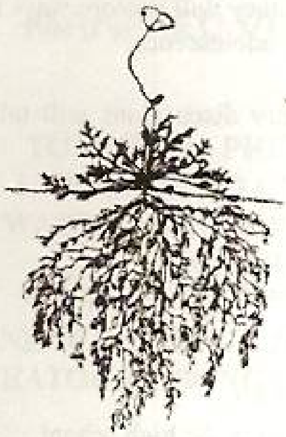
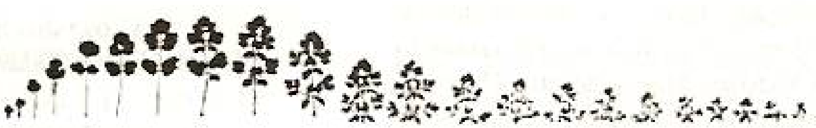

Waldorf Science

Explorations in Phenomenology as Practiced in Waldorf Schools

A Science News Roundletter

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VOL. 7, #14 **Spring 2001**

NOTE FROM THE EDITORS

A great deal of attention has been given by the media to factual errors in science test books. The most significant and numerous errors are contained in textbooks for the middle school grades. John Hubisz, a professor of physics at North Carolina State University, led a study which found hundreds of errors in twelve textbooks used in middle school physical science classrooms. Of these books, used by 80% of the nation's public schools, he said, none met an acceptable standard for accuracy. The Hubisz study said the books reviewed contained irrelevant photographs, over-complicated illustrations, experiments which don't work, numerous textual/factual errors, and diagrams and drawings that represent impossible situations.

Some of the more egregarious errors include an illustration with the Equator passing through Texas and a picture of singer Linda Rondstadt identifying her as a silicon crystal! More disturbing were the factual fallacies and misconceptions. For example, he cited one example that incorrectly defined Newton's first law of motion by equating speed with velocity. Hubisz's study, funded by the Packard Foundation, follows a 1999 report by the American Association for the Advancement of Science which strongly criticized high school biology texts and all middle school science texts.

This edition of the Waldorf Science Newsletter represents the fourteenth newsletter during the past seven years. We now ask you for your guidance.

How does your school receive these efforts–positively, enthusiastically, or apathetically?
Has the newsletter served its purpose and should it quietly retire?
Should it continue to be gratis to all schools or should the newsletter be sold by subscription only to those schools wanting it?
Should it be carried only as an AWSNA Publication with orders being made on-line and through the catalog?
How can the editors receive more articles and notes to share?

Your opinion is important to us. Please write, e-mail, or phone the editors.

HIGH SCHOOL RESEARCH CONFERENCE

From October 18–22, 2001, around one hundred invited high school teachers will participate in a research conference to be held in Andover, Massachusetts. The conference, the first of its kind in North America, is sponsored and organized by the AWSNA Waldorf High School Research Project.

The conference will begin with research reports available for reading and discussion on projects undertaken during this past year by Waldorf high school teachers across the continent on such diverse topics as:

- Developing the Capacities of Thinking and Judgment in High School Sciences
- Circulation of Living Fluids
- Chaos: A New Math Main Lesson
- Puzzles Using the Domino Rule
- Handwork and Mathematics
- Teaching Modern Themes in History
- Idealism and Humanity
- Curriculum Focus on Islam
- Kinesthetic Learning in Adolescent Education
- Dance as Movement History
- World Music as a Source of Improvisation and Composition
- Teaching Art to Waldorf High School Students in an Urban Environment
- Digital Arts in the High School
- The Place of Grammar in the Curriculum
- Teaching High School German
- Movement Education in Foreign Language
- Developing Communication Skills Curriculum in the High School
- Remedial Work in the High School
- Experiential Education
- Vision Quest for Teenagers
- Environmental Stewardship Program
- Outdoor Education in Waldorf High Schools
- Social and Emotional Skills Curriculum
- Peer Counseling in Adolescence
- Service-learning at the Heart of Learning
- Recent Brain Research on the Development of Study Skills
- Drama and the Education of Youth
- High School Approach to Drama
- How Does the Language of English Literature Reflect the Consciousness of the People of Any Given Time?

The conference will then proceed with three central elements:

1. The attendees will consider the physiological, psychological, and spiritual changes of youth today with Dr. Michaela Glöckler, head of the Medical Section at the Goetheanum. Together, they will explore ways to meet the changing needs of adolescence.

2. Cross-disciplinary discussions will take place on topics such as:

- social development and the teenager
- study skills
- social and emotional skill development
- peer counselling
- service learning
- communication skills
- remedial education in the high school

3. Afternoon workshops on high school curricular and extra-curricular subjects will take place including:

- physical and life sciences
- mathematics and computers
- humanities and language arts
- fine arts, performing arts, practical arts
- movement and outdoor education

In addition, the conference participants will follow up the work of Colloquia which have been held on the following disciplines:

Chemistry
Symptomatology
American History and Literature
Mathematics
Movement

It promises to be a rich and fulfilling conference. All North American Waldorf high schools have been invited to send a participant.

The AWSNA High School Research Project is coordinated by a Planning Group consisting of:

Andy Dill, Kimberton Waldorf School
Douglas Gerwin, Center for Anthroposophy
Antje Ghaznavi, Pedagogical Section Council
David Mitchell, AWSNA
Betty Staley, Rudolf Steiner College
Connie Starzynski, Chicago Waldorf School

CHEMISTRY CONFERENCE WITH MANFRED VON MACKENSEN

TOWARDS A PHENOMENOLOGICAL APPROACH TO CHEMISTRY AND THE WALDORF HIGH SCHOOL CHEMISTRY CURRICULUM

JUNE 16 THROUGH JUNE 24, 2001
SARATOGA SPRINGS, NY

A workshop with Manfred von Mackensen will take place in Saratoga Springs, NY, coordinated by Michael D'Aleo. The workshop will begin on Saturday evening, June 16th and will run through Sunday afternoon, June 24th.

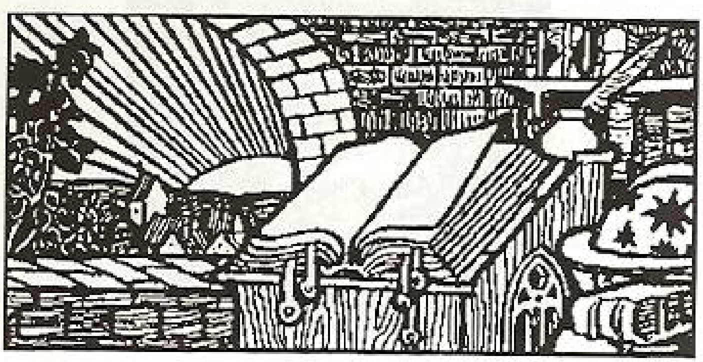
The workshop will offer teachers and scientists an opportunity to participate in a process of discovery of a phenomenological approach to chemistry. The conference will focus on the twelfth grade chemistry course.

The fee for the workshop is $45.

For further information on additional costs, accommodations, directions, and meals and to sign-up for the workshop, please contact:

Michael D'Aleo
Spring Hill Waldorf School
122 Regent Street
Saratoga Springs, NY 12866

School Phone: (518) 587-0549
Home Phone: (518) 587-0457
e-mail: spalight@netzero.net



PHYSIOLOGY UPDATE

In the March 2001 edition of *Scientific American* you will find an article entitled "Making Sense of Taste" by David Smith and Robert Margolskee. The authors write about how the tongue registers the sensations of sweet, salty, sour, and bitter and how the brain interprets the signals from our taste buds as different tastes.

They lament about a commonly cited illustration which appears in many textbooks showing the map of the toungue. This map (below) is incorrect and is the misinterpretation of research reported in the late 1800s.

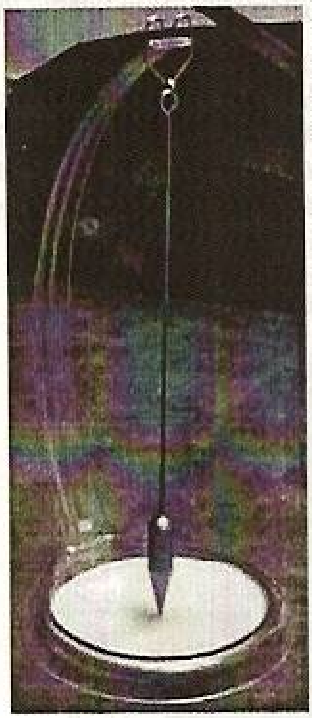
Smith and Margolskee state, "In reality, all qualities of taste can be elicited from all the regions of the tongue that contain taste buds. At present we have no evidence that any kind of spatial segregation of sensitivities contributes to the neural representation of taste quality . . ."

See the full article for a more complete explanation.

PICTORIAL EARTHQUAKE

On February 28, 2001, a magnitude 6.8 earthquake occurred, located some thirty miles below the surface of the earth and a few miles from Olympia Washington. The quake caused the earth to shudder for about 40 seconds.

It so happened that a shop in Port Townsend, Washington, had several sand tracing pendulums on display (see photo on left), which captured some fascinating artistic patterns from the quake.

