example, does the difference remain constant? The ratio?






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