Waldorf High School Physics

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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 only run two 45-minute periods for one and a half hours total. In general we have each year one three-week main lesson block giving us 2x15=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 5x37weeks = 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, and we really do not want to do this. We are teaching, after all, all students, not only those with an interest in science or college. The solution which I have used is to offer extra chemistry 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 three-fold
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.

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.

<u>Communication and Transportation, not Thermodynamics</u>
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 these 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 cellphone. This means the <u>internal</u> 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 cellphones. 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 students constantly using their cellphones, 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.

According to Stockmeyer, in Stuttgart Waldorf schools were already bringing in internal

combustion in 9th grade in the 1940s. American schools need to catch up! 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 are 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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Taffel, Alexander, Visualized Physics
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 seam 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
Bernouli'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 heating 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 100ºC, 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 possible 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.

<u>Heat</u>

Character and location: expansion, activity. Warm: e arth 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

<u>>Convection. KMnO4 in beaker of water, heated on one side; smoke in window, fish tank with 2 holes in cardboard cover, candle under one</u>

>Radiation. 1)Thermometers one under black paper, one under white, in sun or heat lamp. Temperature after several minutes

<u>2) Boiling water in two metal cans, one shiny, one blackened. Temperatures after several minutes</u>

Practical applications

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

<u>Solids</u>: 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. The rod is hung in boiling water long enough to reach 100ºC. The rod is then 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

<u>Liquids</u>: A 250 ml Erlenmyer 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

Appendix
Masefield, "Cargoes"
JRR Tolkien, "Clap! Snap! the black crack!..."
Lab Desk Check-in
The Engine House
Engine Components and their Purposes
Internal Combustion Engine History
Rudolf Diesel
Pressure
The Four Stroke Cycle Engine
Charles' Law (2)
Boyle's Law
Heat Capacity and Latent Heat (3)
Heat Capacity of Corn Oil
Heat and Work
Heat Conduction
Radiation

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 for at least a limited introduction should be included.

Since the block requires some mathematics even for a limited understanding, teachers are faced at the start with resistance or non-interest on the part of many general students, 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 or 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

10-2(9)

Poem: Gerard Manly 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, startingwith1/8"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 a disengaged young lady screamed, when the car hit the money, "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 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. 3 years wrote Principia

Principia. Major contents. definitions, 3 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. 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

Appendix

Gerard Manley Hopkins, "God's Grandeur"
Isaac Newton Quotes
Superball problem
Derivation of Kinetic Energy formula
Laboratory Notebook and Reports
Measuring the Acceleration of Gravity
Vectors and Forces (2)
Centripetal Force experiment
Forces in Equilibrium (2)
Newton's Second Law (2)
Momentum Changes in an Explosion
A Collision in Two Dimensions (2)
Elastic Collisions
Conservation of Momentum and Energy (Elastic Collisions)
Centripetal Force (2)

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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
Rudolf Steiner and the Atom

Poem: 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, Priestly, Coulomb
Earth's electric field, thunderstorms, lightening,
Experiment with Scotch tape

Electroscope
Shielding
Leyden Jar, Wimshurst machine, electrophorus, capacitors
Van de Graaff generator (observe cautions), Faraday pail
Coulomb's Law

<u>Electricity and Magnetism Compared</u>
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.

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

<u>Electromagnetism</u>
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.

<u>Electronics</u>
LC circuits, oscillators, antennas, receivers, radios
Vacuum tubes, TV
Transistors

<u>Appendix</u>
Course Requirements
John Masefield, "Sea-Fever"
Gerard Manly Hopkins, "God's Grandeur"
Psalm 8
Experiment: Magnetism

Electricity and Magnetism: Similarities and Differences
Electrostatics Demonstrations
Experiment: Electrostatic Forces
Electricity and Magnetism: Seminar Book and Review Topics

12th 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.

<u>References</u>

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<u>Physical Science Study Committee, Physics</u>
Rohan, Johannes W, <u>Functional Morphology</u>
Steiner, Rudolf, <u>Light Course</u>
Zajonc, Arthur, <u>Catching the Light: the Entwined History of Light and Mind</u>

<u>Poem: Wordsworth, "The Rainbow"</u>
Henley, "Invictus"

<u>Seminar Topics:</u>
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
12-2 (16)
Plain mirrors. parallax. Object and image. Real and virtual images
Concave and convex mirrors. Focal length. Image, distances, sizes
12-2 (17):
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

<u>Teaching Notes</u>

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."

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...

Plain Mirrors: Simple mirrors, about 2" by 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).

Appendix
Course Requirements
Seminar Book Contents
Wordsworth, "My Heart Leaps up When I Behold"
Sound and Light at the Creation (Genesis)
The Rainbow (Genesis)
"This Little Light Of Mine"
Merle Travis, "Dark as a Dungeon"
William Ernest Henley, "Invictus"
Visual Centers of the Brain (from Rohan, Functional Mophology)
Optical Illusions:

Static (12, 1 color)
Dynamic (3, 2 color)
Simultaneous Contrast (3, all color)
Experiments: Vision (2)
Experiment: Reflection from a Plain Mirror (2)
Reflection Jokes
Experiment: Concave Mirror
A Brief History of the Microscope (Popular Mechanics)