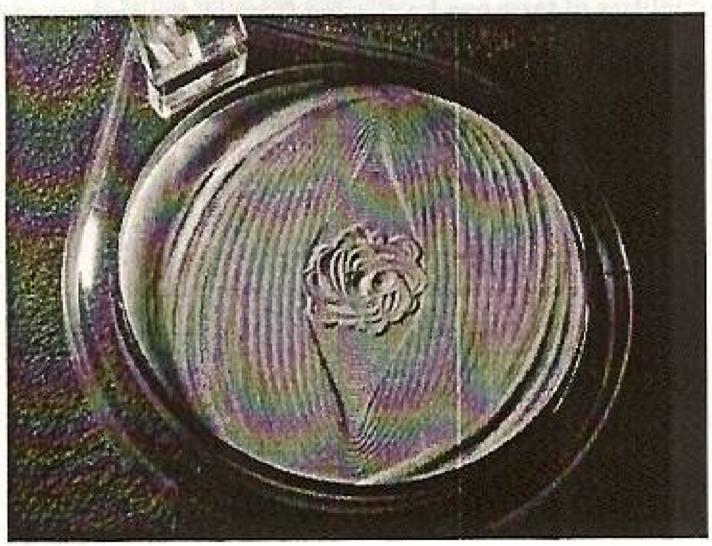


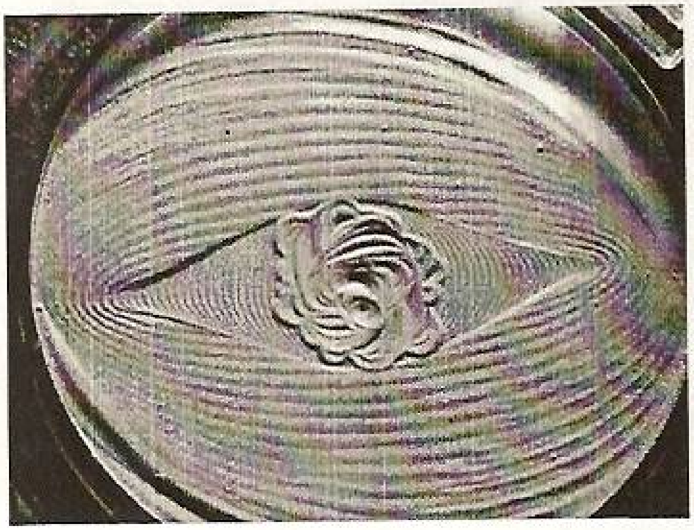
Each pendulum was set into motion by the movements of the quake, and the plumb-bob traced a unique rosette pattern of the movement on the fine sand in the tray.

The entire story can be read on-line at:

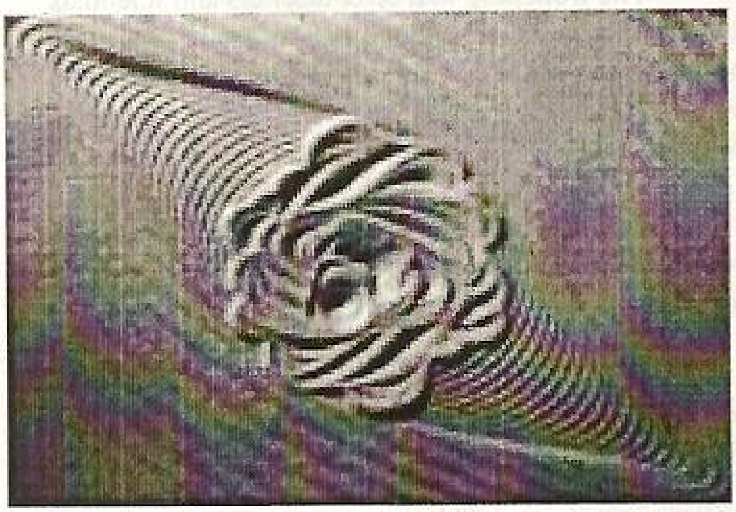
>www.earthquakerose.com<

Here are some of the photos taken shortly after the ground stopped moving:





The smooth curves you see to the outside of the Earthquake Rose are what you normally see when someone sets the pendulum in motion to make a tracing. . . and without seismic assistance.



It is amazing how a massive and destructive release of energy can also contain such delicate artistry within its chaos.

A geophysicist commented: "The sand preserves two features of the earthquake waves quite nicely. The motions caused by the earthquake moving the pendulum's base started small, and the initial tracings were overwritten as the strength of the ground's motion increased."

Boiling with Snow

(Boiling Water at 40° Celsius = 104° Fahrenheit)

Grade 9 Physics Experiment
by
Henry Saphir

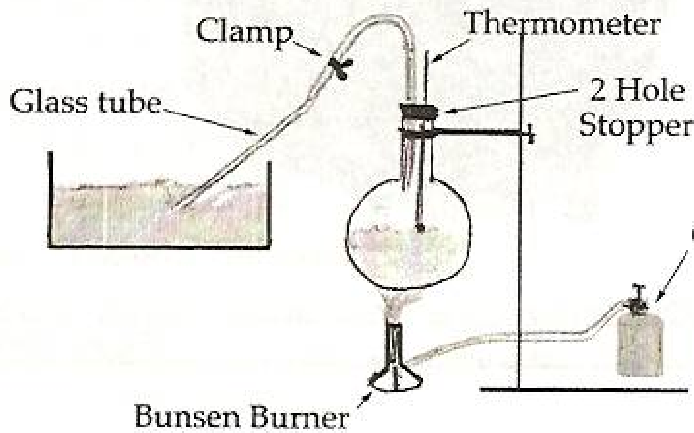


Figure 1 Overall setup

When I was preparing to teach my first ninth grade *Warmth, Coldness & Electricity* block in 1993-94, Keith Francis suggested the following experiment to me in a phone conversation. In 1996 I watched the late Stephen Edelglass perform an even more elegant and comprehensive version of this experiment in his tenth grade Chemistry block. The version described here is the simpler one that I have used in ninth grade physics blocks.

The setup is relatively simple. A large round-bottom flask is partially filled with water, closed with a two-hole stopper, and held in a lab stand. One of the holes holds a thermometer (–20 to +120° C range) which is *partially submerged in the water.* The other hole carries a piece of glass (or plastic) tubing which passes in through the stopper, ending in the *air space above* the water. On the outside, a piece of rubber tubing (which has a pinch-clamp, so it can later be clamped shut) is attached to the glass "exit tube" to a glass "delivery tube" ending submerged in a water basin. Students and the teacher wear safety goggles. Later some snow (or cold water) and a "cooling rag" are needed.

When all is ready, a Bunsen burner flame is placed beneath the flask.

Figure 2 detail of flask

The first observation is to note dew-like condensation on the *outside* of the flask (see details in Figure 2, above). This condensation disappears within 1–2 minutes. Soon after this, condensation is noticed now on the *inside* of the flask, above the water level.

Just after the Bunsen burner flame is placed beneath the flask, bubbles start to appear at the end of the delivery tube inside the water and rise to the surface of the water. In time, these bubbles become smaller, and once the water begins to boil in the flask, no more bubbles rise to the surface; instead a "hammering" noise is heard. Meanwhile the temperature reading on the thermometer has steadily gone up and approaches 100° Celsius—the water in the flask is boiling.

If one allows the water in the flask to boil for a while, a noticeable increase can be noted in the temperature of the originally cool water in the basin containing the end of the submerged delivery. Meanwhile, the hammering noise continues ever since the water in the flask started boiling. The thermometer rise stops around 100° C.

No Boiling with Heat!

When the **tube is clamped shut** for a short time, while the Bunsen burner is still heating the flask, the boiling stops while the temperature rises. BE CAREFUL— THIS IS TO BE DONE ONLY FOR A FEW MOMENTS AS THE PRESSURE BUILDS UP VERY FAST AND COULD LEAD TO AN EXPLOSION.

Boiling again

Now the Bunsen burner is turned off, and the hose is clamped shut. The water stops boiling, and its temperature slowly decreases. At this time, some snow is put on the upper part of the flask above the water level. If no snow is available, some cold water can be poured over the flask or a rag soaked in cold water could be placed on the flask. Suddenly the water starts to boil again, with large, almost violent bubbles. If the temperature is checked it might be noted that the temperature might have dropped to around 80° Celsius (176° Fahrenheit)—but still the water is boiling! Once the boiling has stopped again, the top of the flask is cooled again with snow or cold water—again the water may start to boil, this time maybe at 60° C (140° F). Sometimes I have been able to get the water to boil at temperatures as low as 40° Celsius or 104° Fahrenheit.

At the end of the experiment the hose clamp is released, and immediately water from the basin gushes back in through the hose, and fills almost the entire flask.

Review ("Exact Sensorial Imagination")

Afterwards I ask the students to first orally describe and then record the sequence of our observations, with a drawing of the details of the setup, and the parts labelled.

Discussion

On the next day we review and discuss our observations. We work out appropriate concepts, now. For example, we note that when heating cold water on a gas stove, condensation appears on the outside of the pot. This is not the case on an electric stove. This leads us to conclude that (contrary to some quick guesses) the condensation is not condensed water vapor from the air but instead the condensation of a by-product of the combustion of the gas—water vapor as a product of combustion. The condensation on the inside, though, is condensed water vapor.

The bubbles that rise at first are air bubbles, while the later ones which implode with a "hammering" noise under water must be steam bubbles—they don't rise to the surface, since the steam simply condenses back into water when cooled by the water in the basin.

The fact that the boiling stops while the temperature rises when the hose is clamped shut seems to indicate that the boiling temperature depends on the pressure. If the pressure is higher, the boiling temperature is higher, which is a principle used in pressure cookers.

In the later part of the experiment, the pressure seems to have been reduced. This is verified by the observation that the flask immediately filled with water once the hose clamp was opened—the steam created when the water in the flask was boiling had purged out all of the air that had originally occupied the gas space above the water in the flask.

When snow (or cold water) was placed on the upper parts of the flask, some of the steam must have condensed, leading to a dramatic decrease in volume and hence reduced pressure. From the observation that under these circumstances the water still boiled while at temperatures far beneath the normal boiling temperature, we can deduce that the boiling temperature of water decreases as the pressure is reduced. This goes very nicely with the fact that while water may boil more easily at higher altitudes, it takes longer to cook food there.

An important industrial application is that by artificially lowering the pressure (for example by using a vacuum pump), fruit juices can be boiled at low temperatures (and hence concentrated), which is used to produce fruit juice concentrates while conserving many of the qualities of the nutrients which would be destroyed by normal boiling at 100° Celsius (212° Fahrenheit).

The students usually love the intricacies of the experiment (definitely more challenging than grade school!) and at the same time can be challenged to clearly justify every step in their explanation. As teachers, we can use every opportunity to point out technical applications and uses, to help our students "to understand the technology-saturated world that we live in today."

