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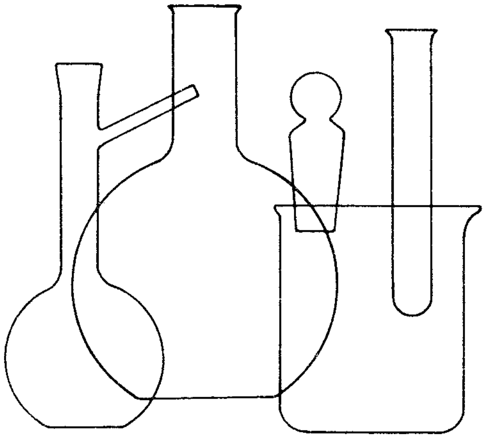

# CHEMISTRY
# IN THE
# TWO-YEAR
# COLLEGE

VOLUME XIII 1974

2YC₃ COMMITTEE ON CHEMISTRY IN THE TWO-YEAR COLLEGE
DIVISION OF CHEMICAL EDUCATION • AMERICAN CHEMICAL SOCIETY

# Foreword

This issue of Chemistry in the Two Year College includes papers given in 1974 at the various conferences. The theme of the Pasadena meeting was "A new Look at Old Ideas". The Program Chairman was Wanda Sterner and Bill Timberlake was the $2YC_3$ Proceedings Editor. These people were responsible for organizing the program and reporting it to us. Getting all the papers together is not an easy job. Often we forget that many people help to get this job done by serving as recorders. In Pasadena Joan Stafford, Virginia Schelar and Jack Hileman served as Recorders.

The Canadian meeting at Regina was a very large meeting with many fine papers. The Program Co-Chairmen were Graham Welch and Jans Diemer. Included in the program was a Symposium entitled "New and Old' The Balance Traditional and Innovative Approaches to Chemical Education". The $2YC_3$ Proceeding Editor was Douglas K. Jardine and he did a wonderful job in the gathering of the papers.

The third conference was held in Houston, Texas. A Symposium with the theme of "Nuclear Power - Today and Tomorrow" was one of the most exciting we have heard. It was under the leadership of Edith Bartley as Program Chairman. John Mitchell was the $2YC_3$ Proceedings Editor and the papers came to me sooner than any conference to date.

All of these people have played a key role in helping to put the journal to press and we want to thank them for a job well done. Each of these programs were organized under the guidance and coordination of Ethelreda Laughlin as Chairperson of the Committee on Chemistry in the Two-Year College.

We hope that all of you will support the Division of Chemical Education, after all we as teachers in two year colleges play a significant role in chemical education. Tom Lippincott, editor of Journal of Chemical Education is showing his support by introducing a $2YC_3$ feature column in the journal 4 times a year. The Journal of Chemical Education must be an important tool for all chemistry teachers and we encourage you to use it.

In Volume XI of our journal we suggested a new feature which we called "Innovative Images". We have received only one response and it is included in this volume of our journal. We would like to hear from more of you and share your ideas with our readers.

Jay Bardole
Editor

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# HIGH SCHOOL – COLLEGE INTERFACE
## WHITHER the Fads in Science Teaching

R. W. Parry
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Presented to a General Session of the Thirty-eighth, Two-Year College Chemistry Conference, Pasadena City College, Pasadena, California 91106, March 30, 1974.

It is a real pleasure to be given the privilege of speaking to this first meeting sponsored by the Committee on the High School-College Chemistry Interface. I was Chairman of the Division of Chemical Education of the American Chemical Society when this committee was created and I have more than a casual interest in its success. Most teachers of science are agreed that education is best when it occurs as a more or less continuous process rather than as a series of spectacular "symmetry forbidden transitions." For that reason education is well served when teachers know what their students have had and/or will receive in a given subject area. Using this philosophy, the Division of Chemical Education created the committee on the Two Year College about eight years ago. Bill Mooney of El Camino College was named Chairman of the organizing committee. As a result of vigorous efforts by Bill and members of his committee, the Two Year College Program has become one of the best in the Division of Chemical Education.

In an effort to make a similar link to the high school community, with whom we in four year college teaching also share problems and subject matter, the Division of Chemical Education created the Committee on the High School Chemistry-College Chemistry Interface. An excellent committee including Ted Molitor, Chairman, Art Campbell, Jim DeRose, Phyllis Dietz, Allene Johnson, Ed Larsen, and Dick Whitney was appointed. We tried to get representation from both high school and college teachers as well as representation from different parts of the country. They are off to a fine start and the A.C.S. certainly wishes them well in their efforts to bridge the high school-college gap. Full cooperation of The Society is assured.

So much for the background, let me now consider with you the topic of "Fads in Science Teaching." America is very susceptible to fads or crazes of all kinds. All of you can remember the era of the Hula Hoop, the skate board, the quotations from Chairman Mao's Little Red Book, etc. Usually such a fad rises to a resounding crescendo, makes lots of money for a promoter, then slips quietly into oblivion. A few such fads may, however, leave a mark on the society which spawned them. A few years ago protesting among college students--even burning buildings-grew to a form of a fad encompassing a relatively small group. The beard or long hair become the badge of this group (as well as of rock singers) and it was rapidly adopted by others until it influenced the hair styles of the nation. The protest movement left many very good, as well as some very bad legacies to the years that followed.

Today the raging fad is streaking. A lot of people, like me, accept this fad as a rite of spring. I do not share the view that it represents a moral crisis in our nation. I was particularly amused by the news report that a coed streaker, who was modeling a smile, was apprehended by the police on the campus of a southern college. Immediately the days of King Arthur and the Knights of the Round Table returned. Two hundred pushing, threatening males surrounded the police car until the coed was allowed to complete her 400 yard dash back to the dormitory.

Is science above all of these fads? Not at all, but unfortunately, very few chemistry buildings are streaked. Fads in science, like the protest movement which centered on an unpopular war, usually are triggered by some socially significant event. Science and science education are too large to be displaced violently by any events other than the most significant ones. Thus major national or international fears usually can be found as background for fads in science teaching. One might raise the question, are fads good or bad? The answer is easy--they are both, good <u>and</u> bad. Some have more good; others have more bad. Each must be analyzed with an open mind. Let's look at some of the fads of the past few years.

In the late 50's the Russians orbited Sputnik. Almost immediately the nation began to worry about the "science gap." The public was frightened and education which had been studiously ignored, suddenly became a national problem. The Congress, almost in a spirit of panic, opened its purse to the National Science Foundation and said,"Teach the kids about science, but don't bother us. We are too old to learn." You all know the result. A number of programs in Physics, Math, Chemistry, Biology, and Geology were initiated and funded. New Math is now used to work out national budgets. Don Phillips of the Science Education Office of the American Associate for the Advancement of Science very neatly described these projects as "discipline oriented, content centered, with an inquiry approach." He also noted, "Science educators, with government financial support, had adopted a policy to produce a group of highly knowledgeable and highly trained scientists and had decided to begin this training as early as the elementary grades." He goes on, "As we move into the 70's curriculum developers, science educators, and indeed the lay person, are questioning some of the emphasis of science education in the 60's."

What is the background of the questioning? Let us explore. As a result of the social protest of the sixties, many of the traditional values of society were questioned. Science, because of its direct connection to all branches of the real world--including military operations--was brought under public scrutiny and attacked as a heartless or pointless exercise which had no concern for the individual and the real problems which he faced twenty-four hours a day. Scientists were charged with all of the evils of pollution, even though the public is even now completely unwilling to give up any of those gifts from science and technology which have been so roundly berated. I am told of a group of students, who were so incensed by the evils of the automobile as a polluter, that they dragged a car--(in less than perfect condition)--into an intersection, using a truck. They assembled as a group around the car after arriving in automobiles, then they ceremoniously ignited the car as a protest, let it burn in a glorious pillar of smoke, as a symbol of their contempt for its ability to pollute, then they climbed in their cars and went away blaming Science, General Motors, the Educational System, and Lyndon Johnson for the world's problems.

Scientists and science educators were understandingly amazed and distressed at their sudden and shattering fall from the pillars upon which society had placed them. New fads and new language became the magic litany for the pentitent scientist. The language of the pentitent is again neatly presented in the following quotation from a recent article in Science. I quote, "Training future scientists and technologists capable of analyzing problems of the world, and confronting these problems demands major changes in the discipline oriented curricula now being used. Science education, indeed all education, must develop in the students both an awareness of the difficulties facing our society and the capability to contribute toward their solution.

A curriculum attempting to accomplish these ends must be multidisciplinary and must concentrate on developing problem-solving ability." Let us look at the prescription in this--the latest of fads centering on the problems of society.

(1) Education must develop awareness of difficulties facing society. (Apparent from waiting in a gas line or from a look at an eye-burning smog layer.)

(2) Must develop capability to contribute to solution. (Agreed, but <u>How</u> is question of debate.) Will say more later.

(3) Must have major changes in a discipline oriented curriculum (now being used) to a multidisciplinary one. (Same course or different ones?)

(4) Concentrate on developing problem solving ability. (Good if one can do it.)

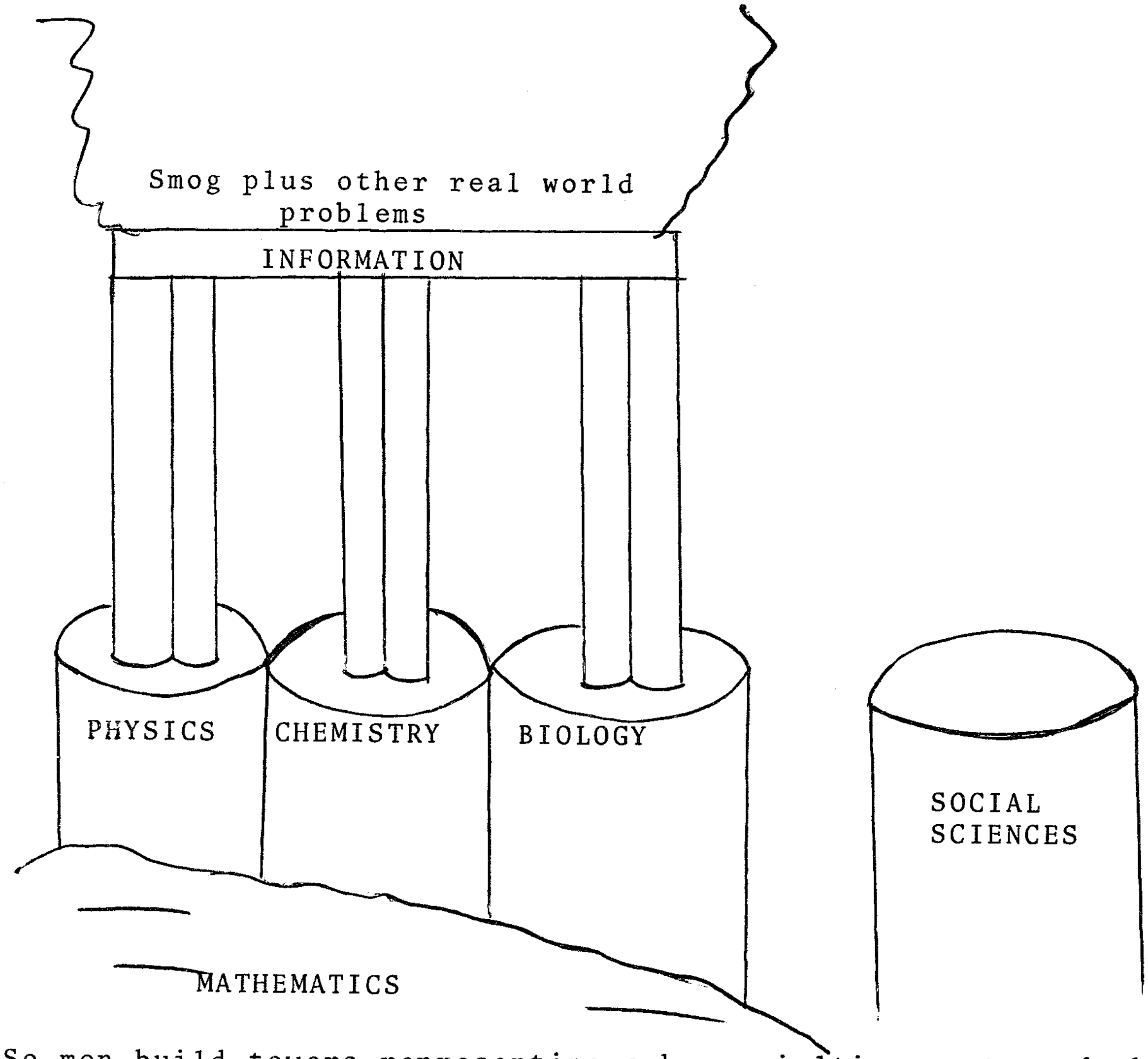
In general I believe that students are aware of the problems of society from their everyday life. The major thrust of education must be to develop a capability to contribute to their solution. Most people would indeed agree that help to solve the problems would be welcome. Is a broad and multidisciplinary training for the student the way to go? I do not think so and let me tell you why. The problems of the real world are extremely complex and are not susceptible to solution by superficial methods. Let me give you one example of this which recently came to my attention. Photochemical smog is a problem which we all recognize. Most people, even those with a minimum of chemistry, know that this is somehow connected with oxides of nitrogrn and that these come from cars. In our classes discussing equilibrium we show that the theorem of LeChatelier leads to the conclusion that NO can be formed from air by very high temperatures. Automobile cylinders provide conditions for the reaction:

$$N_2(g) \; + \; O_2(g) \; + \text{energy} \longrightarrow 2NO\ (g)$$

We then note that NO is a reactive colorless gas which turns to a brown gas, $NO_2$, when a stream of the NO is allowed to escape into the air. We can even show the experiment. We can then state that it is this $NO_2$ which is acted upon by sunlight to initiate photochemical smog. This is great information except for one thing--a major part of it is not true. NO produced in an automobile cylinder in the parts per million range is not oxidized to $NO_2$ in air. Why? The answer is a complex one which is misunderstood by most chemists as well as students and it centers on a very subtle point of kinetics.