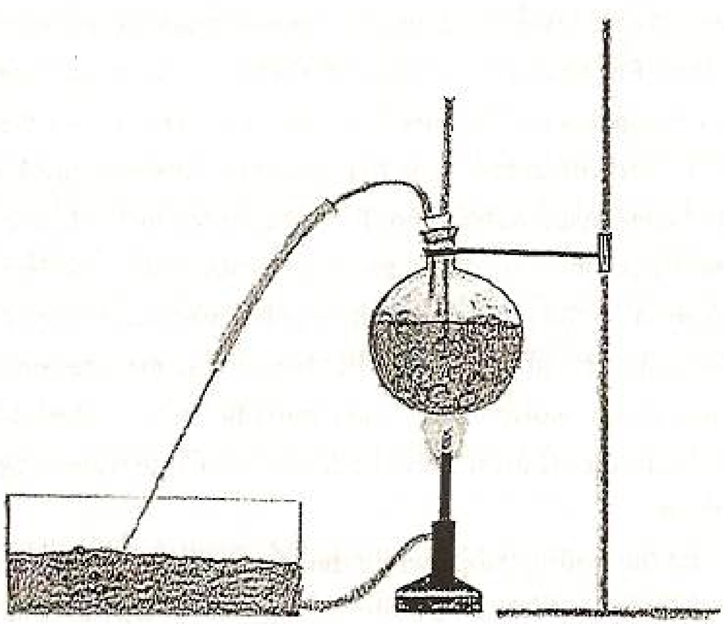


Figure 3: Overall setup (drawn by another student)

Toward a Waldorf High School Science & Technology Curriculum for the 21st Century

by

Dick "Cedar" Oliver

Introduction

This paper is an attempt to articulate my vision of how the science and technology curriculum and science facilities at High Mowing School will be developed over the next few years. Keep in mind that, although I've developed these thoughts over many years of working with teenagers, the specific courses I outline here are largely untested. I'm sure that they will change significantly as I teach them over the coming years, and some or all may be entirely inappropriate in other settings than High Mowing School (a 9th-12th grade boarding and day school established in 1942). My hope, however, is that by sharing my own thoughts in some detail here, I can also inspire more discussion among colleagues throughout and beyond the Waldorf movement about how science and technology education can look toward the new century.

Part I: Science Curriculum

It is often said that science education lies at the very heart of the Waldorf high school curriculum. In Waldorf elementary schools, the logical, scientific mode of thinking is intentionally not brought into full fruition even though much is done to prepare for it. Not until the adolescent years do we as educators guide the intellect toward truly objective rationality—the kind of rational thought that forms the foundation for modern science and technology. While the elementary school student needs the freedom to remain in a dreamy state reminiscent of life in centuries past, the high school graduate must also be free to stand fully awake in the 21st century world.

This process of human development leaves us with two central questions:

- How can we help students develop the kind of crystal-clear, precise, and intricate thinking which lies behind much of our modern world?
- How can we help students strengthen and preserve the fluid, warm, and responsible thinking that can so easily be lost in our modern world?

The polarity between these states of mind is a fundamental feature of the human condition in our times, and it is a fundamental task of education today to harmonize these discordant states of the human soul.

Science and technology—our knowledge of the physical world, and our capacity to alter it—are the fields of human endeavor where the contrast between cold rationality and compassionate responsibility appears most stark. Can we introduce students to these fields in such a way that they remain truly free to think both rationally and responsibly, both clearly and fluidly? Can we enable them to build an intimate relationship to the objective physical world without forsaking their personal relationship to subjective spiritual realities?

Only by facing these challenging questions can we hope to plan science curricula and facilities to meet the deepest needs of adolescents in the coming decades.

A Solid Foundation

Like most other Waldorf high schools, High Mowing offers a carefully considered sequence of science main lesson blocks timed to answer the inner development of adolescents. Not all of the blocks have been offered due to scheduling and staffing limitations, but the general sequence is outlined below.

	9th Grade	*10th Grade*	*11th Grade*	*12th Grade**
Physics	Thermodynamics	Mechanics	Electromagnetics	Optics
Chemistry	Inorganic/Organic	Acids/Bases	Atomic Theory	Biochemistry
Earth Science	Geology	Meteorology	Astronomy	Ecology/Evolution
Life Science	Physiology	Embryology	Botany	Zoology

* History through Science has also usually been offered in the senior year.

Though each teacher should of course rediscover and "re-create" these subjects anew, the overall organization of topics provides a wide-ranging, developmentally appropriate introduction to the essential aspects of science that every student should be exposed to before graduation. I do not recommend that significant changes be made to the science main lesson block sequence—other than providing the facilities and faculty to more consistently deliver all or most of these blocks while we also increase our enrollment.

Building on the Foundation

Are the traditional science main lesson blocks enough to help today's adolescents develop and balance both precise scientific thought and a compassionate, responsible connection to nature? On a more practical level, we must also ask whether these blocks are enough to satisfy current and future college admissions requirements.

The main lesson block can be an excellent format for conveying intellectual content, experiencing the deeper human meaning of that content, and building "beginner-level" skills. The science block teacher's task is to identify the most essential phenomena and offer students a direct living experience of those phenomena so that they can discover the corresponding concepts through their own individual and group effort. However, even when teachers succeed in creating extraordinary educational experiences during the main lessons, it is clear that many students need the opportunity to go deeper. I would identify several specific capacities that are especially difficult to develop within the format of a three or four week, 90- or 120-minute class:

1. The ability to perceive and engage in the rhythms and cycles of the natural world
2. The endurance to carry out projects involving sustained concentration and labor
3. The practical proficiency to apply knowledge in "real-world" contexts
4. The capacity to discover, pose, and investigate one's own questions
5. The persistence to make errors and false starts but still continue toward a goal
6. The self-knowledge gained from finding and extending personal limits
7. The true mastery of subjects and skills in which an individual is uniquely gifted

The Naturalist Program at High Mowing has set a precedent of developing precisely these sorts of capacities in regard to the life sciences and Earth sciences. The teacher has created an educational context where, instead of an instructor providing the experimental apparatus and experiment goals, students have the opportunity to create their own tools and uncover their own personal goals. By conducting classes outdoors in the forest, the Naturalist Program also provides students with an opportunity to undertake long-term projects, develop a deeper level of intimacy with Nature, and experience rhythms, environments, and rites of passage that would be difficult or impossible to access within the traditional classroom main lesson format. The study of science is tightly integrated with social studies and creative artistic work as well.

I feel fortunate to be able to point to the Naturalist Program as an example of the type of "deepening" that students need to complement their main lesson blocks. Though the recommendations I will make later in this letter concerning laboratory-based physical sciences may appear outwardly dissimilar to this program, my goal is to provide the same type of deepening of student's experience in laboratory science that are offered in the environmental and ecological sciences.

Environmental Science and Laboratory Science

If the two most fundamental human capacities we hope to foster with our science curriculum are crystal-clear, intricate thinking and fluid, compassionate thinking, then it would be somewhat natural to expect that studying physics and chemistry might foster clarity and precision, while the life sciences and Earth sciences would tend to inspire warmth and sensitivity. There is truth to this notion, and yet it is physical science—from whence we get all things nuclear and chemical—which actually requires the most compassionate responsibility from us. Likewise, it is the complexity of the living world that most demands intricate and accurate thought.

Environmental Science

Sensitivity $\rightleftarrows$ Precision

Laboratory Science

When we learn to be sensitive to the living world, we are led by it toward compassion. Only through our own inner efforts can we then move through compassion, toward clarity and thus gain a balanced and true knowledge of Nature. Conversely, working with precision in the mineral world clarifies our thinking, and through our own inner efforts that we can then move through clarity, toward compassion and develop a balanced picture of our relationship to physical reality. Another way to express this would be to say that the living world can give us the capacity to think compassionately, while the mineral world can give us the capacity to think clearly. These are the means by which we must work as educators if we are to succeed in a genuine study of these realms. The ultimate ends that we strive for, however, are exactly reversed: when sensitivity to nature allows compassion to blossom, only then do students truly have the potential to develop clear thinking in a responsible way. Paradoxically, when precise control of the mineral world blossoms into clarity of thought, only then does the student truly have the potential to develop steadfast and trustworthy compassion.

While all this may sound a bit abstract, I present it as a picture of how the Naturalist Program and physical science program might approach the same two fundamental tasks from opposite directions. If students can be immersed in the natural world in such a way that genuine love of all life and a deep sense of responsibility are allowed to flow into their souls, then through hard work they may begin to clearly see and think about the world in an entirely new, more accurate way. Only through this type of transformative journey—of which the Naturalist Program is an excellent example—can a young person be led to true thoughts about the living world and the role of humanity within it.

Again, the converse applies to physical science. If students can be immersed in the mechanical, mineral world in such a way that crystal clarity and meticulous precision are allowed to flow into their souls, then through hard work they may begin to develop a feeling for the workings of the cosmos and appreciate the majesty and wonder of physical reality in an entirely new way. Only through this type of journey—of which I hope our laboratory science program will be an example—can a young person be led to a genuine love for the physical universe and compassionate responsibility concerning the role of human beings in it.

Deepening Physical Science Education

How, then, might a teacher lead a student on such a journey? What activities could a teenager engage in that might let clarity and precision "flow into their souls" from the very nature of the physical world itself? History suggests an answer to this question: As human beings developed the type of thinking we call now call "clear" or "logical" (another word, perhaps more accurate, would be "mechanistic"), they began to build the type of artifacts we now call "machines." As this new mode of consciousness grew stronger, they began to use those machines to seek mechanical "laws" underlying physical reality.

More specifically, they built machines out of certain materials—in fact, materials not normally found in nature. These materials are of course the metals, particularly copper and iron, refined from natural ores (often crystals) and sometimes alloyed with tin, zinc, lead, carbon, and other crystalline substances. It was through the discovery, liberation, and utilization of these materials that humankind was able to leave the "stone age" and refine the ability to think in more modern ways about the universe and our role in it.

Clear, rational thought is, from a certain point of view, actually "metallic" thinking—that is, making connections and divisions in the way that we first expressed and developed by making and using metal tools. From this perspective, then, an educational goal would be to bring each class of students into the "bronze age" and "iron age" up through the modern age of steel buildings and copper-based communications technology.

Glasswork also plays a key role, both historically and pedagogically. Just as the disordered inner structure of a glass is physically the opposite of a highly ordered metal surface, work with silica glass allows the construction of scientific instruments to contain, mix, and synthesize. These provide a balance to the tendency of metal instruments to pinpoint, divide, and analyze. Few areas of science can be investigated without developing both of these types of technology. By designing and building instruments out of these two types of crystalline material, we develop complementary aspects of "crystal-clear" thought.

Interestingly enough, it is precisely the construction of machines—the "scientific apparatus"—that is left out of most physical science courses, no less in Waldorf schools than in other schools. I would suggest that if we are to take students beyond simply understanding the thoughts of others to the point where they are asking their own questions about physical reality, then they should be designing and constructing their own scientific tools and apparatus. To allow complete and accurate thinking to develop, this should ideally include the experience of finding and refining the materials as well.

Three industries lie hidden behind every science laboratory: the mine, the refinery and the machine shop. Only when students are able to directly participate in these industries do they have the freedom to produce their own complete thoughts that lead from the natural, living world to the constructed world of scientific experiments and theories. The most important of these industries from a pedagogical perspective is the machine shop; it is through working with iron, copper, and silicon to embody one's own thoughts about the world that precision and clarity can "flow naturally into the soul" from the very nature of the material and activity.

By constructing and employing apparatus of one's own design within a social context of earnest philosophical investigation, students can begin to make finer distinctions in their thoughts about physical reality. Testing the accuracy of their thinking with ever-greater precision, they can be led toward a deep and genuine experience of the "clockwork" of the universe and become gradually more conscious their own hidden assumptions about the reality they inhabit. This activity, coupled with study of the work of others (both peers and the great scientists of history), leads to deeper and deeper mysteries within copper (electricity), iron (magnetism), and silicon (semiconductors). Ultimately, it also leads to modern physics, where the "mechanisms" seem so utterly unlike machines that the fundamental nature of existence and knowledge come into question.

When students then finally study machines made with new materials such as radioactive isotopes or superconductors, their perspective may be quite different than before they themselves become machine-builders and "natural philosophers." That difference—a difference of the heart, when somehow the intimacy of intensive work and thought becomes a sense of awesome responsibility—is one symptom of the inner effects of this journey.

The Physical Science Laboratory

To be a bit more concrete, I offer a year-long track course called (unimaginatively) "Physical Science Lab" where students work individually and as a group to construct and carry out physics and chemistry experiments of their own design. Students pose and pursue their own questions that arise out of individual and group philosophical work and also study how other scientists have approached similar questions in the past. They keep individual lab journals documenting their own assumptions and theories about the nature of reality, instrument designs, experimental results, and philosophical implications. Considerable time is spent writing technical and research reports, as well as less formal essays and short science fiction stories. Technical drawing and drafting of schematics can also be an integral step in the design and construction of instruments.

Another important aspect of this course is giving students an experience of the cultural context of scientific research, including discussion of how that culture affects the subject matter and results of the scientific endeavor. The format of class meetings, group decision-making, and sharing of results are carried out in a way that mirrors historical and contemporary "scientific culture." Like the Naturalist Program, this course clearly includes a great deal that could easily be classified as "English," "Art," or "Social Studies," rather than "Science."

When possible, students would actually refine their own materials, but for practical and economic reasons much of the metal, glass, and other raw material will always need to be purchased in refined form. In this regard, a key piece of the program is the planned expansion of the Naturalist Program to include the experience of smelting and/or forging metals. Another crucial experience upon which the lab science program rests is the craft of pottery, out of which all more modern technologies and sciences ultimately arose. In a very real sense, students' work in the pottery studio provides the foundation stone upon which a study of science can be built.

A Proposed Life Science Laboratory

The science block classes, the Naturalist Program, and the Physical Science Lab together form a balanced and cohesive set of science courses. However, I believe that a third perspective on science is necessary to create a truly comprehensive college-preparatory science curriculum.

I have offered the view that the Naturalist Program and the Physical Science Lab can help students learn to be both dispassionately objective and compassionately subjective—in other words, to unite and harmonize the two sides of human thinking. Another way to look at this is to see the Naturalist Program as an effort to help modern teenagers build a connection to the world as it was experienced in previous ages. The Physical Science Lab, on the other hand, seeks to awaken truly modern consciousness. Ironically, the method of connecting to the past is to develop a sensitive awareness of nature in the present moment, and the method of awakening modern consciousness is to study and experience the history of science and society.

In a sense, these two journeys both lead to a common destination: tomorrow's world, where scientific knowledge gives human beings the power and responsibility to manipulate and preserve (or destroy) all life on Earth. In order to take that step into "future thinking," students need the opportunity to apply both sensitivity and precision to the study and stewardship of living beings.

Bioengineering and agriculture—the most modern and most ancient arts—are the arenas where both compassion and clarity come to fullest fruition. Their practice is likely to be a profoundly important issue throughout the 21st century and beyond, directly affecting the lives of everyone on the planet. The Biology and Organic Chemistry blocks provide a minimum level of literacy in biochemistry to all students, and some Waldorf schools choose to teach Organic Chemistry to freshmen and go deeper into Biochemistry topics in the senior year. Even if our block class offerings were strengthened in this subject area, any student interested in medicine, politics, technology, or science should be able to go deeper into these central topics of our times.

A junior/senior-level elective would give students the opportunity to explore the physical basis of life and the enlivening of physical matter in a hands-on laboratory/greenhouse setting. Ideally, breeding and stewardship of plants and animals would also be integrated into the course. If at least a year of the Naturalist Program and/or Physical Science Lab were a prerequisite, the Life Science Lab could also serve as a final step in the path toward unification of scientific thinking and compassionate responsibility.

It is not difficult to envision the possibility of a gardening and/or farming program that could go far beyond one lab-science course. Integrating the daily care of living beings more fully into the educational experience could have a profound positive impact on the entire curriculum, not only in science classes but throughout the campus, from dining hall to dormitories. We are currently developing a proposal to move in this direction at High Mowing, though an academic Life Science Lab course would also still be needed to fully prepare students for college.

Part II: Art, Science, and Technology

Physical Science and Digital Art meet in the realm of technology, and in a fundamental sense both involve creating worlds that are built upon but set apart from Nature. There is also a deep connection between the Digital Arts (This will be explained in the next *Waldorf Science Newsletter* in Cedar Oliver's article on appropriate Computer use.—*eds.*) and Life Science Lab. The Communications and Logic main lessons are designed to also provide a foundation for understanding modern conceptions of genetic information and the complexity of living ecological systems. (My senior math course in Dynamics also introduces closely related concepts in both the physical and life sciences.)

In essence, both communications theory and the contemporary Life Sciences lift our thinking out of the "physical laws" of matter into higher-level principles governing the formative forces that organize matter. They both challenge us to understand how the outer power to control transmission of information also demands inner capacities of self-knowledge and responsibility. This elevation of thinking is vital to a genuine understanding of 21st-century science and society, and also an important element of the transition from adolescence to adulthood.

The Big Picture: Arts and Sciences

The following diagram depicts one possible view of the relationship between the science electives at High Mowing, along with the arts and crafts programs that give students skills and experiences to support development of scientific thinking. (The point here is not to suggest that certain courses are necessarily prerequisites for others—the temporal order of students' experiences is less important than providing the full cycle of arts and sciences during the high school years.)

Naturalist Program ⟶ Physical Science Lab ⟶ Life Science Lab

Connect Present to Past *Connect Past to Present* *Connect Past & Present to Future*

Sensitivity ⟶ Compassion Precision ⟶ Clarity Sensitivity & Precision ⟶ Communication
Compassion & Clarity ⟶ Responsibility

Textiles ⟶ Pottery, Woodwork ⟶ Studio Arts, Photography ⟶ Digital Arts

Given that we improve our facilities and staffing to make the main lesson blocks more consistently robust and the proposed electives possible, our students will be able to meet and exceed the admissions requirements for even the most competitive technical colleges. Perhaps more importantly, students will have the opportunity to fully awaken the capacity to think with intense clarity, intricate precision, and loving responsibility through deeply personal exploration of the natural world.

The Bigger Picture: Waldorf Education in the 21st Century

The approach to science and technology I've proposed is somewhat different than the science curriculum traditionally found in Waldorf high schools. Indeed, one can interpret the writings of Rudolf Steiner and other master teachers as advocating against students designing their own apparatus and conducting their own experiments. Instead it is generally recommended that Waldorf science teachers focus on carefully prepared demonstrations of phenomena, with as little mechanical instrumentation as possible standing between students and a direct experience of Nature. Students are thereby guided toward a discovery of the appropriate concept for a perceptual experience through their own inner effort. This "phenomenological" approach to science is deeply founded in the nature of the human being, and at its best it can be dramatically successful in giving students a genuine, holistic, and unbiased conception of natural phenomena.

Though Waldorf teachers' opinions vary on how strictly phenomenological the high school science lessons should be, I believe that phenomenology-based demonstrations and classroom activities may be the best possible way to introduce students to the fundamental physical characteristics of Nature during their main lesson blocks. However, every Waldorf science teacher I've spoken with has encountered a fundamental limitation to the traditional approach to phenomenological science teaching; it provides no obvious way to enter the realm of 20th century science, which is almost entirely based on phenomena and concepts that simply cannot be observed at all without complex technology.

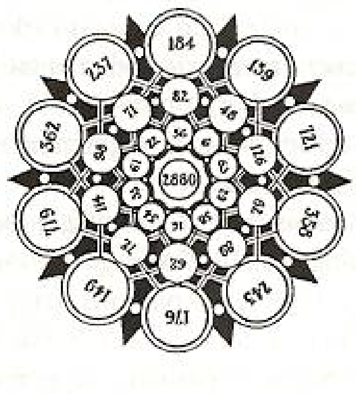
Indeed, in terms of the actual human experience of modern scientists, the only "phenomenon" under observation is the technology itself. One way to look at this situation is that the thoughts of the scientists, as embodied in their instruments, have become the primary subject matter of science. Both theoretical and laboratory science in our time have much less to do with an experience of nature's reality than with an experience of a created reality. This is true not only of modern subjects such as quantum mechanics, information science and complexity theory, but of any scientific endeavor whose results rest on laboratory apparatus as the medium of observation.

When we provide students with pre-built instruments, we are in effect hiding the greater part of the actual phenomena from them. They cannot therefore connect accurate concepts to their perceptions. In order to gain a genuine understanding of instrument-based scientific investigation, the instrument itself must become the object of study.

It would be a grave mistake, however, to assume that the "phenomenon" of a scientific instrument or experiment could be studied in the same way as a naturally occurring phenomenon. Unlike Nature, whose inner secrets are available to us through careful observation of her outer forms, human thoughts can be understood only by thinking them ourselves—from the "inside out," as it were. This is true even of human thoughts that have been "crystallized" into a physical machine or piece of equipment. While we can arrive at a true understanding of natural phenomena only through observation and reflection on that observation, the route to understanding the experiment itself can only be found through the act of designing and conducting it. This type of understanding is greatly aided by a study of the biographies of great scientists and by philosophical inquiry into one's own beliefs and thought processes.