The rate of conversion of NO to $NO_2$ is given as $k\,[NO]^2\,[O_2]$. Note that the rate is dependent upon the square of the NO concentration. Mechanistically we picture that two molecules must collide with an oxygen molecule, not one. If NO concentration is in the parts per million range, the probability that two molecules will collide with one oxygen molecule is vanishingly small. The reaction is so slow that $NO_2$ would not be present in significant quantities if it were not for more complicated processes which involve hydrocarbons, water vapor, light, etc. The problem is much too complicated for a superficial analysis. As Dr. Jack Calvert, one of the most knowledgeable men in the world on this area[2] has pointed out, we do not really understand many features of the complex processes involved. We do not need generalists. We need many highly trained specialists covering many different disciplines who can talk with each other. We are truly at the frontier of knowledge in most of our really significant practical problems. Maybe our discipline oriented training is not really so terrible after all. I visualize this problem with a rather graphic model. (Fig.1).

The disciplines of Physics, Chemistry, and Biology can be visualized as gigantic poles driven down to the bed rock of mathematics by the labor of many thousands of people who have gone before. The identification and makeup of the discipline reflects in some way the success different investigators of an earlier era had in correlating their observations, theories, and models. Pieces were broken out and collected into chemistry when the whole of science became too hard to understand by any one man. Standing on the general foundations of any one of these disciplines we look at our real world problems. They are fuzzy and confused. Our ability to understand and solve is dependent upon getting closer.



So men build towers representing sub-specialties up toward the problems above. These towers are built by specialists and must be firmly based on the rock-solid foundations of the major disciplines, not on a jury rigged interdisciplinary background which will sway and collapse when the winds and pressures come up. From the solid sub-towers up near the problem, men can pass planks of information back and forth to link the specialties and the specialists, and to increase the probability that the very complex problems of the world can be solved. Now men are up to the level where their input can be useful. Good solid, discipline oriented science is not out of date nor is it poor training for today.

Let me close by referring to a fairly recent report in Science[3] which I believe illustrated my point. In 1965 Harvard medical students spent two years studying such basic science as biochemistry, anatomy, pathology, pharmacology, etc. They were consistently at the top of National Board Exams in all of these disciplines. In 1968, after a very careful and very well prepared study, a new "core arrangement" was instituted in which the training centered around organ systems of the body---a multi-disciplinary approach if you wish. Grades were abolished and desire to learn was substituted as the only motivating factor. This year the faculty reinstituted grades[3], over student objections (75% students liked the no grade pattern) and began to return to the discipline oriented basic science courses rather than the multidisciplinary approach. Reasons given were

(1) poor performance of students on National Board Exams which the faculty felt were fair and meaningful: Harvard students dropped from first to tenth and fifteenth, etc., as a group in the nation.

(2) critics of the core felt that the general level of student preparation for clinical subjects was lowered and they were successful in convincing their colleagues that this was a real phenomenon.

The debate over the Harvard Medical curriculum is still in progress and emotions are running high on all sides of the question, but the data accumulated so far do not lead one to believe that the day of the discipline oriented approach is over. This trial at least was not a resounding success, though it may have had many good features in it.

In short, I wonder if the new complex problems of the 70's call for abolition of discipline oriented studies. In my opinion, our problems call for even more careful training of specialists, with that training locked into the secure disciplines of modern science. For very hard problems we need very bright, very well trained people. We can deliver.

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# INSTRUCTIONAL METHODS

## Motivation: A New Look at an Old Idea

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Presented to a Symposium on Aiding the Learning Process at the Thirty-Eighth Two Year College Chemistry Conference, Pasadena City College, Pasadena, California 91106, March 29, 1974.

The reason there are so many ways to be a good teacher is that students react most to what they "sense" rather than "do." When I sense being competent and successful in my teaching I get a really good feeling about what I am doing. These feelings are important to me so I do what I can to maintain them. It is not out of a sense of duty that I invest more time and effort in my work than is asked of me. It is because I always enjoy the good feelings I get when I feel I have been competent and successful doing something that is important to me. These feelings are primary motivators in my life.

Students also want to feel competent and successful. When they sense competence and success doing things that are important to them, they are willing to produce whatever output is required in order to maintain those feelings.

Five ingredients of the chemistry program at M.S.J.C. which I consider to contribute to an atmosphere in which a student can "sense" competence and success are.

1. having units of study described by specific course objectives organized into verbal, quantitative, and laboratory-activity categories

2. maximizing the degree to which the students can accomplish the course objectives independently

3. requiring the student to demonstrate mastery of each unit for which he is to receive credit; and requiring a minimum level of mastery as prerequisite to the study of succeeding units

4. providing earned units of credit in proportion to the number of units mastered by the student

5. clarifying the reasons that make the course important to the student and the instructor; and identifying elements that enhance the student's perception of his capabilities, and that enable the instructor to help the stu-utilize more of his potential

We all like knowing what is expected of us by those who evaluate our work. Thoughtful, justified, clearly stated objectives, grouped according to the basic performance skills required for mastery, give the instructor and the student a common direction and help both identify areas of difficulty. When well written objectives are used, the instructor feels comfortable-even confident in his role; and the student gets a "Hey, I can do this," feeling.

Specific objectives are a starting point for the instructor who intends to evaluate a student's performance, but they fall short of their intended purpose when they are not accompanied by resource materials that enable students to accomplish their assigned tasks. It is also important that resource materials enable students to accomplish their assigned tasks with a minimum of dependence upon the instructor. Sensing "I learned it on my own" contributes a lot to my feeling of self-confidence and self worth.

When I know I have described, explained, compared, contrasted, evaluated, analyzed, computed or performed every learning task for which I have received credit my sense of competence is heightened and my feeling of personal accomplishment deepened. Knowing that I can try again if I fail - that I can try until I succeed- changes my perception of evaluation from threat to challenge. It should be pointed out that total mastery evaluation is less convenient for the instructor than testing based upon sampling, but it is more conducive to the development of student competence.

The general college chemistry course at M.S.J.C. is divided into five one-semester hour units, each defined by objectives. Students are encouraged to earn the five units. However, if a student is unable to do so during the semester he may request to receive credit for the number of units successfully completed. When a student completes fewer units than the number for which he is registered, he receives a credit/no credit grade. Letter grades are given only to students who complete the number of units for which they register. A student may enroll for the remaining number of uncompleted units any semester the course is offered.

This variable credit plan has been popular with students because they feel it is an equitable means of obtaining credit for what they have invested in the course and an acceptable alternative to failure. They believe Bob Dylan when he sings "there's no success like failure and failure's no success at all."

Use of this plan has been encouraged by the Administration because it contributes to a more precise measure of the institution's educational productivity in terms of total units of credit earned.

A management-by-objectives system cannot be successful without identifying significant constraints which keep students from achieving all that it is possible for them to achieve. Studies made at M.S.J.C. have shown "lack of motivation" as a principal constraint keeping students from achieving full benefits from classes taught by this system. The self-actualization process is a highly structured, positively oriented group process which seeks to increase student achievement and teaching and teaching effectiveness.

The process increases student achievement by:

1. developing the student's understanding of his value system, what his primary motivators are and how to positively reinforce those motivators

2. developing techniques for long-range and short-range goal setting

3. providing a vehicle for assessing personal, intellectual, and social assets, and for utilizing these strengths to reach realistic, positive goals

4. instigating changes in self-perception which lead to increased motivation

5. increasing satisfactions and positive feedback from interpersonal relationships

The process increases instructional effectiveness by:

1. increasing the instructor's skill in identifying strengths in a student; and encouraging positive reinforcement of those strengths

2. increasing the instructor's understanding of his own value system and how his classroom instruction may be influenced through values held

3. providing an objective method, based upon values and strengths, to define areas of conflict and to resolve these conflicts

4. instigating changes in self-perception and perception of others which provide new dimensions to the instructor, thereby increasing his effectiveness in student relations

My teaching of chemistry at M.S.J.C. is quite traditional. It differs not so much in what the student does as in what he "senses" he is doing. The present course structure contributes more toward the goal of students feeling good about themselves and the subject than did the course structure I used previously as measured by student retention and units of work completed. Students tell me it provides an extra pay-off by combining grades with good feelings. I accept as fact, motivation plays a major role in human achievement. Experience convinces me that a course can be designed to have a positive influence on motivation.

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# Single Concept Games

Karen Timberlake
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Presented to a Symposium on Aiding the Learning Process at the Thirty-Eighth Two Year Chemistry Conference, Pasadena City College, Pasadena, California 91106, March 29, 1974.

Over the past few years, I have become concerned about some of the difficulties which my students were having with chemistry, particularly in the non-majors class and the chemistry for health sciences where the students have no background in chemistry, and no requirement for any future chemistry classes. I began to find that some of the problems repeated their pattern every semester and I sought to define some of these problem areas.

Many of the students seem to have and would even express strong feelings of fear, doubt and anxiety toward the subject of chemistry. For most, the class is a requirement in preparation for an allied health career. These students are very excited about health and medicine with many already working in a medical setting, but they do not include chemistry in their excitement. They seem to question their own capabilities to possibly cope with the subject matter.

I am not sure of all the reasons for this, but I can try and make a few guesses. For some, a poor background in math seems to inhibit their understanding or confidence to understand. Many however, score above 80 or 90 on the SCAT examination. Many have simply not come in contact with chemistry, and in several instances, even steered clear of chemistry. 80% of the class is made up of women and many seem to accept as fact that chemistry is not meant to be understood by them. In still other cases, a student has had a painful experience with chemistry or science. In every situation, there seems to be a block or a negative attitude toward chemistry and as a result, I see a student who is afraid of chemistry, afraid to try, tense because chemistry is required and learning little chemistry.

When a student has been successful in the class, I noticed an increase in confidence, in the effort to achieve, and better test scores. Parallel to this success was a change in the attitude of the student. Many students have been shocked to find that at the end of the semester, that they were actually enjoying chemistry and were sorry it would soon by over. Students have changed majors from art, nursing and home education, to a field in the sciences, and done well in subsequent chemistry courses.

I began to wonder if I could improve the learning capability of more students by trying to alter the student's initial response to chemistry given that a negative attitude was indeed blocking a successful learning experience. Would a change in attitude and development of self-confidence to chemistry aid in developing a positive learning framework? Could I recondition the student from a negative attitude about chemistry to a more positive attitude thereby improving learning potential?

I became aware that in the first 5-8 weeks of class that I spent a great deal of time aiding students to unlearn old attitudes or responses. Through much encouragement and positive reinforcement for even the smallest step in progress, I realized that a process of extinction or unlearning of previous behavior was necessary before the student and I could communicate more effectively. So, now my semester starts slow while I provide as many successful chemical experiences as I can, and then moves faster as I see and feel the increase in confidence and desire to learn along with a decrease in negative attitude.

I also began to look for a way to speed up this extinction process and was reminded of a math game which I had seen operate several years ago. A young friend of ours in the 3rd grade gifted class, was having difficulty with multiplication and division, and resisted taking the time to drill. Even during a drill, she would make the same mistakes over and over. The math lab in her elementary school taught her a card game based on the processes of multiplication and division. The game was played with other people and the first one to get through the math demanded by the numbers on the cards was the winner. She played constantly, and the resistance to learning the multiplication tables faded. She learned her tables rapidly and thoroughly enjoyed the time spent. She has since continued to get top grades in math, and I have not yet seen any further negative attitude or resistance toward learning math.

So I wondered if some type of game would help my students learn some of the basic concepts in chemistry. My students had a similar negative attitude which I felt was blocking their learning behavior even though they were 28 years old instead of 8. Perhaps some single concept games could bring about some changes in attitude. I began to bring games into the laboratory at the same time the concept was begun in the lecture.

Since most students have pleasant associations with old games, a relaxed atmosphere was achieved. The rules for the games are related to development of single chemical concepts which satisfy a set of behavioral objectives. The students must recognize and verbalize the chemical terminology in order to play the games, and then must reach a goal indicating the learning of a chemical concept in order to win a game. The other students in the game may correct errors. Correction by a member of one's peer group is much less traumatic than the same correction by the teacher.

The cards and dice seem to represent something concrete and real to the students which can be moved about, combined or separated. Increased visualization seems to hasten internalization of the concepts. Along with meeting certain behavior objectives related to the subject, I see positive attitudes develop out of the games as the student encounters many opportunities for positive reinforcement. The games lead to successful achievement and participation in a chemical idea, and there is a minimum of negative experience during this very critical learning period.