As science moves further into elaborate technologies and theories, direct experience of Nature becomes no less important for every high school student. Yet, it does become increasingly vital that students also experience and understand the human process out of which technologies and experimental science arise. The great challenge facing science teachers today is to bring a study of human thought into the curriculum more and more, without crowding out the still-essential study of directly accessible natural phenomena.

Schools everywhere are succumbing to the temptation to replace "out-dated" industrial arts facilities and shop classes with abstract, passive study of science and technology. Waldorf education should do precisely the opposite—that is, center its science and technology programs more than ever around practical, creative activities that place human hands and natural materials in service to our highest faculties of thought.



Magic Number Explosion

The Thermal Decomposition of Calcium Carbonate

A student experiment demonstrating the thermal decomposition of the salt calcium carbonate into the acid anhydride carbon dioxide and the base anhydride calcium oxide.

by

John Hoffman

A few years ago for a tenth grade main lesson block in the Chemistry of Salts, Acids and Bases, I wrote up a student experiment for the thermal decomposition of calcium carbonate. The objective of the experiment was to show the students that, when heated, the salt calcium carbonate ($CaCO_3$) decomposes into the base anhydride calcium oxide (CaO) and the acid anhydride carbon dioxide ($C0_2$). The students were to observe that the carbon dioxide coining off the heated calcium carbonate powder reacts with water to produce an acid solution of carbonic acid ($C0_2 + H_20 \rightarrow H_2CO_3$) and the residue calcium oxide reacts with water to produce a basic solution of calcium hydroxide ($CaO + H_2O \rightarrow Ca(OH)_2$)

The method for detecting the carbon dioxide was simple. About two grams of finely powdered calcium carbonate was placed in the bottom of a 25mm x 150mm test tube and the test tube fitted with a #4 one–hole stopper. The short length of an approximately 8cm x 20cm right-angled, 5mm glass tube was inserted in the hole of the stopper. A 20mm x 150mm test tube was filled about one- third full with a water/pH indicator solution and the long end of the right-angled glass tube submerged in this solution (see Fig. 1). I assigned four different pH indicators for variety. Because I was familiar with the lime cycle and lime slaking kilns, I did not perform this experiment beforehand. This was a mistake. The carbon dioxide part of the experiment was a failure. After heating the calcium carbonate until the test tubes began to sag, not one student was able to get even a hint of an acid solution. The carbon dioxide simply came off too slowly and was not soluble enough in the water/pH indicator solution to produce a detectable acid reaction. However, after the test tubes cooled, water/pH indicator solution added to the calcium carbonate powder did test basic indicating that calcium oxide had been produced. Although the experiment was only half a failure, the students were disappointed.

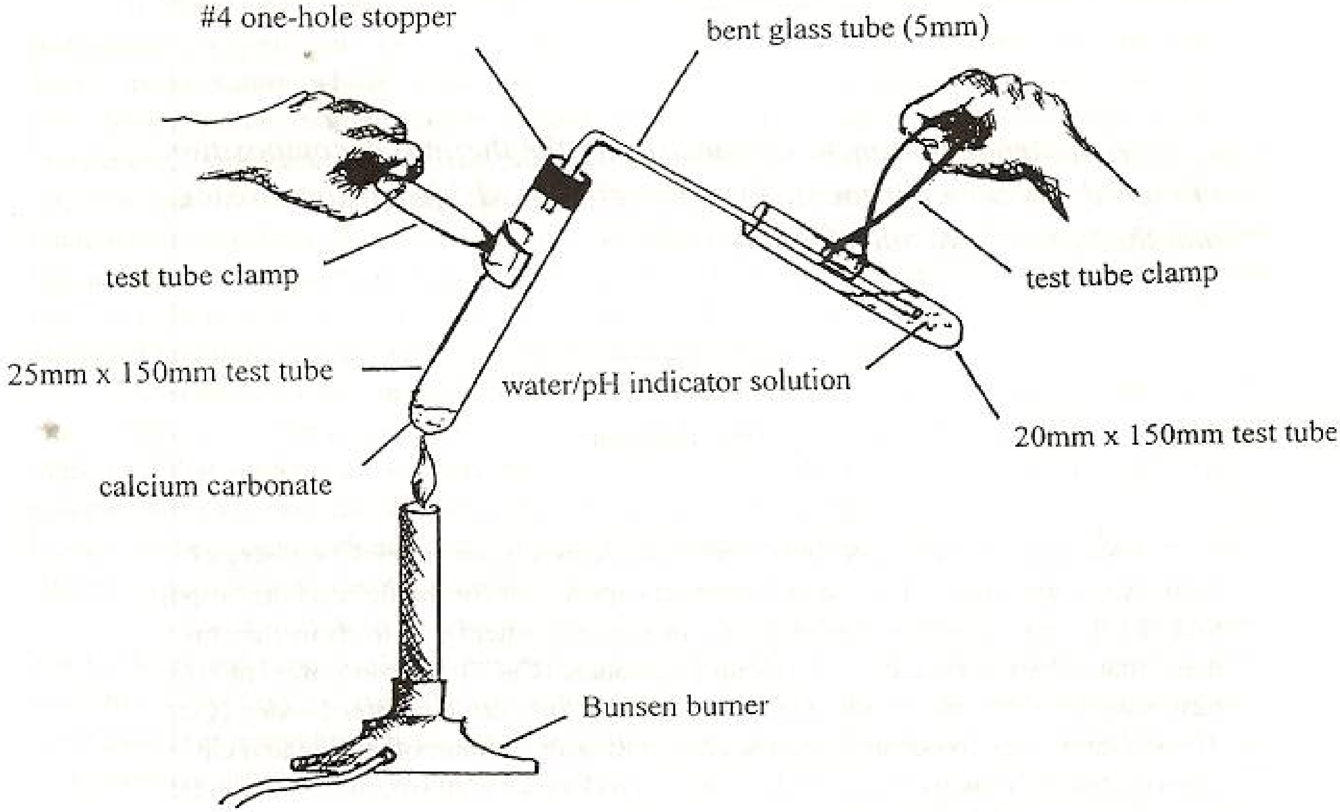


Fig. 1 Carbon dioxide gas bubbled through a water/pH indicator solution

Because of the importance of this experiment, I worked on the carbon dioxide part again this past summer. I used the same procedure but with a simple modification. Since calcium carbonate powder is light and fluffy, it is a poor conductor of heat. I added enough water to the powder to make a thick paste and spread the paste around the bottom and 2-3 cm up the sides of the 25mm x 150mm test tube. The heat from the burner could now be concentrated on a thin, fairly compact layer of calcium carbonate. I set up three test samples with the paste and let them dry overnight. The next day two of the samples looked dry and one was still visibly damp. However, when the test tubes were fitted with the stoppers and right-angled glass tubes and heated, all three samples were found to have considerable moisture. The evaporating steam bubbled violently through the water/pH indicator solutions. Within less than a minute all three samples gave a positive acid test with the water/pH indicator solution. Encouraged, I made up a number of damp paste samples and tested them immediately. They too gave positive acid tests. Evidently the carbon dioxide was being dissolved by the steam, thereby making maximum use of the carbon dioxide.

This fall I successfully tested the experiment with two chemistry classes. Although it is a simple experiment, the following procedures and precautions must be observed

1. Anyone near the experiment must wear safety glasses. Considerable steam is produced. Some of this steam condenses into water drops on the upper surface of the test tube. These drops run down into the hot end of the test tube and can evaporate explosively.

2. Check the right-angled glass tube to make sure it is not too pinched at the bend. This is especially important if students are doing the glass work.

3. Never conduct the experiment with a watery paste. Excess steam will be produced. Make a fairly dry paste. This paste can be used immediately. The upper surface of the test tube must be free of paste or calcium carbonate particles.

4. Use a test tube clamp or gloves to hold the water/pH indicator test tube. This test tube gets very hot.

5. Use a good burner with a trim, hot flame. After about thirty seconds of heating, a yellow glow should be beginning to show around the bottom of the test tube.

6. When heating the 25mm x 150mm test tube, keep it as vertical as possible to prevent particles of calcium carbonate/calcium oxide from being swept out through the tube. (A sudden base reaction in the water/pH indicator solution is an indication that this has happened. You will need to start over.)

7. Care must be taken not to allow water/pH indicator solution to be drawn back into the hot test tube. This will happen once most of the water is driven off the paste. As soon as you get a positive pH indication, remove the glass tube from the water/pH indicator solution. Always remove the glass tube from the water/pH indicator solution before taking the 25mm x 150mm test tube out of the burner flame.

8. Not all pH indicators are sensitive enough for this experiment. Test your indicators before giving a demonstration or assigning them to students. Fresh purple cabbage juice works well and is recommended.

❋ ❋ ❋ ❋

Crystal Reveals Unexpected Beginnings

by

J. Gorman

Birth is a tough process, particularly for crystals. Before a crystalline structure forms, atoms or molecules mingle in a solution, making and breaking attachments.

After enough particles gather in a cluster, and surpass a critical size, crystal growth speeds along.The initial clumping, called nucleation, helps determine a crystal's size, composition, and other properties. Scientists have developed theories about nucleation for decades, but they hadn't actually witnessed nuclei forming in solution until . . . .

At last, researchers report they've directly observed this early step in protein crystallization, and they were surprised at what they saw. The nucleus doesn't have the form that they expected, they report in the Aug. 3 *Nature*.

Peter G. Vekilov and Siu-Tung Yau at the University of Alabama in Huntsville used an atomic force microscope to view the protein apoferritin as it crystallizes.

Previous efforts at direct observation of nucleation in solution were thwarted because the crucial process can take place anywhere in the liquid and it happens very quickly.

To overcome these challenges, Vekilov and Yau waited for apoferritin clusters to approach the bottom of a glass cell where the researchers already had placed an apoferritin crystal as a docking point. When a cluster stuck, the team could study it at a resolution high enough for discerning individual molecules and for determining whether the cluster had the characteristics of a nucleus.

"The whole design of the experiment is very clever," comments David W. Oxtoby of the University of Chicago. "You're actually seeing the crucial step of something when it is first deciding, 'Okay, yes, I will become a crystal.'"

At the critical moment, a nucleus can gain or lose a molecule with equal probability. Vekilov and Yau observed clusters immediately before and after this point. "We have some aggregates which are smaller than the nuclei and some which are larger," says Vekilov.

They found that all of these clusters had roughly the same shape—a flat layer of apoferritin molecules with a few more molecules on top. Each such cluster looked like a raft containing some 20 to 50 molecules.

An apoferritin cluster is just smaller than a raftlike critical-size nucleus (left) and just larger (right). Each ball indicates a molecule about 13 nanometers in diameter. On the left, four rods, each made of four or five molecules, form a flat plane.
— (Yau and Vekilov)

"Since they all have this raftlike shape, we interpolate that the nucleus is also raftlike," says Vekilov. Nucleation theory has assumed that atoms and round molecules form spherical nuclei. Since apoferritin is roughly spherical, it therefore ought to form spherical nuclei as well. "Obviously, this is not the case," says Vekilov.

"Everyone has always assumed that these would be little round balls, and therefore all of the theoretical predictions of when you would see crystallization were based on these models," says Oxtoby.

"Now, you have to doubt everything," agrees Vekilov. Researchers can't just assume they know the structure of the nucleus of any crystallizing material, he says. And, he adds, more experiments are needed to verify or modify models of how solids form.

"There are many, many technological and health-related issues in which you want to control the rate of nucleation," says Vekilov. Protein crystallization plays a key role in diseases such as sickle cell anemia and cataracts, and researchers use crystallization when developing drugs. Scientists also grow crystals to determine a protein's structure through X-ray crystallography.

What's more, understanding crystallization could help engineers improve the strength of materials such as metals. "If you can control nucleation, you can control the properties of the metal," says Vekilov. And that, he adds, could lead to many technological improvements, such as stronger turbine components for jet engines.

In a lecture that stirred controversy throughout Britain, Prince Charles argues that we will never achieve sustainable development without a rediscovery of the sacred.

Prince Charles gave this talk at the conclusion of the annual Reith Lecture series which took sustainable development as its theme this year.

—David Mitchell

Sustainable Development

Sustainable development is a matter of enlightened self-interest. Self-interest is a powerful motivating force for all of us, and if we can somehow convince ourselves that sustainable development is in all our interests then we will have taken a valuable first step toward achieving it.

But self-interest comes in many competing guises, not all of which, I fear, are likely to lead in the right direction for very long, nor to embrace the manifold needs of future generations. I am convinced we will need to dig rather deeper to find the inspiration, sense of urgency, and moral purpose required to confront the hard choices which face us on the long road to sustainable development. So although it seems to have become deeply unfashionable to talk about the spiritual dimension of our existence, that is what I propose to do.

The idea that there is a sacred trust between mankind and our Creator, under which we accept a duty of stewardship for the earth, has been an important feature of most religious and spiritual thought throughout the ages. Even those whose beliefs have not included the existence of a Creator have, nevertheless, adopted a similar position on moral and ethical grounds. It is only recently that this guiding principle has become smothered by almost impenetrable layers of scientific rationalism.

I believe that if we are to achieve genuinely sustainable development, we will first have to rediscover, or re-acknowledge, a sense of the sacred in our dealings with the natural world and with each other. If literally nothing is held sacred any more—because it is considered synonymous with superstition or in some other way "irrational"—what is there to prevent us treating our entire world as some "great laboratory of life," with potentially disastrous long-term consequences?

Fundamentally, an understanding of the sacred helps us to acknowledge that there are bounds of balance, order, and harmony in the natural world which set limits to our ambitions and define the parameters of sustainable development.

In some cases, nature's limits are well understood at the rational, scientific level. As a simple example, we know that trying to graze too many sheep on a hillside will, sooner or later, be counterproductive for the sheep, the hillside, or both. More widely, we understand that the overuse of insecticides or antibiotics leads to problems of resistance. And we are beginning to comprehend the full, awful consequences of pumping too much carbon dioxide into the earth's atmosphere. Yet the actions being taken to halt the damage known to be caused by exceeding nature's limits in these and other ways are insufficient to ensure a sustainable outcome.

In other areas—such as the artificial and uncontained transfer of genes between species of plants and animals—the lack of hard scientific evidence of harmful consequences is regarded, in many quarters, as sufficient reason to allow such developments to proceed. The idea of taking a precautionary approach, in this and many other potentially damaging situations, receives overwhelming public support but still faces a degree of official opposition as if admitting the possibility of doubt was a sign of weakness or even of a wish to halt "progress." On the contrary, I believe it to be a sign of strength and of wisdom.

It seems that when we do have scientific evidence that we are damaging our environment, we aren't doing enough to put things right, and when we don't have that evidence we are prone to do nothing at all, regardless of the risks. Part of the problem is the prevailing approach that seeks to reduce the natural world, including ourselves, to the level of nothing more than a mechanical process. For whilst the natural theologians of the eighteenth and nineteenth centuries, like Thomas Morgan, referred to "the perfect unity, order, wisdom and design" of the natural world, scientists like Bertrand Russell rejected this idea as rubbish. "I think the Universe," he wrote, "is all spots and jumps without unity and without continuity, without coherence or orderliness." Sir Julian Huxley wrote in *Creation: A Modern Synthesis*, that "modern science must rule out special creation or divine guidance." But why? As Professor Alan Linton of Bristol University has written, "evolution is a man-made 'theory' to explain the origin and continuance of life on this planet without reference to a Creator." It is because of our inability or refusal to accept the existence of a guiding hand that nature has come to be regarded as a system that can be engineered for our own convenience, or as a nuisance to be evaded and manipulated, and in which anything that happens can be "fixed" by technology and human ingenuity. Fritz Schumacher recognized the inherent dangers in this approach when he said that "there are two sciences—the science of manipulation and the science of understanding."

In this technology-driven age it is all too easy for us to forget that mankind is a part of nature, and not apart from it, and that this is why we should seek to work with the grain of nature in everything we do. For the natural world is, as the economist Herman Daly puts it, "the envelope that contains, sustains and provisions the economy"—not the other way round. So which argument do you think will win—the living world as one, or the world made up of random parts, the product of mere chance, thereby providing the justification for any kind of development?

This, to my mind, lies at the heart of what we call sustainable development. We need, therefore, to rediscover a reverence for the natural world, irrespective of its usefulness to ourselves—to become more aware, in Philip Sherrard's words, of the "relationship of interdependence, interpenetration and reciprocity between God, Man and Creation." Above all, we should show greater respect for the genius of nature's designs, rigorously tested and refined over millions of years. This means being careful to use science to understand how nature works—not to change what nature is, as we do when genetic manipulation seeks to transform the process of biological evolution into something altogether different. The idea that the different parts of the natural world are connected through an intricate system of checks and balances which we disturb at our peril is all too easily dismissed as no longer relevant. So in an age when we are told that science has all the answers, what chance is there for working with the grain of nature?

As an example of working with the grain of nature, I happen to believe that if a fraction of the money currently being invested in developing genetically manipulated crops were applied to understanding and improving traditional systems of agriculture which have stood the all-important test of time, the results would be remarkable. There is already plenty of evidence of just what can be achieved through applying more knowledge and fewer chemicals to diverse cropping systems. These are genuinely sustainable methods. And they are far removed from the approaches based on monoculture which lend themselves to large-scale commercial exploitation, and which Vandhana Shiva condemned so persuasively and so convincingly in her lecture.

Our most eminent scientists accept that there is still a vast amount that we don't know about our world and the life forms that inhabit it. As Sir Martin Rees, the Astronomer Royal, points out, it is complexity that makes things hard to understand, not size. In a comment which only an astronomer could make, he describes a butterfly as a more daunting intellectual challenge than the cosmos! Others, like Rachel Carson, have eloquently reminded us that we don't know how to make a single blade of grass. And Saint Matthew, in his wisdom, emphasized that not even Solomon in all his glory was arrayed as the lilies of the fields.

Faced with such unknowns it is hard not to feel a sense of humility, wonder, and awe about our place in the natural order. And to feel this at all stems from that inner, heartfelt reason which, sometimes despite ourselves, is telling us that we are intimately bound up in the mysteries of life and that we don't have all the answers. Perhaps, even, that we don't have to have all the answers before knowing what we should do in certain circumstances. As Blaise Pascal wrote in the seventeenth century, "It is the heart that experiences God, not the reason."

So do you not feel that, buried deep within each and every one of us, there is an instinctive, heartfelt awareness that provides, if we will allow it to, the most reliable guide as to whether or not our actions are really in the long-term interests of our planet and all the life it supports? This awareness, this wisdom of the heart, may be no more than a faint memory of a distant harmony rustling like a breeze through the leaves, yet sufficient to remind us that the earth is unique and that we have a duty to care for it.

Wisdom, empathy, and compassion have no place in the empirical world, yet traditional wisdoms would ask, "Without them, are we truly human?" And it would be a good question. It was Socrates who, when asked for his definition of wisdom, gave as his conclusion "knowing that you don't know."

In suggesting that we will need to listen rather more to the common sense emanating from our hearts if we are to achieve sustainable development, I am not suggesting that information gained through scientific investigation is anything other than essential. Far from it. But I believe that we need to restore the balance between the heartfelt reason of instinctive wisdom and the rational insights of scientific analysis. Neither, I believe, is much use on its own. So it is only by employing both the intuitive and the rational halves of our own nature—our hearts and our minds—that we will live up to the sacred trust that has been placed in us by our Creator or our "Sustainer," as ancient wisdom referred to the Creator.

As Gro Harlem Brundtland has reminded us, sustainable development is not just about the natural world, but about people too. This applies whether we are looking at the vast numbers who lack sufficient food or access to clean water, or those living in poverty and without work. While there is no doubt that globalization has brought advantages, it brings dangers, too. Without the humility and humanity expressed by Sir John Browne in his notion of the "connected economy"—an economy which acknowledges the social and environmental context within which it operates—there is the risk that the poorest and the weakest will not only see very little benefit but, worse, they may find that their livelihoods and cultures have been lost.