When a learning game is introduced, it is followed with a worksheet for the students to complete as well as appropriate laboratory exercises. The worksheet is completed faster, and with fewer questions, less hesitancy and less confusion than observed in previous semesters. The laboratory was approached with more confidence and understanding.

The initial feelings and fears have given way to a desire to learn and a belief by the student that the material will eventually be understood and does not give up. For me, the use of a single concept learning games have been the catalyst in effecting a more positive learning behavior in my students.

A summary of the slides describing the puzzles are given:

### ELEMENT SEARCH PUZZLE

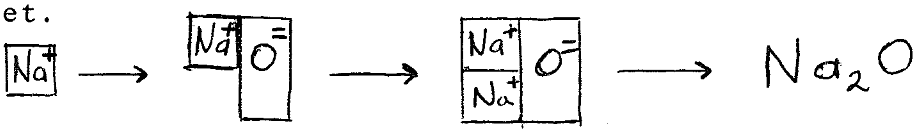
In this puzzle, the student searches for names of elements. To verify the name, a list of elements must be used reinforcing the recognition of names of elements. This particular puzzle was developed by one of my students a few years ago as a project. She had spent more hours on this project which also included a cross word puzzle than on any other college project. You can appreciate the number of chemical definitions and concepts you would consider in putting such a puzzle together.

As the student goes through the element search puzzle, each name found is written in the space provided below the puzzle. When the student completes the full number of names, there is immediate success and positive reinforcement. Students were telling me that they spent hours on the puzzle, and were quite pleased with themselves that they had found all the names.

### IONIC FORMULAS

This game introduces the student visually to the necessity of equalizing positive and negative charges to achieve an ionic formula with an overall charge of zero. By making the size of the cards proportional to the electrovalence of each ion, the student achieves the correct combination of cations and anions when a full geometrical shape is completed, square or rectangular.

To find the correct formula for sodium and oxide, the student first places the positive ion on the left. Adding the negative ion, the student immediately sees that the size, and therefore the net charge, is not correct. Using multiples of the starting cation and anion, success is achieved when shape, in this case a square is completed. The correct formula is then written in the workbook which the student already knows is correct, thus eliminating doubts. Polyatomic ions are included in this set.



This exercise seems to aid the student to move quite rapidly through this possible problem area.

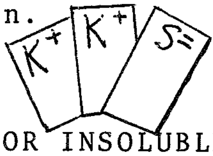
Extension of this game can aid in visualizing moles of ions in a formula weight, number of equivalents in a mole, one to one relationship of equivalents, and dissociation of ionic compounds in water.

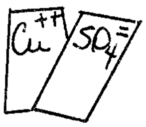
For instance, if one relates 1 equivalent to that amount of material which carries one mole of charge, this demonstration illustrates that there are 2 equivalents in a mole of ferrous ion or that one-half mole of ferrous ion equals one equivalent

### FOX: IONIC FORMULAS

In this game, the correct completion of ionic formulas and naming of those formulas is stressed. A group of students plays and one student can eventually win. During the play, peer group learning occurs with players correcting each other while hearing and verbalizing the names of ionic compounds.

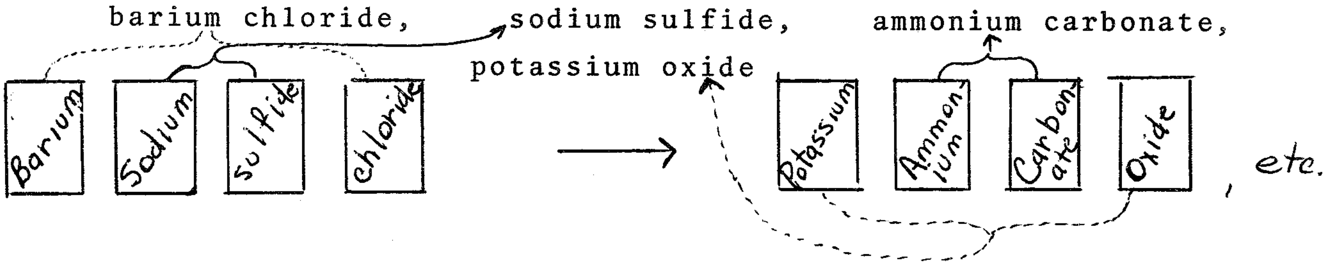
To give you some idea of the time period here, this game and the previous game are introduced the day that formation of ions and their names are discussed in lecture. The games and an ionic formula worksheet were finished in one to two hours and laboratory work began.





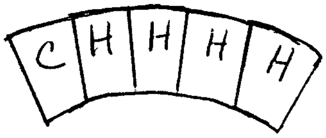
### SOLUTAIRE: SOLUBLE OR INSOLUBLE

The solubility rules and solution of an ionic substance and the formation of insoluble precipitates make up this game. The student removes as many cards as possible from the four stacks by forming only combinations which are soluble in aqueous solution. The game ends when no more soluble combinations are possible among the top cards.



### PRECIPITATE

In keeping with our theme of chemistry ideas revisited I would like to introduce two games which were shared with me by Bessie Butcher, a retired chemistry teacher. This game was developed by her in 1938 for her high school classes and uses each card as representative of an atom of an element. The game which can be played as rummy, involves making a hand of complete ionic and covalent formulas.

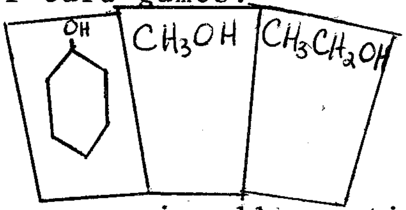


### CHEMISTS

Another of Miss Butcher's games involves the association of chemists with their contributions to chemistry. The game involves making sets of cards that put together a card with the chemist name and a card with the chemical work played like fish.

### FUNCTIONAL GROUP RUMMY

In one semester, my treatment of organic chemistry to lead into some biochemistry is very dependent upon the learning and recognition of functional groups. This game is played like rummy using cards on which are written the structure of an organic compound. By drawing and discarding a card each round, the student wins by completing two sets of cards. Each set contains three structures which have in common, the same functional group. In a two hours session playing this game, after building models of organic compounds, the students showed strong recognition of functional groups. They had not yet learned to name the compounds, but could classify a compound according to its structure and start to guess at some reactions for that compound. Some students made up their own personal set of cards, or checked out a set to use as flash cards. Some adapted the game to other familiar types of card games.



### ORGANIC REACTION SCRABBLE

Games such as this are occasionally mentioned in the Journal of Chemical Education. I tried this one adapting it to the limited number of reactions which I emphasize, and found that students were aided in recognizing a sequence of reactions which can occur given compounds and reaction conditions, an advantage in dealing with metabolic reactions such as the citric acid cycle.

I hope to continue developing games such as these and encourage you to try a single concept game for those learning areas where your students have the greatest degree of difficulty. I have been using 3 x 5 index cards or cutting down card stock. Students will welcome you as a player and are very proud when they win. Who knows, we might even get our schools together for a tournament of functional group rummy.

# Constructing Multi-Media: Behavioral Objectives as Tools

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Presented to a Symposium on Aiding the Learning Process at the Thirty-Eighth Two Year College Chemistry Conference, Pasadena City College, Pasadena, California 91106, March 29, 1974.

Somewhat narrowly defined though it is, "multi-media" today has come to refer primarily to a strategy of instruction (as distinguished from learning) in which information is imparted more or less simultaneously via an audio and a visual channel to a perhaps sometimes passive victim who we like to think of as a student. In these remarks I would like to suggest some constructive alterations of this image we sometimes have of multi-media. Many of you here already are aware of this, and practice it. I will ask those to bear with me until we get to some examples of slides. I can be proud of the slides since I was not the photographer.

So, consider what we would like to have for our students; a well conceived, organized plan for communication, exciting (or at least not boring) which _is_ useful for that student when they continue further in the educational process, or useful to them when they finish. For centuries, we have sought this goal by lecturing, writing, cajoling, even by asking tricky questions in our examining. More recently, technological developments have come to our aid, all the way from printed books to computer managed instruction. Especially in the past few years, behavioral psychology has developed a few theories (which more recently appear to be less than tenable) that mix well with current technological developments, and this is what we often call "multi-media".

A different branch of technology, however, has not been as commonly involved in multi-media and the thrust of my remarks can be summarized by the suggestion that we ought to also incorporate the techniques of Operations Research intimately with the other principles of the design and use of multi-media. In brief, I refer to a "systems approach" to instructional design; and I would like to illustrate what can be done by taking one example, instruction in laboratory technique for beginners in chemistry.

The technique of systems approach, too briefly described, requires that we first plan the instructional system, monitor the output, and then modify the feed back to improve the output, the next time around.

Suppose, then, that we wish to instruct our students in simple glass handling, such as cutting glass tubing, bending it to form an Ell or Vee, or drawing a capillary, or making a small nozzled piece.

As an experienced teacher knows, we teach this by showing and provide opportunity for the student to practice, while we constructively criticize the attempt and occasionally show again a bit of the original instruction. As any experienced teacher knows, this procedure is satisfactory--if you have the time to teach each one individually. The same can be said for instruction in the use of the balance, or the centrifuge, or the pipet, vol flask, and buret. Many of us have tried to solve the problem by using multi-media as part or all of the instruction.

Let's consider the problems involved in converting instruction in lab technique from person to person to a multi-media presentation. Probably foremost, we must now plan better since we will not get immediate feedback from the student when we don't quite get our message across. In a word, we must now know, in advance, exactly what we wish the student to <u>do</u> if he has learned successfully. Clearly, we ought to adopt a behavioral approach within the multi-media presentation.

So, what behaviors need to be achieved? After all, glass handling is reasonably simple. Actually, glass handling is simple only after one has learned, not before. To execute the manipulations involved in cutting a glass tube to a suitable length and then bending it to form an Ell, let us say, involve at least three dozen <u>different</u> behaviors. If we take an activity which is not too much more sophisticated, say preparing a standard solution of a reagent from a given bottle full of undissolved solid, there are more than one hundred different behaviors to be mastered. Or, consider only the proper use of a buret in a titration, say of an acid versus a base; this activity includes approximately three dozen different behaviors.

(What are some of these? A quick and incomplete listing: Close the cover of a match book before lighting the match. Adjust the burner flame. Identify the hotter and cooler regions of the flame. Bend the glass when it is out of the flame. Put the hot(bent) piece on a fire resistant surface. Test a recently heated piece of glass by placing the palm of the hand near, not touching, before grabbing hold of that piece firmly. Distinguish between a clean and dirty pipet. Read a vernier on a one pan balance; or otherwise obtain a maximum precision in a weighing. Fill a vol flask to the mark by adding solvent dropwise at the very end of this operation. Inspect a buret tip to insure that there are no bubbles trapped, before titrating. Recognize the end-point color change.)

When we consider the large number of different behaviors a student must master for any so-called simple laboratory technique, it is indeed remarkable that they are able to become competent. (Clearly, our students today must have good teachers!)

I have emphasized the large number of different behaviors which must be mastered by a student simply to make my point: We cannot teach lab technique, or anything else, well unless we as teachers are aware of each behavior we wish to inculcate. Too often, I confess, in the past I have surely only taught a few of the requisite behaviors and the poor students had to get the rest somehow by osmosis. That they succeeded in many cases is to their credit, not mine.

It is reasonable to suggest, then, that the explicit specification of the detailed, nitty-gritty, behaviors which the student must master, if spelled out in advance by the teacher, will surely promote an improvement in instruction. This is especially true if we propose to put that instruction into a multimedia format.

I prefer slides and audio-tape cassettes, others have tried to use movies with a sound track or with a tape cassette. It seems to me that in teaching techniques, movies are at a distinct disadvantage. By their very nature, movies move. Often the behavioral details are only on the screen for a fraction of a second; too short a time for the student to examine closely. Slides, by their nature, will wait on the student until he or she is ready to move on (especially if we eliminate automatic slide progression via a signal from an audio tape electronically tied to the slide projector--this arrangement tends to put the student to sleep, anyway). It can be argued that students can look at the movie loop again, which is true, but I know of few who will actually do so. Hence, in a nutshell, I prefer slides to movies.

We prepare our slide sequence by first listing the behavioral objectives, in detail, which a student could be expected to exhibit after becoming proficient. Preferably, these are listed in a sequential order. Thus, suppose we wish to teach the use of a one-pan semi-analytical balance; the objectives might be:

1. Identify (perhaps by making a simple, labeled, sketch) the operating parts of the balance.
2. State that the first step in the lab is to prepare a lab notebook entry describing the nature of the work to be done.
3. Then at the balance, check the instrument to be sure it is level; if not, adjust it to a level condition.
4. Check the balance pan and the interior of the balance case for crumbs and pieces left by the last user.
5. If not clean, either clean (if so specified) or call the instructor (if local lab policy so indicates).
6. Release the balance, to the semi-release position.
7. Adjust the balance to zero.
8. Return the lever to the "locked" position.
9. If a reagent is to be weighed, protect the balance pan by placing a watch glass, or other suitable container, in the approximate center of the pan.

And some several steps later:

122. Return the balance to the "rest" condition, check the compartment for cleanliness, take the weighed sample and your now marked-in lab notebook back to the assigned lab work space.

As is evident, most the objectives are psycho-motor behaviors (although a few, such as entries in the lab notebook, the inculcation of cleanliness, care to insure that very hot (or cold) objects are brought to room temperature before weighing, etc. are otherwise classified) can be described simply as a meticulously prepared set of operating directions. This is precisely the point!

Unless we, as teachers, take the time to ourselves determine exactly and in detail what it is we wish the students to be able to do, and in proper sequence, in all matters related to laboratory technique, we will continue to teach technique in an inefficient (or worse) manner.

The incorporation of behavioral objectives fits easily into our work as we plan a multi-media presentation. When those objectives are carefully selected, in advance, and designed into the media presentation, effective instruction is the result.

Clearly, initial efforts should be tested and re-tested before finalizing the product. (here is another advantage of slides and audio tape cassettes: it is reasonably easy to edit mistakes out, as distinguished from the difficulties encountered when you discover a goof in a movie film you have just produced.)

Our final product when tested with equated groups of approximately fifty students each (one was a control) has shown that time spent by the students in setting up the equipment and in using it in the laboratory work was reduced as much as 50%, with some gain in chemical comprehension, in addition. Our work is merely the beginning, since we cover only these elementary procedures; laboratory safely, simple glass handling, weighing, filtering, and centrifuging, using a pipet, vol flask and buret; manipulating common gases; measurement of molecular weight, gases and solutes in solution; and pH measurement. Much more remains to be done; I urge those who like to have adventures in preparing their own multi-media to repeat our work and do it better and to extend the strategy further into areas beyond those related to mere laboratory techniques.

The possibilities are almost endless, ranging all the way from instruction on, say, atomic structure, through Raoult's Law, to the function of RNA and DNA.

As a caution, however, it should be noted that the preparation of multi-media materials is very time consuming. We estimate more than 1000 man hours of work for each hour of final presented material, so it is very inefficient unless you hope to use it with many many students. To reiterate, all one needs (in addition to time) is a specification of a teaching goal, followed by a listing of detailed behavioral objectives which are ultimately translated into the media, and presented. I know of few activities in chemical education which are as stimulating and as enjoyable to work on. Our work in this area at Auburn University is continuing with my graduate students, but everyone else is urged to join in.

In closing I would like to acknowledge the support of McGraw-Hill, who initially funded this project, and of E.I. Dupont de Nemours who have made it possible to continue, cur-

rently. The editorial assistance and competent chemical help of Miss Nancy Marcus is also acknowledge, along with the instruction in behavioral psychology and educational pedagogy from Nicholas Fiel. Some of the studies with students were carried out by Brenda Hill, and the photography in the slides was by William Claiborne.

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# Change: Why and When

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Presented to a Symposium on The Old and New Approach to Chemical Education at the Fortieth Two-Year College Chemistry Conference, University of Saskatchawan, Regina, Saskatchawan, June 6, 1974.

I would not blame you at all, if, when you saw the title of this talk in your program, your reaction was something like, "Yech, not again!". One of the most changeless features of conferences and publications over the past decade has been the presentation of talks and articles about change. Nearly everything that could be said, has been--although it does not follow that everything that could be changed, has been. You may be relieved to know that I don't intend to present an inclusive summary of the literature; some of which is excellent and some of which is very superficial. Instead, as a prelude to the topics, I'd like to raise a few rather practical questions that, I think, we as practitioners need to consider when we are investigating alternatives, methodologies, or other changes within our role as instructors.

Earlier this year, I was invited by a professor at UBC to participate in a panel discussing the hinderances to educational reform in post-secondary education. It seemed to me that he was making at least a couple of assumptions. First, that post-secondary education was in need of reform; and second, that reform is being, and has been, hindered. There is a tendency in the popular press to treat these questions very superficially and to give the usual reasons; administrative interference, lack of funding, faculty conservatism, or others that we are all familiar with. But, before leaping to these simplistic generalizations, perhaps we need to ask more probling questions. If there has not been reform, does this mean there has not been change? or does it mean that the changes have not led to reform?

Well, has there been change, significant change, in education? I must admit that a month or two ago, when I visited the Greater Victoria Musical Festival, and heard little children under vigorous direction of matronly ladies beseeching in questionable intonation, "The sweet Afton to flow gently" and "Bonnie Boy to speed like a bird on the wing", I wondered if no one had written any new school music in the past fifty years; if students, teachers, were too conservative to venture; or if budgets were the hindrance to reforming the music educational program. On a much broader scale, John Goodlad, another Canadian who is now relocated in the United States, as dean at UCLA, recently completed a national study of U.S. schools to determine the extent of changes in instructional methodology resulting from millions of dollars spent in technological research and development. His findings led to a popular new song, "No one knows what goes on behind closed doors". He concluded that when the teacher closed the door, instructional procedures remained virtually unchanged over the past quarter century, in spite of the infusion of immense resources.

Is post-secondary education much different? The largest percentage of students in our colleges and universities are still taught, most of the time, by lectures, with one teacher to one class; sometimes aided by a chalkboard, and always by books. There is still a great emphasis on degrees, evaluation frequently is based only on three-hour final exams emphasizing recall of facts; and so on, in this vein we could catalogue current practices which could demonstrate that significant changes have not occurred in post-secondary education. And there are plenty of writers willing to do this.

But I could just as well argue the other side and say that changes in post-secondary education have been tremendous, both in number and in substance. For illustrations, the proportion of the young adult population pursuing post-secondary training is higher during recent years than in any previous generation; there has never been such a proliferation of disciplines, of programs and courses; the purposes of post-secondary education have changed from preparation of clergy to preparation of police officers, social workers, environmental technicians; the size, complexity, organizational variety of campuses is radically different from the traditional, ivy-covered liberal-arts college new knowledge in the sciences has resulted in significant changes in curriculum content; the availability of instructional technology is increased; open admission policies are becoming common; and so on, and so on.

So the argument rages between those who claim that there has been too much change with a resultant loss in quality of product, and those who claim that radical changes are needed and have not occurred. Frequently the conflict results from a difference in the time frame the combatants are willing to accept. Some are not willing to accept change by oxidation as a slow process, but want an explosive combustion. They want immediate, spectacular change in the educational system.

For others, the conflict is more than disagreement regarding "rate", but reflects entirely differing perceptions based on incompatible frames of reference; and these, of course, are influenced by their own particular values and ideals. Although specific examples can be provided to give evidence of change, or of lack of change, our arguments do not result in constructive communication if we fail to recognize the substantial impact of personalities, values, ideals, different ways of looking at people and society, and different ways of valuing the instructional process. Surely it has been these subjective areas that have resulted in the conflicts of the past decade, in the dissipation of energies that should be constructively channelled, in the lack of communication as we talk past each other; and these factors continue to be the source of frustration as all of us work towards the goal of improving learning by improving the instructional process.

The differences in ideals and perceptions do not only divide educators into those who seek reform and those who wish to maintain the status quo. They also, to be terribly simplistic, divide those who would reform post-secondary education into two major types: first of all, those who basically wish to maintain existing educational goals and simply be more effective in reaching them.. that is, to do what we're already doing, better; and secondly, those refuting existing goals, structures, and methods as not reflecting the needs and demands of society, who seek to bring about reform by creating totally new institutional roles. It is absolutely essential, therefore, if we are to engage in productive conversation regarding a particular instructional alternative, that we be quite open with each other in describing, at the same time, our values, perceptions, and ideals; and stating clearly whether the purpose of the innovation is to change existing goals of chemistry instruction or to retain existing goals, but work towards them in a more effective, and perhaps also efficient, manner. Surely I cannot consider the innovation's applicability in my situation or evaluate any of its aspects without clarification of these basic issues of philosophy and purpose.

It seems to me, in my job, that there are two comments about instructional innovation I hear much too frequently. First, a quotation that goes something like this, "Well, we've always done that. That's really no different at all. It's just a few new words." We usually make this comment in describing the other guy's program. The second most frequently heard comment is, "This is the first time in Canada" or "the first time in North America. A brand new idea." We usually make this comment when describing our own program. Both of these comments represent dysfunctional attitudes towards instructional reform. The person who claims, for example, that modularized instruction is just the same as all other systems he now uses for organizing material, probably is failing to perceive the essential differences. Frequently, the response, "Well, it's really not any different than what we've been doing" is used as a protective shell, insulating us from the irritant which might incite us change.

On the other hand, the claim that any program is brand-n while it wins considerable press coverage, fails to recognize the historical antecedents which often have very significant contributions to make to the innovation. The result is often wasted effort in remaking errors, and losing opportunities f enrichment of our own innovative scheme based upon the experi ences and practices elsewhere. I would suggest that all of u in the business would do well to be less anxious to wear the label "unique", and to be more interested in developmental instructional improvement.

Most instructors who make serious and realistic attempts to improve their management of the teaching-learning situati then, make themselves aware of the available technology, the full range of methodological alternatives, and the literature and research describing their uses; and then find the most effective means of adapting a given technology to their parti ular situation. I am sure that's what Steve, Graham, and Pe ny have done in their own adaptations of instructional techno gy. We, as participants in this symposium, have the opportu ity of building upon their experience, and it is in our best interests to listen closely to what they have to say, to inc porate their data within our body of knowledge, and then to build and develop adaptations which might contribute towards the goals that we value in our own instructional programs.

Research has been appropriately defined as plagiarism f two or more sources, and it's not hard for us to recognize t most of what we perceive back home in our own colleges as un innovation, is at least 90% plagiarism. And that's okay. W not okay, to my way of thinking, is the mindless way in whic we are inclined to transplant instructional techniques.

When I was a very young man, my wife and I moved into o first small house, which had an enormous backyard completely inundated with blackberries, tall grass, rocks and cans. In the enthusiasm of youth I decided we'd convert it to a produ vegetable garden. One neighbor, who was an excellent garden was so pleased to see someone trying to make improvements to the place that he encouraged me on. He always grew beautifu tomatoes and as a result of his generosity, we were able to quire a few new young plants. We transplanted them to our n garden and excitedly watched. . . as they slowly wilted, wit ered, and wiped out! If anyone in the future tries to convi me that tomato plants are worth adding to my vegetable gard that a tomato plant is a good plant--I know better, from experience. We tried it and it didn't work. This parable has very obvious interpretations. Read in place of "tomato plan any instructional innovation (AT, CAI, Team Teaching, Open L How many times have you heard people say about these, or oth innovations, "I tried it, it didn't work, it's no good." A gardener would try to tell me however, that the failure of t tomato plant was not due to a lack of vigor of the plant, bu to my failure to prepare the soil, or to provide the proper nutrients, or to provide water, or to weed out extraneous plants (otherwise known as weeds) which dissipated the energy needed by the tomato, or that I failed to prune the plant, to discipline its growth to make a productive plant. I hope what the parable lacks in subtlety will be compensated for in clarity. When we adopt a given instructional procedure, how systematic are we in preparing the students for its use? In preparing our fellow instructors for meshing their roles with those of the new instructional system? In preparing our administration to provide the support services required? Do we have well-developed software of substance? Do we prune the innovation to suit its productive purpose, or does it become a gargantuan monster that disciplines us? Do we weed out much of our previous activity which dissipates energy and isn't productive under the new procedure?

I suppose it's possible that if my plants had succeeded, my little girl could have come along just when the plants were in their beautiful yellow blossom, and said, "Daddy, why didn't you plant dandelions? Their flowers are bigger and yellower and prettier." And that's really not much more ridiculous than some evaluations of instructional innovations. How frequently have you had a colleague, or administrator, or some other casual evaluator, pass a judgment on an instructional procedure because it doesn't do something which it was never intended to do. Just as I should have explained to my little girl that the puspose of the plant was to produce succulent tomatoes rich in vitamins; so we must be careful to clearly explain, to ourselves and others, the purposes we have in adopting or adapting a given instructional device or technique. And then we must make sure that our evaluation provides information related to the accomplishment of these purposes. A computer is neither good nor bad for instruction. It is a mass of metal, wires, and electric currents. CAI is neither good nor bad--CAI practice can be <u>either</u> good or bad. When the capacities of the computer are selectively applied according to sound pedagogical principles to achieve specific purposes, it can become a powerful ally.

But where are all the new-fangled technologies, procedures, and instructional materials coming from? Who are the prime originators? Manufacturers and publishers like to tell us, "Educators have demanded and we've responded." Well, maybe. But probably it isn't always that simple and direct. At least occasionally, clever marketers have detected areas of vague unease in some quarters of the instructional system and have developed a product, often promoted as "teacher-proof"--which makes me think the teacher hasn't always requested it. The producer leaps into this confusing scene with all the vigor of a gypsy medicine man offering one technical cure for gout, arthritis, accountability, or whatever else it is that ails our instructional system. He'll let us be the first in our block to have a beautiful electronic gadget which for only $995 (federal tax excluded) will present us with exactly the same dry materials that can be found in his $1.25 workbook, only we don't have to turn the pages. How many devices that you've seen, real do nothing else. Please don't interpret what I'm saying to mean that I advocate a lock-out of all media suppliers from conferences such as this. They often have extremely useful information; as a matter of fact, they are frequently our only source of information. Nor am I anti-technology, or anti-electronic media. What I am asking is that we keep ou own spectacles clean and identify precisely what the techno does best and how it fits our particular instructional goal and setting.