So if we are serious about sustainable development, then we must also remember that the lessons of history are particularly relevant when we start to look further ahead. Of course, in an age when it often seems that nothing can properly be regarded as important unless it can be described as "modern," it is highly dangerous to talk about the lessons of the past. And are those lessons ever taught or understood adequately, in an age when to pass on a body of acquired knowledge of this kind is often considered prejudicial to "progress"? Of course, our descendants will have scientific and technological expertise beyond our imagining, but will they have the insight or the self-control to use this wisely, having learnt both from our successes and our failures? They won't, I believe, unless there are increased efforts to develop an approach to education which balances the rational with the intuitive. Without this, truly sustainable development is doomed. It will merely become a hollow-sounding mantra that is repeated ad nauseam in order to make us all feel better. Surely, therefore, we need to look toward the creation of greater balance in the way we educate people so that the practical and intuitive wisdom of the past can be blended with the appropriate technology and knowledge of the present to produce the type of practitioner who is acutely aware of both the visible and invisible worlds that inform the entire Cosmos.

The future will need people who understand that sustainable development is not merely about a series of technical fixes, about redesigning humanity, or re-engineering nature in an extension of globalized industrialization, but about a reconnection with nature and a profound understanding of the concepts of care that underpin long-term stewardship. Only by re-discovering the essential unity and order of the living and spiritual world—as in the case of organic agriculture or integrated medicine or in the way we build—and by bridging the destructive chasm between cynical secularism and the timelessness of traditional religion, will we avoid the disintegration of our overall environment.

Above all, I don't want to see the day when we are rounded upon by our grandchildren and asked accusingly why we didn't listen more carefully to the wisdom of our hearts as well as to the rational analysis of our heads; why we didn't pay more attention to the preservation of biodiversity and traditional communities or think more clearly about our role as stewards of creation. Taking a cautious approach, or achieving balance in life, is never as much fun as the alternatives, but that is what sustainable development is all about.

Cosmic Ray Studies on Skis

Science investigation letter – John Petering

excerpted from an article by Brian Jones, Department Physics, Colorado State University; in *The Physics Teacher*, Vol. 31, November 1993

Background

I would like to share the following interesting approach to a "real field investigation" possibly for the eleventh grade physics. In it, Professor Jones describes a fascinating approach to exploring how cosmic rays are "truly cosmic." A study of the complete article is highly recommended before attempting the experiment.

Robert Andrews Millikan is best known as the one who developed the famous "oil drop experiment" to determine the charge on the electron. But he was also recognized in 1927 on the cover of Time *as the one who "detected the cosmic pulse" of extraterrestrial rays.*[1]

Professor Jones points out that Millikan gives a good summary of the early ideas about cosmic rays, as well as a readable story of much of early twentieth century experimental physics in his book Electrons . . . and Cosmic Rays.[2] *Excerpts from this book might be helpful background reading for students.*

Early on, physicists typically measured radioactivity using an electroscope, which lost its charge when exposed to a radioactive source, due to ionization of the insulating air caused by passage of α, β, *or* γ *rays. But researchers also established that electroscopes discharged even when there was no known source of radioactivity present. This led to puzzles about the nature and source of these unknown "rays."*

Experiments with balloons, or even atop the Eiffel Tower, showed the discharging rate generally decreased with increasing height, implying that the radioactive source was within the Earth. However, later experiments at greater altitude revealed the discharge rate increased again! No daily variation was observed, which implied that the Sun was not a possible source. Thus, after many other experiments, it seemed the rays were of truly cosmic origin.

Professor Jones attempts to show by several simple experiments that a component of the background radiation is indeed extraterrestrial. The first of these is described below.

Field Work I: The Ski Trip

A key finding of early researchers was that the level of ionization observed in their electroscopes actually increased with altitude—this was a clear sign that at least some component of the radiation had to be coming from a source other than the Earth. Most of the early experiments were done with balloons. This is not feasible for an undergraduate lab experiment, so we turned instead to the Rocky Mountains just west of Fort Collins. I found that an earlier generation of students at Colorado State University had done an experiment in which the background radiation intensity had been measured as a function of altitude by driving over Trail Ridge Road in Rocky Mountain National Park. Since the peak of the road is well over 2000 meters above our elevation in town, some difference was observed. There were, however, two serious difficulties with this approach. A practical difficulty was that the road is typically closed by snow from late October to late May—and thus was not available for a spring semester class. The second difficulty was that local sources of radioactivity from the Earth can mask the effect that we would be looking for. One of our students took data on the background radiation at different elevations in Rocky Mountain National Park and was not able to find a consistent trend with altitude, which we attribute to varying local sources of radioactivity.

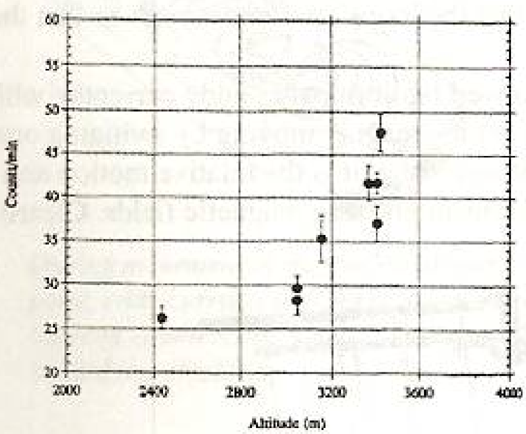
The solution to this Earth background problem was obvious to Coloradans. We were interested in the component of radiation *not* coming from the Earth and so wished to shield our detectors from radiation sources in the ground. It turns out that our mountains receive an impressive level of shielding in the winter in the form of snow. For a dense snow base of more than 1 meter, the background gamma intensity received from the Earth is reduced by as much as 95%; this depth of snow or greater is typical at ski areas. On a ski hill, with the snow cover, most of the background radiation seen comes from cosmic rays, effectively isolating this component for study. To verify the shielding effect, students measured background rates at similar altitudes at the bottom of a ski hill and from a location nearby where the snow had been plowed. The data from the plowed area showed a significantly higher count rate, as would be expected.

I decided with the class that a ski trip would be in order. At a ski area, we could effect a large change in altitude in a short time over a short horizontal distance, and we would be shielded from background sources that would tend to mask the effect of the variation of radiation with altitude that we were looking for. The students were quite enthusiastic about the idea, and I gained a certain satisfaction from knowing that a day of skiing could be so nicely justified.

We chose to make our measurements at Vail, Colorado. The management was kind enough to offer us a very favorable rate, and the vertical drop possible was nearly 1000 m (over 3000 ft.). Students took turns using a portable Geiger counter to measure background counts per unit time as a function of altitude, skiing down and riding the lifts up to reach different parts of the mountain at different elevations (see photo, right). This made for an excellent class outing.

Student taking an altitude reading from the barometer while recording a ten-minute count of background radiation

The data that *we* obtained, which were shared by all members of the class, clearly showed the trend in the background radiation as a function of altitude (see graph below). The clear signal of increasing levels of radiation with altitude showed us (as it did the early investigators) that the latter two hypotheses had to be valid (sources distributed throughout the atmosphere or from an extraterrestrial source). Either the reduced thickness of the atmosphere at higher altitudes was allowing more extraterrestrial rays to come through or higher concentrations of natural radioactivity were present at higher levels in the atmosphere. Students were then given the task of choosing and making a measurement that would favor one or the other hypothesis.



Field Work II: Shielding

Further parts of the investigation studied the penetrating power of the radiations, and (as Millikan found in 1935) some were far more penetrating than any known natural source, thus radioactive isotopes suspended in the atmosphere could not explain the variation observed with altitude. *These are described in the article, which should be studied if you want to do some of this work.*

Some other interesting further references on cosmic rays are given below.[3,4]

Endnotes:

1 *Time* magazine, April 25, 1927.

2 R.A. Millikan, "The Discovery and Origin of the Cosmic Rays" p. 6, in *Electrons, Protons, Photons, Neutrons, and Cosmic Rays*, University of Chicago Press, Cambridge and London, 1935.

3 M.W. Friedlander, *Cosmic Rays,* Harvard University Press, Cambridge and London, 1989.

4 NCRP Report No. 45, *Natural Background Radiation in the US* (National Council on Radiation Protection and Measurements), Washington, DC, 1975, p. 63.

Experiment 1

Lentz's Law Demonstrations

Three Faces of Lentz's Law

Simple Activities in Eleventh Grade Physics

Early in the eleventh grade physics block, we often study magnetic fields as an expression of current and then investigate mutual induction and the transformer. The following step often shows how an induced current creates an induced magnetic field which exactly opposes the originating magnetic field. This has practical application in "back EMF" limiting the speed of an electric motor. But we can note how initial current (or electromagnetic field) calls forth a counter-balancing electromagnetic field—Nature maintain the balance.

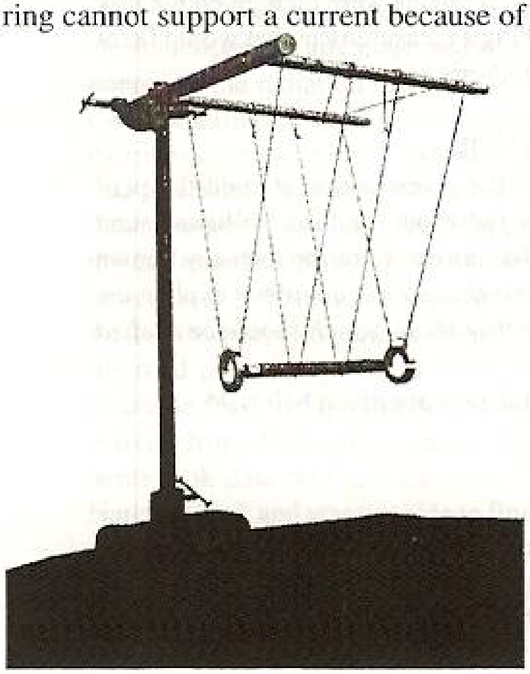
"Jumping Ring"

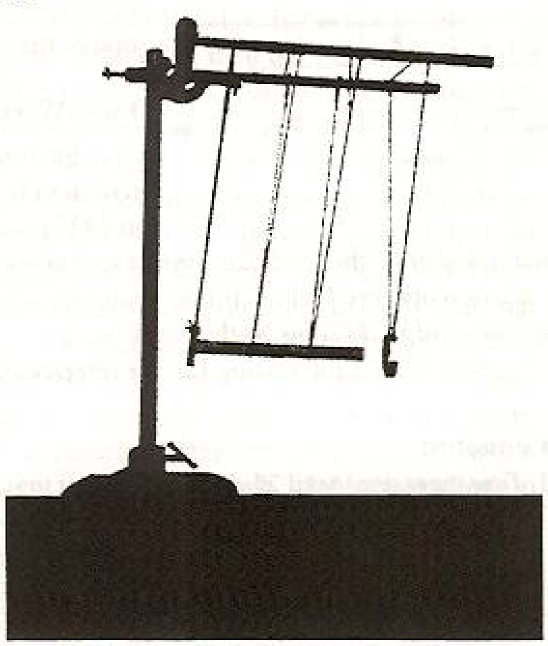
One classic demonstration uses a primary coil with a vertical iron core, and a non-ferrous metal ring (copper or aluminum) slipped on. When the coil is energized with AC, eddy currents are induced in the ring, forming a magnetic field which opposes the source magnetic field, at each instant. As a result, the ring jumps up and perhaps even off the iron core. However, if you don't have the 500-turn coil on hand, there are two other versions which can be done with simple equipment but are just as effective, as follows.