Note, that I've said "what it does best", not "what it can be forces to do". Most promotors of an instructional i vation designed to meet one original purpose, seek wider ut (and therefore sales) by identifying other aspects of the i structional operation that it can do, with a little push. examples can be cited: cuisenaire rods in elementary schoo arithmetic; 16 mm films, even VTS, have been frequently in category. I'm too young to remember, but Jans tells me that Hitler developed a very effective piece of technology, desi to meet a specific objective. He called it a Tiger tank and was used very effectively to wage offensive war. Hitler was also famous because he had an objective of providing transpo tation to the people, economically and efficiently. Well, tank provided transportation and carried men, but where woul we all be if he had mass-produced tanks and abandoned the Vo wagen. We have many "tanks" in educational technology, when "Volkswagens" were all we ever really needed.

I'm not sure what you've heard in these comments, but l me summarize for you what I've heard as I listened to myself I hear about a half dozen questions which I choose to consid as I enter a discussion regarding instructional innovations:

1) Is the innovator searching for more effective or ef cient ways of realizing familiar goals in Chemistry instruction--or is he trying to reach some previous unidentified goals? If they're different, can he d scribe them? Do I accept them as valid for my prog

2) What is the essence of the technique that makes it ferent from what I've been doing? What really chan in the instructional operation if I adopt the new t nology?

3) Has the innovator taken into account related experi projects or research--or is his claim to uniqueness blinding him to the potential for developmental inn vation?

4) What preparation or adjustment of other elements in the system would be necessary if I were to successf transplant this instructional alternative into my s ation?

5) What evaluation procedures will I establish right from the outset? Will these give me the appropriate data to judge whether the intended purposes are being realized, or will I use dandelion criteria on tomato plant innovations?

6) Is this technique or technology the most appropriate for this intended purpose--or am I trying to adapt a tank when I should have bought a Volkswagen?

## A C.A.I. Package that Really Works

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Presented to a Symposium on the Old and the New Approach to Chemical Education at the Fortieth Two-Year College Chemistry Conference, University of Saskatchawan, Regina, Saskatchawan, June 6, 1974.

Whether or not the goal alluded to here can, or even ought to be fully attained, may be debatable. I, for one, feel very strongly that C.A.I., like any other instructional tool, should be applied primarily to those tasks that it alone can accomplish best. Of these various learning devices (audiotapes, the printed page, classroom encounters, etc.), CAI is unique in that the computer's ability to keep track of the progress and special difficulties of individual students furnishes the essential feedback element that distinguishes an "instructional system" from a mere means of presentation of instructional material.

In order to exploit these special qualities of CAI, very careful attention must be given to exactly what the students are expected to learn, and the "subskills" that must be mastered in order to attain a specific higher-level skill. The former condition implies the existence of a meaningful set of explicit learning objectives for the course, while the latter implies a microteaching approach in which a given goal is achieved through a stepwise sequence of increasingly sophisticated exercises.

Consider, as an illustration, the following sequence of tasks that are prerequisite to an understanding of a learning objective like "be able to find the simplest formula of a binary compound from its weight percent composition".

"In the compound $Si_3N_4$, the mole ratio of Si:N is __?__"

"For each mole of N in the compound $Si_3N_4$, there are _____ moles of Si."

"The mole ratio of Si:N in a compound is .75; re-express this same mole ratio in the form Si:N = 2: __?__."

"Find the simplest formula of a compound in which the mole ratio of X:Y = 1.275"

An ability to understand and work out exercises based on mole ratios and proportions would seem to be a direct prerequisite for achieving a real understanding of "simplest formula" problems, as opposed to the mere ability to solve these problems by an algorithmic or "recipe" method.

It is in areas such as these that I feel the computer can "really teach chemistry" if the C.A.I. materials are carefully designed and sensitively applied within the context of the tota course.

We are presently developing a large "package" of C.A.I. materials which are known collectively as "GENCHEM". GENCHEM is a collection of interactive instructional programs, data, and utility functions designed to support a course in General Chemistry at the secondary school and college levels. Rather than being a "canned" or pre-designed C.A.I. course in chemistry, it provides the basic materials from which the teacher can construct a learning aid that is tailored to the particular kind of course that is being taught. The flexibility of GENCHEM is such that it can serve as the major component of a C.A.I.-based "Keller plan" course, or at the opposite extreme (and less "effectively"), as a supplementary learning aid for students enrolled in a traditional "three-lectures-per-week" course.

In addition to its role as a set of operating software, GENCHEM is also intended to serve as a source collection of computer-based instructional strategies that others can incorporate into their own C.A.I. materials, or can translate into interactive languages available on their own local computer systems. GENCHEM at Simon Fraser University is written in a high-level authoring language based on APL, but which bears much resemblence to IBM's Coursewriter III, which we had been using earlier. The language is well documented and can be followed by anyone having an elementary understanding of APL and a general familiarity with the concepts of program flow and implicit branching in computer-assisted instruction.

## A FLEXIBLE C.A.I. SOFTWARE PACKAGE FOR GENERAL CHEMISTRY

"GENCHEM" is a collection of interactive instructional programs, data, and utility functions designed to support a course in General Chemistry at the secondary- and University levels. It is not a "canned" or pre-packaged C.A.I. course in chemistry; instead, it provides the basic materials from which the teacher can construct a learning aid that is tailored to the particular kind of course that is being taught. The flexibility of GENCHEM is such that it can serve as the major component of a C.A.I. based "Keller-plan" course, or at the opposite extreme, as a supplementary learning aid for students enrolled in a traditional "three-lectures-per-week" course.

In addition to its role as a set of operating software, GENCHEM is also intended to serve as a source collection of computer-based instructional strategies that others can incorporate into their own C.A.I. materials. For this reason, GENCHEM is written in a high-level authoring language bearing some resemblence to IBM's Coursewriter III, and which also allows APL statements where these are required. The language is well documented and can be followed by anyone having an elementary knowledge of APL and a general familiarity with the concepts of program flow and implicit branching in computer-assisted instruction.

Translation of GENCHEM into other languages such as PLANIT, Coursewriter, TUTOR, PILOT, BASIC, or "conventional" APL is fundamentally possible, although none of these languages presently incorporates all the features that are exploited in the extended York/APL implementation that we are presently using.

Even within a given course environment, different students will need to access C.A.I. materials in different ways. For example, some students wish to select course modules associated with specific subject topics, or with explicit learning objectives if these are defined for the course. Others identify their learning needs by means of questions about certain of the assigned homework problems. Many are happy merely to tell the computer that they are "in Week 5" of the course, being willing to submit to whatever pre-planned tutorial regime is offered for that week's work. Another distinction exists between organized tutorial sequences and random-selected "self-testing" modes.

In GENCHEM, we attempt to provide for all of these approaches. At its most fundamental level, GENCHEM consists of a large number of modular exercises, each of which illustrates or provides exercise on a specific aspect of a given topic. In most cases, the details of these exercises such as numerical values, names of elements or compounds, and general working of questions can be varied dynamically, in either a random or predefined fashion. This means that the same basic software can be used at different levels of sophistication at various stages of the course, and that the student can repeat the same basic exercise without being confronted with the same numerical values, etc.

At higher levels of structure, groups of these modular exercises can be linked together to provide coverage of a broader area, such as "simplest formula of a binary compound". These various topics can be joined into still higher-level blocks covering entire subject areas, such as "quantitative composition of compounds". At the top of the hierarchy, one can specify the content of an entire "course" by an appropriate linkage of subject blocks. At this level, it becomes desirable to implement automatic recording of student progress and performance, so that the teacher can monitor the student's progress through the course, and prescribe any additional instruction that may be necessary.

At its present stage of development, GENCHEM covers only about a quarter of the "subject" matter of a typical introductory course, albeit the most "difficult" quarter. The various instructional modules have evolved from our nearly six year's experience in using IBM's Coursewriter III C.A.I. system for chemistry instruction. One of the main lessons of this experience is that the "effectiveness" of C.A.I. (or any other instructional device) as a learning aid depends very strongly on the manner in which it is incorporated into the overall course. If it is presented merely as an "add-on" (requiring "extra work" on the part of students), then it will be of limited use. Ideall each component of the total course (audiotapes, C.A.I., texts, study guide, and even lectures) will be used for what it can accomplish best, each one allowing for the presence of the other.

Thus in my own teaching, the use of audiotapes and computer-assisted instruction has enabled me to eliminate all but a small fraction of the ordinary number of lectures; the time so gained enables me to conduct more of my own tutorial sessions and to meet with individual students who require my help. The course is defined in terms of specific performance objectives, which are keyed to the various learning materials, including, of course, C.A.I. Students are evaluated on an absolute scale, on which a "C" grade is defined as "80% or better attainment of 75% of the objectives tested". In the three semesters that I have used this system, less than 1% of the course grades have been below "C".

## Innovative Learning Modes in Introductory Physical Chemistry

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Presented to the General Chemistry Session of the Fortieth Two-Year College Chemistry Conference, University of Saskatchewan, Regina, Saskatchewan, June 7, 1974.

The optimum method of learning varies from person to person. All learning modes involve utilization of one or more of the senses but, conventionally, in the study of chemistry, as in many other disciplines, the combination of sight and sound is emphasized. For the student, the ideal weighting of sight to sound, the methodology of approach to these two senses and the rate of presentation are not constant factors.

Traditionally, the means by which a student acquired knowledge were through the presentation of information in a formal lecture several times each week with the addition, in chemistry, of a laboratory experience which was perhaps related to the classroom material. Necessarily, this approach does not permit the student to proceed through course material at his or her optimum rate, nor does it allow for variation in the best weighting of sight to sound. While many students may at best thrive or at worst survive under such a learning mode, several alternatives have been developed over the past few years which cater to a wider spectrum of students' learning abilities. Of these, only two will be briefly mentioned.

The audio-tutorial or audio-visual-tutorial approach to learning has the distinct advantage that integration of the experimental and theoretical in the laboratory science can be complete. However, an early protagonist of audio-tutorial in general chemistry recently commented that when printed transcripts of the audio-tapes were provided, few students utilized the audio-tutorial facility.

The completely self-paced Keller Plan approach to learning has received much attention recently, but is fraught with many problems, the most serious perhaps being the lack of supervision in pacing from one experienced in the subject.

Over the past four semesters, the components of an experimental introductory Physical Chemistry Learning System (PHYCLS) have been or are being developed at John Abbott College. It is the purpose of PHYCLS to incorporate the best features of other learning modes and,hopefully, to eliminate some of their disadvantages. It should be noted, however, that students are not obliged to register in PHYCLS and may participate in a more traditional approach which may or may not include some of its components. The undesirability of instantly imposing an innovative or developmental learning system on all students in a given course cannot be overemphasized.

## Physical Chemistry Learning System (PHYCLS)

PHYCLS at John Abbott College has developed over the past four semesters as an expressed need by students to supplement material which was inappropriately presented, in terms of our curriculum, in any currently available textbook or combination of separates. The learning core is "Concepts in Physical Chemistry"[1], a set of student workbooks. Learning is reinforced through a carefully designed set of integrated laboratory experiences. Evaluation will be by means of "Computer Generated Individualized Problem Sets"[2], an educational research project recently funded by the Quebec Provincial Government. Student motivation, frequently lacking in audio-tutorial or Keller Plan approaches, retains the essential presence of the presumably knowledgable instructor as a source of motivational or inspirational material in voluntary overview lectures.

Each of the four essential components of PHYCLS - workbooks, laboratory, evaluation and motivation - will be briefly discussed.

## PHYCLS Workbooks

The set of student workbooks and its function is listed in Table 1.

"Concepts in Physical Chemistry"
Table 1

| Title | Function |
|---|---|
| Introduction | Describes student use of the remaining books in the set with particular emphasis on explanation of the format as an aid to self-study (con't.) |

Table 1 (con't.)

| Title | Function |
|---|---|
| Physical Properties of Solutions<br>Chemical Kinetics<br>Chemical Equilibrium<br>Ionic Equilibria<br>Electrochemistry | Five segments of material, each appropriate to approximately three weeks of study, designed to give the student a relatively deep understanding of the processes involved in the physical che istry of solutions without undue emphasis on mathematics or chemical thermodynamics, a topic considered pertinent to more advanced courses in physical chemistry |

A sample page, from the text on Chemical Kinetics, serves to illustrate some features of the workbooks which differ from conventional texts (Figure 1). Apart from description of concepts, the text is interspersed with numerous worked examples followed by problems which give the student immediate feedback on his or her ability to manipulate the concepts discussed. Each section is concluded with a brief summary of wha is expected of the student.

## PHYCLS Laboratory

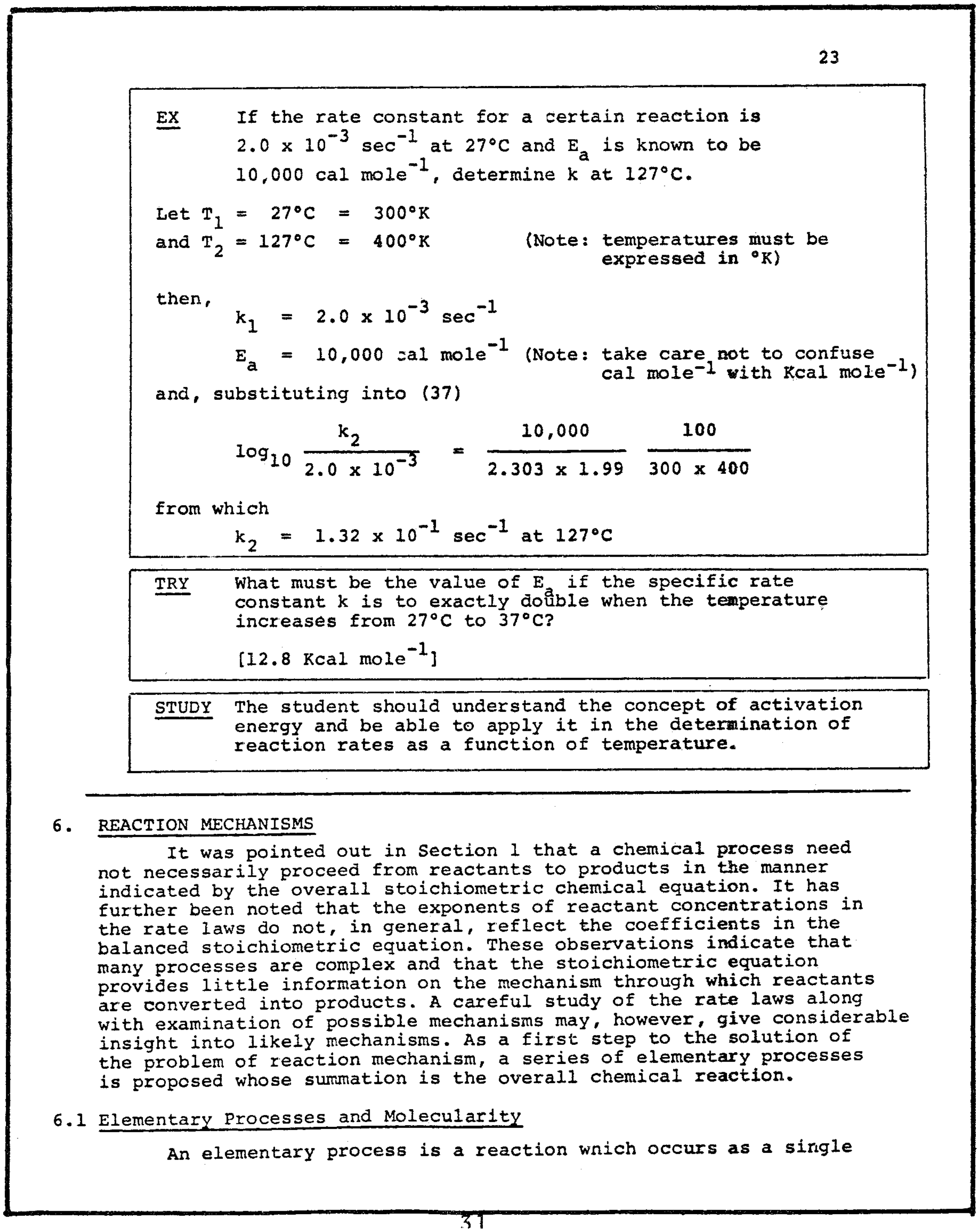
While the workbooks used for self-study in PHYCLS are completely amenable to self-paced learning, the laboratory program is not. The constraints of staffing, total number of students and laboratory utilization in our present circumstances, do not permit the student to proceed through the laboratory experiences at his or her own pace. Accordingly, the student's ability to self-pace is restricted to a three-week module by necessity, thereby eliminating one of the problems of the Keller Plan, namely that students may take substantially more tha one semester to successfully complete a one-semester course. By restricting self-pacing to three-week modules, the additional learning task, to become totally independent and responsibl is not imposed upon our predominantly teenaged students.

As indicated above, the laboratory and study programs are closely integrated by careful design of experiments such that each program may reinforce the student's learning and retentio through the other[3].

## PHYCLS Evaluation

A major problem with any self-paced learning system, whet the module by an entire course or just a small unit, is the eva uation, both by self and by instructor, of the student's progre in understanding course material. The PHYCLS workbooks allow the student a certain measure of self-evaluation. However, the major evaluative procedure in this course is provided by Computer Generated Individualized Problem Sets (CGIPS),[2]. CGIPS are used for purposes of repeatable evaluation during and repeatable testing at the conclusion of each of the five course modules. Student diagnositc facilities, such as those available with CHEMTIPS[4] will be incorporated into the system as it develops.

Sample page from "Concepts in Physical Chemistry"
Figure 1



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EX If the rate constant for a certain reaction is $2.0 \times 10^{-3}$ $sec^{-1}$ at 27°C and $E_a$ is known to be 10,000 cal $mole^{-1}$, determine k at 127°C.

Let $T_1$ = 27°C = 300°K
and $T_2$ = 127°C = 400°K (Note: temperatures must be expressed in °K)

then,

$$k_1 = 2.0 \times 10^{-3}\ sec^{-1}$$

$$E_a = 10{,}000\ cal\ mole^{-1}$$ (Note: take care not to confuse cal $mole^{-1}$ with Kcal $mole^{-1}$)

and, substituting into (37)

$$\log_{10} \frac{k_2}{2.0 \times 10^{-3}} = \frac{10{,}000}{2.303 \times 1.99} \quad \frac{100}{300 \times 400}$$

from which

$$k_2 = 1.32 \times 10^{-1}\ sec^{-1} \text{ at } 127°C$$

TRY What must be the value of $E_a$ if the specific rate constant k is to exactly double when the temperature increases from 27°C to 37°C?

[12.8 Kcal $mole^{-1}$]

STUDY The student should understand the concept of activation energy and be able to apply it in the determination of reaction rates as a function of temperature.

## 6. REACTION MECHANISMS

It was pointed out in Section 1 that a chemical process need not necessarily proceed from reactants to products in the manner indicated by the overall stoichiometric chemical equation. It has further been noted that the exponents of reactant concentrations in the rate laws do not, in general, reflect the coefficients in the balanced stoichiometric equation. These observations indicate that many processes are complex and that the stoichiometric equation provides little information on the mechanism through which reactants are converted into products. A careful study of the rate laws along with examination of possible mechanisms may, however, give considerable insight into likely mechanisms. As a first step to the solution of the problem of reaction mechanism, a series of elementary processes is proposed whose summation is the overall chemical reaction.

### 6.1 Elementary Processes and Molecularity

An elementary process is a reaction which occurs as a single

## PHYCLS Motivation

Only a relatively small percentage of students enrolled in the introductory physical chemistry course at John Abbott College proceed to more advanced studies in physical chemistry. Accordingly, PHYCLS attempts to demonstrate to all students, terminal and professional, how the concepts presented relate to their chemical environment. This objective is achieved in two ways. Firstly, the workbooks themselves[1] contain discussion of special topics relevant to pollution, corrosion and metabolic function to mention but three. Secondly, an optional series of motivational lectures is available. Each lecture qualitatively overviews the material in one of the five course modules (Table 1) and relates this to "real-life" situations through demonstrations, student performed armchair experiments[5] and lap-dissolve slide sequences[6].

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3. "Concepts in Physical Chemistry, Laboratory Manual", 3rd Edition, Chemistry Staff, John Abbott College, Montreal, in press
4. "ChemTips: Computer Managed Individualized Instruction in Large Classes", Bassam Shakhashiri, University of Wisconsin at Madison, presented at Conference on Computers in Chemical Education, Kingston, Ontario, June 1974
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# An Analysis and Assessment of Individualized Instruction in First Year Chemistry at Mount Royal College

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Presented to the General Chemistry Session of the Fortieth Two-Year College Chemistry Conference, University of Saskatchewan, Regina, Saskatchewan, June 7, 1974.

This paper begins with a brief explanation of why we ventured into individualized instruction, then gives some of the more significant discoveries we have made in the three years we have been using this method, and finally reports on our most recent evaluation and the revisions arising out of it.

The following is a summary of the events which led to our adoption of individualized instruction.

In 1931, Mount Royal College became a private Junior College in affiliation with the University of Alberta. About the middle of this century it became aware that other Junior Colleges in the United States were shifting their emphasis from preparation of students for university to a diversification of programs designed to serve a wider spectrum of high school graduates. After an attempt was made, with some success, to follow this trend, Mount Royal College was forced through their ambitious undertakings and financial considerations to change from a private to a public institution. This was quite simple, because the government of the province of Alberta, like many others in Canada, was beginning to recognize the need for an expanded post secondary system of education that could serve a wider sector of the population and provide for the needs of a developing technological society.

In 1966 Mount Royal College changed from a private college to a public two year community college. It attempted to serve the community in two ways: first, by introducing many diversified programs of a vocational nature, and secondly, by retaining many of its university preparation courses.

First year chemistry is one example of a university preparation course that has been retained. But such courses proved to be beyond the ability of many of the non-traditional students such as working adults, high school dropouts, housewives, retired persons, etc. In addition, not many restraints were put on students at registration time. These two things together produced a high failure rate.

When Mount Royal College looked elsewhere for a way out of this predicament, it discovered other two year community colleges were having the same experience. Research at Berkley by Patricia Cross and others showed that non-traditional students were figuratively being slaughtered by the conventional university programs.

Educators, including those at Mount Royal College, turned in desperation, to innovation. A new campus suited to innovative methods of instruction was planned and built. For two years prior to the move from the old campus to the new, the newly created department of research and development spent practically all of its energy in gearing the faculty to innovation in order to prepare them for the radical change in environment that awaited them on the new campus.

In the fall of 1971, we made our first attempt to develop a program of individualized instruction in first year chemistry. The evaluations at the end of each semester, since have dictated the need of such extensive revisions that it was necessary to replan the entire program each time. Not until this last semester has an evaluation given us any hope that individualized instruction is a solution to the problem of teaching chemistry to non-traditional students and at the same time maintaining high standards of quality.

Individualized instruction is instruction that permits each student to learn at his own rate. It seemed to us that we could simply make this possible by providing students with written instruction equivalent to what they would receive in a lecture. It was believed that if the objectives were clearly stated and the ways of achieving those objectives were explicitly pointed out, students could study the written instruction independently, each learning at his own rate.

We felt too, that in addition to providing students with a means of pacing their learning to their own ability, independent study would teach them to become independent and to accept responsibility. We discovered, however, that this additional learning task, learning to become independent and accept responsibility, added a difficult challenge that more than offset the advantage of individualized pacing. Newly enrolled students perceived themselves as being transplanted into a harsher environment. Some bolted, withdrawing from the course immediately. Others remained, but in many instances with feelings of frustration and injustice. The remaining students, good traditional students, as always, adapted and thrived. So, in the end, the innovation that had been designed to assist the non-traditional students seemed to be more of a hinderance than a help.

Another unfavorable aspect of this independent study program was that the non-traditional students tended to procrastinate a great deal. Self-pacing encourages putting off to tomorrow what should be done today. So instead of working at their own speed, many students worked below their potential. They seemed to be accustomed to receiving their stimulus through a personal relationship with the instructor and the rest of the class. Because this stimulus was lacking in independent study, many students got hopelessly behind in their work.

In the earliest evaluations, we did not make an accurate assessment of the situation. We did not perceive that procrastination and the reasons for it were preventing us from achieving the anticipated results. We diagnosed the trouble as slow learning. Hence, we decided to try granting an extension of time between semesters to give slow learners an opportunity to complete the course before the beginning of the next semester. But we soon found the real cause. This privilege was so blantantly abused by the procrastinators we had to abandon it to avoid reinforcing this bad habit.

In place of the extension of time between semesters we made provisions for the genuine slow learner. Arrangements were made in the fall of 1973 to credit students who were able to satisfy the standards for the first half of the course with credit for that half. Then they were allowed to complete the other half in the following semester. Another change was an easing in the transition from traditional instruction to independent study to minimize the shock of transplanting the student from one to the other. We believe that these two revisions, the provision for taking the course in one or two semesters, and the retention of some traditional methods of instruction, are responsible for the increased success of our students.

In the revised program for the fall semester, we plan to expand the conventional aspect for the benefit of the non-traditional students. The changes being made are based on the following assumptions:

(1) That the "D" grade students (students who receive the lowest passing grade) benefit most from a learning situation in which they are not isolated from the instructor and their classmates.

(2) That the "C", "B" and "A" grade students can adapt themselves to self-pacing through independent study and benefit from it.

Thus, the fall program will become a hybrid of traditional teaching and independent study. The pace of the traditional teaching will be geared to accommodate the learning rate of the "D" grade student. Other students who aspire to higher grades will do so through independent study.

There will be 26 units to cover in the full course, 13 units in the half course. The first unit will orient the student to the concept of individualized instruction. Then every even-numbered unit from this point on will be a lecture unit based on one chapter of "Preparation for General Chemistry" by Wright and Williamson. Every odd-numbered unit will be a laboratory unit based on an experiment from "Laboratory Manual for Chemistry, Man and Society", by Jones and Dawson. Two lectures each week will be spent on the lecture units for the full course, four lectures each week for the half course. There will be a two hour laboratory period every week in which the experiment of each laboratory unit is done.

Separate batteries of tests will be used specifically to determine the different levels of learning ability achieved by different students. "A", "B", "C" and "D" grades will be assigned according to the results obtained from these tests.

"D" grade tests will be given at the completion of each unit in the lecture periods. These tests will examine students for knowledge of specifics. If a student's knowledge of the specifics is shown to be incomplete by the results of the test, he will be required to write another test on the same unit in a special testing period. This time he must achieve the required knowledge through indepdndent study and tutorial help in a one hour tutorial period provided for him each week. This procedure must be repeated until he can successfully complete the test.