Swinging Rings

One way requires a magnetic rod and two non-ferrous metal rings (one sawed through) as shown below. This was described some years ago[1] and the apparatus was even once sold through Sargent-Welch. But, alas, it seems it is no longer available; however, it is easily produced from hardware components. The rings should be rather thick (aluminum washers 4.6 cm diam. and 0.3 cm thick). Both the magnet rod as well as both rings are suspended with string loops from two support dowels. It is important that the loops are long enough so that the path of the swinging objects is a very flat arc (nearly a straight line).

First we allow the magnet to swing; the split ring will not be moved (split impedes eddy currents), while the solid ring will start oscillating along with the magnet. Then, try to get the magnet moving by swinging one ring or the other; again, only the solid ring will be effective. This emphasizes that it is the relative motion and not any one individual part that causes induction of eddy currents and thus interacting magnetic fields. Clearly the split ring cannot support a current because of the break.



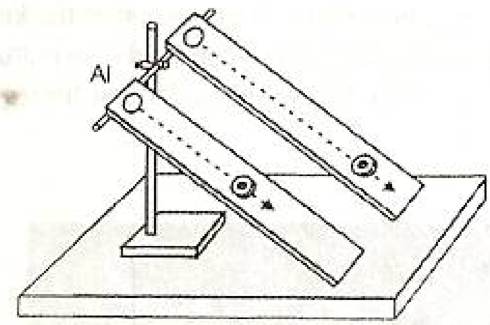


Apparatus for demonstrating Lentz's Law: (left) system at rest; (right) magnet in motion.

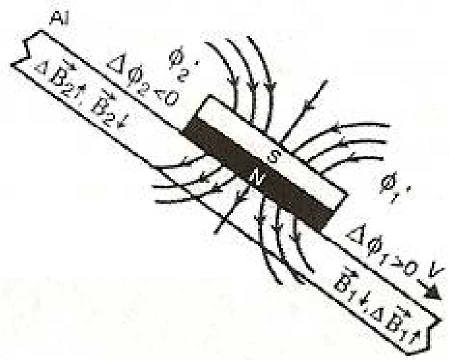
Magnet Race

Another popular setup uses an aluminum tube with a cylindrical "cow magnet" falling inside it. But this is problematic since students cannot see the action inside. An elegantly visible and simple setup was described recently[2] which uses two flat ring magnets, a sloping aluminum raceway (50-100 cm long, 10-15 cm wide), and a plastic raceway of the same size. As the figures illustrate, when the magnets are released from the same height at the same time, the flux in the aluminum at the leading edge of the magnet is increasing and induces a current and magnetic field which opposes the approaching magnet—thus causing the magnet sliding on the aluminum to consistently lose the race 1-2 cm behind the ring magnet on the plastic track.

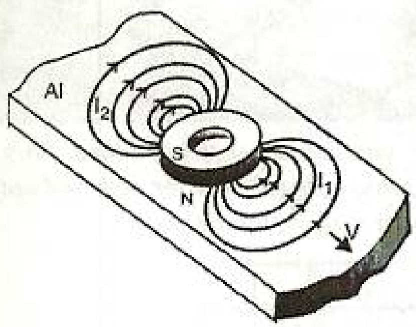
We hope your students have fun at the magnet races.



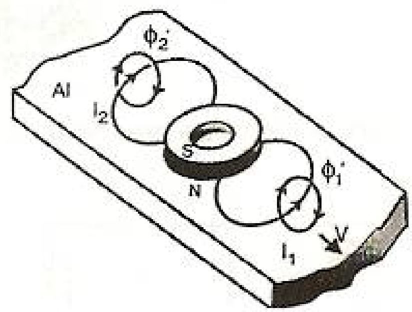
Placement of two identical magnets on two inclined plates (one wood, one aluminum) that form angles with the horizon.



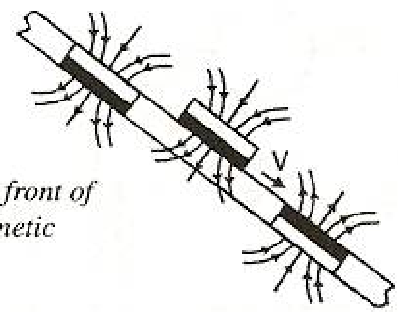
During descent of magnet on aluminum plate, magnetic flux in front of magnet increases while that behind the magnet descreases.



During movement of magnet on aluminum plate, eddy currents in front of magnet are induced counterclockwise while those behind are clockwise.



Sketch of induced magnetic flux in front of the magnet and behind it



Repulsive magnetic forces arise in front of sliding magnet and attractive magnetic forces behind it.

Endnotes:

1 W. Connolly, *The Physics Teacher*, Volume 28, January 1989, p. 50.

2 D.T. Ivanov, *The Physics Teacher*, Volume 38, January 2000, p. 48.

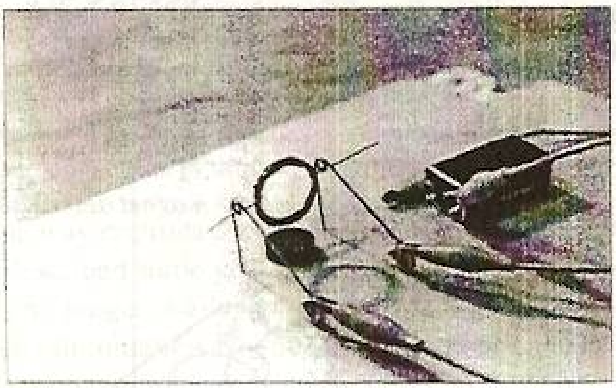
Experiment 2

Mystery Motor Demystified

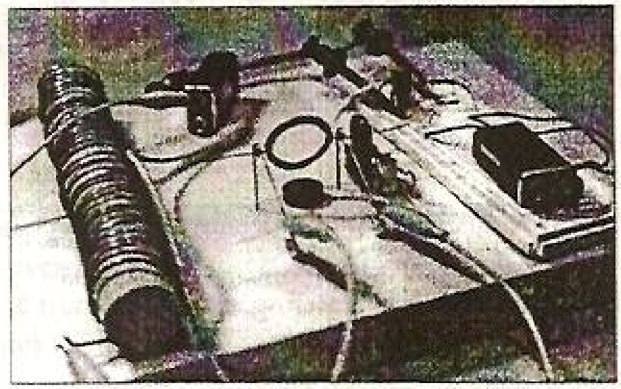
Note on the Physics underlying the "brushless safety-pin motor."

There are several science kits which provide a ridiculously simple motor, consisting of just a small one-inch diameter coil with fifteen turns of wire, whose leads form mechanical supports but with no commutator. Still, the motor runs quite well. But how is this possible?

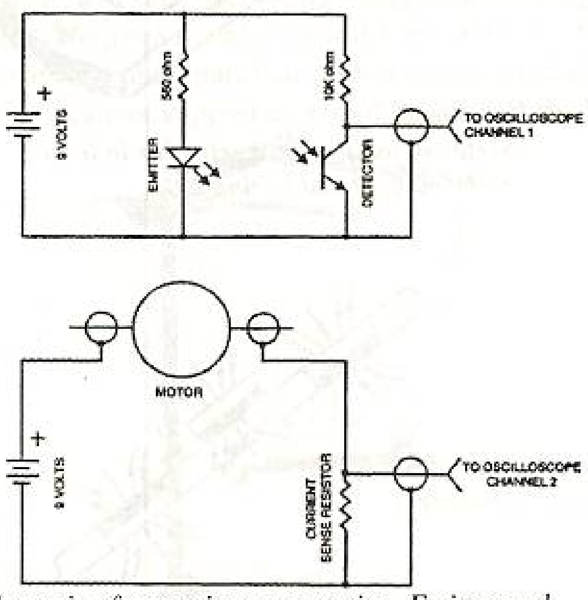
This mystery was investigated by a college physics lab, and their recent report[1] describes the clever way they studied the mechanical and electrical behavior to determine how the motor works. It appears that the key is that the rotating coil is naturally unbalanced and so will 'jump up' losing contact with the conductive armature, and re-establishes contact at the part of its rotation when the heavy side is down. So, we get a driving force only in one direction, keeping the coil rotating without a switching commutator.



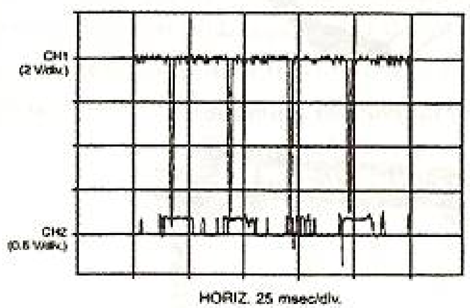
Mystery motor with ceramic disk magnet below wire coil



Mystery motor with instrumentation added. Large coil at left is current-sense resistor. Shutter disk and optical interruptor are at right of motor coil.



Schematic of motor instrumentation. Emitter and detector are part of optical interrupter.



Oscilliograph of motor operation. Upper trace (CH1) shows negative going pulses as heavy side of coil passes bottom. Lower trace (CH2) displays motor current.

Endnotes:

1. A.F. Klittnick and M.J. Rickard, *The Physics Teacher*, Vol. 39, March 2001