"C" grade tests, also given during the special testing period, are designed to test the student's comprehension of knowledge.

Further depth of understanding, especially the ability to generalize, to retain and apply knowledge learned in the units, will be tested for in three term tests. A "B" grade will be granted to students who can achieve an average of 70% or better.

The student will receive an "A" grade for the highest level of understanding which will be indicated by success on a final exam. This will include questions requiring excellent retention of the whole course and the ability to deal with the most difficult concepts. The A, B and C level tests are required of students desiring these grades - they are not compulsory for all students.

The student will be evaluated on the laboratory portion of the course as follows: a "D" grade in each laboratory unit is granted to a student for participation in the experiment and for a copy of his data and calculations. "C" grades are granted to students in the same way as for lecture units, i.e. by successful completion of a "C" level test on the unit. Laboratory questions are included in the term tests for the "B" grade, and half the grade on the "A" level final examination requires satisfactory achievement on a laboratory test consisting of an actual experiment performed and discussed in detail in a written report.

Our analysis leads us to conclude that the ability to engage in independent study is an attribute which is lacking in the majority of students received at this institution. However, individualized instruction does not necessarily have to involve independent study, and we are attaining individualization by offering several options in various areas:

1. Grade-level goal.

Each student can set his own grade-level goal and work to that end through independent study. For example, the student who only wants a "D" grade for certain credit requirements does not have to complete the same quantity of work as required of higher grade levels. This relieves him of the worry and frustration of competing with potential "A", "B" or "C" level students and allows more time to be spent in his major area of study.

2. Course-length goal.

Students who have difficulty achieving success (even at a "D" level) may take a half of the course in one semester and complete it in a second semester. These students have the benefit of twice as many instructor contact hours and a slower pace, thus reducing the pressure and so enabling them to perform more effectively. This is particularly advantageous to the older students who must relearn the techniques of studying.

3. Study-environment preference.

Some students prefer to work in isolation while others require the stimulus of interpersonal relations. This program allows for both preferences by providing for individual and group methods of study. The students can blend these two features in whatever proportion they desire. This can change from day to day, depending upon the mood they happen to be in or the degree of success they experience in the various environments.

The revisions included in the plans for the coming semester are extensions of ideas we have already found to be successful. We therefore anticipate even greater success this fall.

## Generic Learning in Chemistry

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Presented to the General Chemistry Session of the Fortieth Two-Year College Chemistry Conference, University of Saskatchewan, Regina, Saskatchewan, June 7, 1974.

Ability to create is one of the characteristics of humans that distinguishes them from other living things. Without this ability, surely humanity would not have progressed. A creative person makes use of, besides certain skills, intuition. Based on theories of learning, better skill training methods are being developed that require specification of objectives and employ criterion tests to evaluate. But what about intuition? While there is no evidence to prove that we can train students to be intuitive there seems to be an agreement amongst edcational psychologists on the view that learning situations that require knowledge-organizing, viz. generic learning situations, help the student actualize his/her intuition. The famous educational psychologists Bruner[1] and MacKinnon[2] professed in "leading the student always to an intuitive understanding of that which he experiences".

Scientific concepts that required great genious could be presented in such a way that anybody can understand them. Such a presentation not only lacks appreciation of intellect of the inventor, but also does not provide opportunity to the learner to actualize his/her intuition. On the other hand, the discovery approach that the scientist uses is too time consuming to be a useful tool to a teacher in promoting intuition.

The International Commission on Development of Education in its report[3] calls for a basic education that aims at learning how to perceive and comprehend the world while dispensing fundamental knowledge. Such an education requires development of knowledge and skill learning and generic learning situations that are compatible with each other in the light of the concepts learned in the past.

## DAASAN APPROACH: A PRAGMATIC APPROACH TO EDUCATIONAL OBJECTIVE

Most concepts in science can be taught either as skills to be mastered or as facts to be discovered. The discovery method, which helps one develop faculties of observation, judgment and critical spirit, is obviously the method that we want to use in our teaching. This method being a very time consuming one, the teacher is forced to compromise in choosing the number of concepts to be taught through the discovery method. The Directed Activity to Acquire Specific Abstractions in Nature Approach was found to be useful in increasing this number. In the DAASAN Approach the teacher leads the student to discovery through appropriate situations and thus minimizes the time taken to discover. The following table illustrates a pragmatic approach, based on Bloom's taxonomy of educational objectives[4] to help plan learning situations to teach concepts in science:

| ROLE OF | CONCEPTS RELATED TO | | |
|---|---|---|---|
| | KNOWLEDGE & COMPREHENSION | APPLICATION | ANALYSIS, SYNTHESIS & EVALUATION |
| TEACHER | Identifies the concepts and defines specific objectives | | Creates situations that help the student actualize his/her creative abilities. Terminal behavioral objectives known only to teacher |
| STUDENT | Aware of specific objectives of skills to be mastered and acquires them, to be tested later | | Aware of global objective and attempts to interrelate the concepts that he has mastered, to analyze, synthesize or evaluate a generic learning situation set by the teacher |

## IN THE CLASSROOM:

In the classroom, the act of passive learning can be transformed into a generic learning situation by directing the learner to come on his own to the desired conclusion. To save time, one way of directing can be done by posing appropriate questions that encourage/force the learner to use the knowledge that he has already acquired. Other methods include demonstrations and situations that require analysis, synthesis and evaluation. The key factor in all these methods is the way the question is put and the basic material is presented. The comprehension of the concept density is greatly increased by presenting it as the mass of unit volume while the ratio that density = mass/volume helps in mathematical manipulations. On the same token, the question "What information is needed to calculate the density?" might demand of the student more than a question that provides mass of a known volume of matter and asks for calculation of density.

## IN THE LABORATORY:

It is imperative in this method that the teacher design his own experiments and methods that are suitable to his course content and objectives. A detailed procedure to enable the student to carry out the experiment with less difficulty is necessary. However, one should be careful so that the student does not get the impression that he is following steps to success without having to know what is going on. A forewarning about the objective of forthcoming steps in the procedure is beneficial, e.g. now weigh exactly approximately 2 g sample into a beaker by the method of difference. This can be done.....
One must clearly avoid repeating the procedure of a technique in later experiments, e.g. once the student is introduced to a technique, say weighing by difference in the above example, the student must be expected to carry out the necessary procedure onmere mention of the name of the technique (the procedure in the above example could be recalled in later experiments by simply mentioning "now weigh exactly about 1 g by the method of difference").

## EXAMINATION:

A question in an examination that was considered to be difficult by all students is often difficult because it demands of them the ability to organize several skills and knowledge that they have learned. Such questions are not discriminatory. On the other hand, questions that test for skills and knowledge taught are inadequate to test for intuitive skills. Therefore, a generic questionnaire was developed. For this purpose the concepts to be tested on were divided into knowledge comprehension and application and analysis, synthesis and evaluation. For convenience an 80% and 20% respective division was made. Thus the generic learning concepts to be tested formed 20% of the examination.

Each question in the generic part of the examination was analyzed to find out the number of basic tasks to be performed. For those students who could not answer the original question a series of questions with clues that help reduce the number of tasks to be performed were formulated. This helped facilitate proper rewarding of the student's efforts as shown by his performance. The following question is a typical example. Before attempting the question, the student should be proficient in manipulating the concepts: (1) density = mass/volume, (2) $V_{sphere} = \frac{4}{3}\pi r^3$, (3) mass of $6.02 \times 10^{23}$ atoms is called atomic mass, (4) density and atomic mass tables and (5) that the atoms are spherical in shape.

Question I-1: Calculate the radius of a mercury atom. (10 points)

For those students who cannot answer this question, the question is repeated with clues or reconstructed to be answered in parts. Of course the point value will decrease as more clues are supplied.

I-2: Calculate the radius of a mercury atom. ( 9 points)
(Atomic mass = 200 g, density = 13.6 g/ml

I-3: Hint: 200 g of mercury contains $6.02 \times 10^{23}$ atoms (7 points)

I-4-A: Calculate the number of mercury atoms present in 13.6 g of mercury.

B: Calculate the volume of one atom of mercury.

C: Calculate the radius of one atom.

(5 points)

Those students who answer question I-4 show that they have mastered the skills involved, however, lacked the intuition that those students who answer I-3, I-2, and I-1 possess. Failure to answer I-4 indicates that the student has not mastered his basic objectives.

## CONCLUSION:

DAASAN Approach demands that the teacher be innovative in creating generic learning situations that are consistent with students' past experiences. It helps the student actualize his/her intuition and rewards the student's efforts accordingly while dispensing basic knowledge. Thus the DAASAN Approach combines the good aspects of lecture method and innovative methods that employ educational objectives and proposes a radically different way of testing that can be adopted even in computer assisted instruction.

In spite of the recent rapid growth in educational technology, it is becoming increasingly clear to educators[5,6] that the learning process requires the presence of a human being, which permits one to progress, to surpass oneself through mechanisms which are not always apparent. What other approach than the DAASAN Approach strives to achieve this?

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## How Can We Help Kids to Read Chemistry Textbooks

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Presented to a General Session of the Thirty-Eighth Two Year College Chemistry Conference, Pasadena City College, Pasadena, California, March 30, 1974.

I feel as though I have come full circle with this occasion. I began as an undergraduate at the University of California, Berkeley, majoring in chemistry. I knew more about the halogen family of atoms than I did the plantagenet family of English kings, an imbalance in my education that caused me to drop out of school for a year and read voraciously in other areas. When I came back to Berkeley, I changed my major to several disciplines in the liberal arts. In courses in Rhetoric and English, professors were dumbfounded by my writing, which one instructor described as a "nominal style." It took me the next two years of school and three years of teaching English to discover that the Rhetoric I mastered in my exposure to Chemistry and other science courses was significantly different from that in areas of the Liberal Arts. However, one can easily point to the discipline of English and cite words such as onomatopoeia and synecdoche as being jargon of the English teacher as easily as one can point to the specific terminology of the chemistry teacher.

A number of linguists in England are now studying the notion of "register," the language one uses in order to fit the situation he is in. Register is different from dialect which is usually geographical and also from usage which is generally societal: "register cuts across national, social, and regional tongues: it is a variety of a language distinguished according to use."[1] As teachers of chemistry, you spend a great deal of your time speaking to chemistry teachers or to your students whom you want to talk (think) like chemists. This register is not only reflected in the books you read and in the text you ask students to read, but it is continually reinforcing a certain rhetorical level of your reality. For the teacher, there is a predominance of exposure to the chemistry register, while for the student who has five other classes taught by teachers with linguistic variations appropriate to their content, there exist many registers which contribute to making a dilemma for the student.

Let's examine student Z who attends Period 1, a social studies class in which he is asked to read the following:

> Briefly stated the factors which governed the economic development of the southern, middle, and northern colonies and remained persistent through the colonial era were these In the south from Maryland to South Carolina manufacturing and commerce were subordinate to agriculture and traffic in furs...(The) staple products were carried in the ships of England or of other colonies...to England or the Continent (Europe) ...(In) return the manufactured goods of Europe were brought in large quantities to southern plantations to clothe the people or to furnish their homes. Thus the connection between these colonies and the mother country...was a very close one, because the colonies furnished the tobacco, sugar, dye woods, indigo, rice, ginger, and cotton that England needed.
>
> Discovering American History, Kownslar and Frizzle
> Holt.

Then 2nd period he attends a math class in which he is asked to read:

> There are two intake pipes to a large storage tank. Using the smaller pipe alone, it takes twice as long to fill the tank as it does using the larger pipe alone. The tank can be filled in 8 minutes if both pipes are used. How long would it take using only the smaller pipe?

Third period he is asked to read the two poems by Theodore Roethke:

CUTTINGS

Sticks-in-a-drowse droop over sugary loam,
Their intricate stem-fur dries;

But still the delicate slips keep coaxing up water;
The small cells bulge;

One nub of growth
Nudges a sand-crumb loose,
Pokes through a musty sheath
Its pale tendrilous horn.

This urge, wrestle, resurrection of dry sticks
Cut stems struggling to put down feet,
What saint strained so much.
Rose on such lopped limbs to a new life?

I can hear, underground, that sucking and sobbing,
In my veins, in my bones I feel it,-
The small waters seeping upward,
The tight grains parting at last.
When sprouts break out,
Slippery as fish,
I quail, lean to beginnings, sheath-wet.

Fourth period he comes to your class, he is assigned to read:

### 16-3.4 Ionic Character in Bonds to Hydrogen

In Chapter 8 the element hydrogen was characterized as a family by itself. Often its chemistry distinguishes it from the rest of the periodic table. We find this is the case when we attempt to predict the ionic character of bonds to hydrogen.

The ionization energy of the H atom, 313.6 kcal/mole, is quite close to that of the F atom; so we expect a covalent bond between these two atoms in HF. Actually, the properties of HF show that the molecule has a significant ionic character in the bond. The same is true in the O-H bonds of water and, to a lesser extent in the N-H bonds of ammonia. Examination of the properties of a number of compounds involving hydrogen indicates that the ionic character of bonds to hydrogen are roughly like that of bonds to an element having an ionization energy near 200 kcal/mole. We cannot predict, then, the ionic character of bonds to hydrogen from its measured ionization energy. The C-H bond has only a slightly ionic character. At the other end of the periodic table, gaseous lithium hydride is known to have a significant electric dipole, but with the electric dipole turned around. In LiH the electrons are spilled towards the H atom, leaving the Li atom with a partial positive charge. This is in accord with the low ionization energy of Li, 124.3 kcal/mole, which is well below the value of 200 kcal/mole that we have assigned to hydrogen. For our purposes, it suffices to discuss the bonding of hydrogen in terms of an apparent ionization energy near 200 kcal/mole.

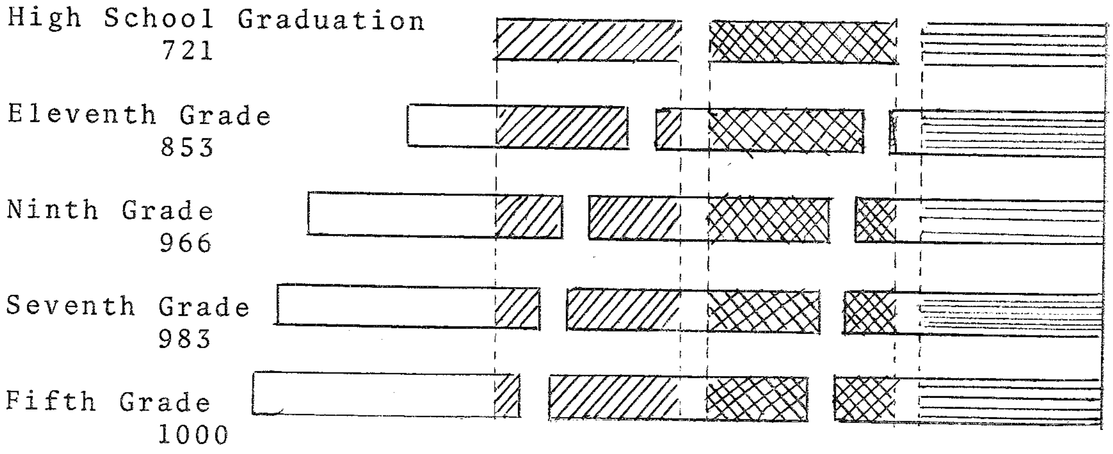
*Chemistry Experimental Foundations*, Prentice Hall

Now the student has a break for lunch and then takes his two afternoon classes in which a fifth and sixth language regi ter is used. For the verbally able, the student can down gear and adjust to each new language environment, but the majority of students do not possess this talent. In fact, if we studie population differentials we could see clearly why students appear to be scoring lower on tests like the SAT. In 1920, 49% of the freshman class in high school graduated in four years. The curriculum was adjusted to the syllabi in the content areas taught by professors at the nearest college. In 1934, 58% of the freshmen graduated. A new progressive curriculum was developed in response to this different population. With Sputnik the trend was to return to the academic, following Brunner, in order to teach students the structure of the discipline by introducing any concept to any group at any time, after which a spiral curriculum in that area further reinforces and broadens the students' understanding.

Paradoxically, in the 1960's minority groups challenged the drop-out phenomena and forced schools to hold in school 78% or more of the population until high school graduation, yet the content in the classes became increasingly abstract, specialized, and distilled of concrete data. Let's look at an average class in 1960 to see how our 1920 grading procedures affect the student population.

Figure 1

Estimated Retention Rates - Fifth Grade Through High School Graduation, 1960



In other words, the grading process is failure-oriented and meant to sort out the elite. Yet, in your classes you have kids who are not linguistically able or not so much as they wer 15 years ago.

So what are we to do? First, "Know Thy Language" and second, Abolish Grading. For this discussion, I will not follow u on the latter recommendation, but only focus down on the notion of language.

I am reminded of the adage, "I don't know who discovered water, but I know damn well it wasn't a fish". Language is so close to us that it is difficult and ego shattering to self-analyze our rhetoric. In chemistry more and more information has been discovered in the last 20 years. My father-in-law, a dentist, took Chemistry VIII, the study of hydrocarbons, as a semester course in 1927 at the University of California, Berkeley. I took the same course in 1957, but the number of hydrocarbons had tripled by that time. Today a chemistry VIII student not only has twice that many hydrocarbons to digest, but the course is no longer a semester long since Berkeley went to the quarter system.

Moreover, Dr. Alexandre Manuila, chief of the office of Publications and Translations of the World Health Organization, reports that an M.D.'s vocabulary is "about 150,000 words and to that one should include other specialized terms in the various subdividisions in medicine that will exceed 500,000".

How has the curriculum adjusted to the information explosion and exponential increase of lingo? Generally it has tended to be more and more abstract, more distilled from the data that undergirds the generalizations. But how much of the specifics can one cut out before readers are lost in abstractions? Let's compare two similar passages from two high school chemistry texts.

> Experimental Identification of Bases
>
> "Another group of materials identified by early experiments resemble acids in a few ways, but most of their properties contrast sharply with the properties of acids. For example, many compounds of this group resemble acids in that they contain combined hydrogen and dissolve in w water to give solutions that conduct electricity. On the other hand, these materials change red litmus to blue and cause many dyes to assume a color quite different from that found in acidic solution. The substances have a bitter rather than a sour taste and feel slippery. (Like acids, these substances are corrosive to the skin.) Finally, when we add one of these compounds to an acid, the identifying properties of both acid and the compound disappear; only electrical conductivity remains as a characteristic property of the mixture.
>
> Materials in this second class are called bases. Typical bases include sodium hydroxide (NaOH), potassium hydroxide (KOH), calcium hydroxide ($Ca(OH)_2$), magnesium hydroxide ($Mg(OH)_2$), sodium carbonate ($Na_2CO_3$), and ammonia, ($NH_3$).
>
> Chemistry Experimental Foundations
> Prentice Hall

Properties of Bases

"Almost every household uses a number of bases. Ammonia water is used for cleaning; lye is a commercial grade of potassium hydroxide; milk of magnesia which is magnesium hydroxide, is used as a milk laxative; baking soda, which is sodium bicarbonate, is used in the kitchen.

We will use ammonia water as our first example. Ammonia, $NH_3$, is a gas; it dissolves readily in water. The resulting solution is called ammonia water. (Years ago, the solution was called ammonium hydroxide, $NH_4OH$; but today, we know that this is incorrect. You may see the formula $NH_4OH$, however, on the bottles of ammonia water in your laboratory.) When ammonia is dissolved in water, it behaves as a fairly good base, not as good as some others, but good enough to take a proton from water. Here is the chemical equation;

$$NH_3 + H_2O \longrightarrow NH_4^+ + OH^-$$

This equation says that ammonia molecules react with water molecules to yield ammonium ions, $NH_4^+$, and hydroxide ions, $OH^-$. But it is also important to read it this way: Ammonia is a base, and it takes a proton from water to form ammonium ions and hydroxide ions. This way of saying it emphasizes that ammonia is a base.

However, ammonia water is a poor conductor. There is a dynamic equilibrium involved in this system similar to that for the weak electrolyte solution of acetic acid. The ammonium ion is an acid, and the hydroxide ion is one of the best bases known. So, about as soon as ammonium ions and hydroxide ions are formed, the reaction in the opposite direction occurs. In dynamic equilibrium there are few ions compared to the number of molecules. Here is the complete equation:

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

Keys to Chemistry
Addison Wesley

In the first passage notice the density of concept of bearing words that are deliberately abstract: "groups of materials," "properties," compounds, etc. Notice too the over-burdened subjects: "The identifying properties of acids and the compound." The abstract statements in the first paragraph are followed by specifics, but the specifics are formulas, another category of abstraction. The method of exposition is comparison and contrast.

In the second passage, on the other hand, the author first refers to commonplace objects that most students know. The mode of discourse here is also expository, but the familiar nouns "ammonia" and "milk of magnesia" precede the abstractions rather than follow, as they do in the first passage. There is abundant use of latin verbs, such as "dissolve","reacts". Also, the writer relies on the passive voice "the resulting solution is called...", although this writer uses the passive voice less than the author of the previous selection.

We have looked at language from two chemistry texts. The language is unique in that it requires a reader to slip from content to formula, which as in mathematics, constitutes an arbitrary symbolic code or artificial language in itself. The prose is supersaturated with concept-bearing words, with everydays words that have technical meanings in the context of chemistry, such as compound, which in linguistics refers to a type of noun and in archery a type of bow, and "resulting solution" to a novel is quite different.

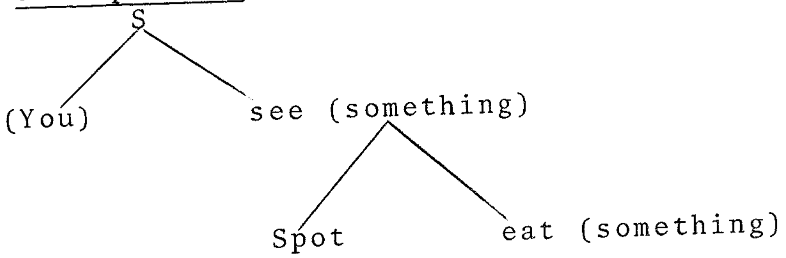
The language is terse, devoid of unnecessary adjectives. There is an absence of the narrative mode, the most natural mode of discourse the younger the student.

Consider the prior knowledge necessary to deal with abstractions. A chapter on atomic theory assumes the student is familiar with radioactivity, atomic structure, atomic weight, number, nuclear equations, isotopes, nuclear fission, reactors, control of the fusion process, etc. The language has a predominance of latin and greek roots and affixes. The author relies on the passive voice and has a tendency to use nominal phrases or nominal clauses functioning as the subject of the sentence.

We have identified the kind of language register of the chemistry text, let's look at it as first, vocabulary and second, syntax. Since 1960, chemistry textbook writers have made an earnest attempt to lessen the vocabulary load. Yet, that is not the real problem, for later on I will demonstrate how syntax really causes more obstacles than vocabulary. However, essential terms in a lesson should be taught experientially. James Britton in <u>Language, the Learner, and the School</u> transcribes a chemistry lesson in which students are looking at a piece of copper exposed to flame. The students comment on what occurs, then one of them says something to the effect that the copper turned black, because of the pollutants in the air, while another says no, it's because the flame is dirty, and the third comments that on the contrary the metal itself becomes black when exposed to heat. Soon the students recommend ways that these ideas can be tested, such as by putting another piece of copper strip in a test tube and putting it over the flame to see if the flame is the cause of the material becoming black. As Britton points out what follows, somewhat naturalistically with very little from the teacher, is that the students describe phenomena, then hazzard explanations, and then develop experimental situations to test these hypotheses. The teacher in this lesson did not use the word oxidation at all, and it was only supplied to the students after they had been discussing the phenomena and wondered what was an economic way of describing the process of a copper strip becoming black.

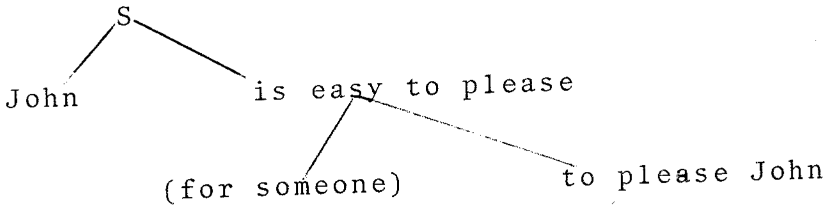
Now let's look at syntax. In the 1960's more became known about language acquisition and, therefore, cognitive development than ever before. The transformational generative linguist provided reading specialists with a handle with which to study language. Simple sentences that we assume children could read, we now know are incomprehensible for many of them. "See Spot eat." from an old fashioned second grade primer would give many students considerable trouble. What is in the subject slot, reading from left to right, is a verb; what is in the verb slot, is a noun; and what is in the object slot, is a verb that usually has a noun following it. Diagramatically this sentence looks like this:

See Spot eat.

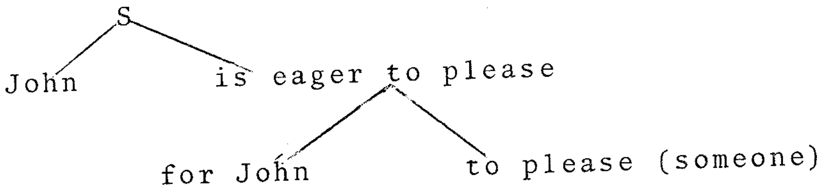


In the sentences "John is easy to please" and "John is ea eager to please", there are really no vocabulary words to trip up students. However, many students between the ages of 5 and 10 cannot comprehend the difference between these two sentences--that John is the object in the first sentence in the deep structure and is the subject in the deep structure of the second.

1. John is easy to please



2. John is eager to please



Carol Chomsky developed a rather fascinating test to demonstrate the developmental nature of internalizing transformational rules by having 40 children come in one at a time and look at a doll she had on her desk. The doll was blindfolded, she asked each child to answer the following question, "Is the doll easy to see?" If the student said yes, she would ask the child to describe it. If the child said "No", she would ask the child to do something so that the doll was easy to see. Among the younger students the children who answered in the negative took the bandana off the doll's eyes.

Now that we considered the problems of vocabulary and syntax, where are we? In the language polluted environment of the student taking six different classes, what is there for the chemistry teacher to do to help him read his assignments? Gordon Taylor has studied the language of chemistry textbooks and finds:

> "Pupils will find chemistry difficult in the early stages because the combinations of categories are unfamiliar and their assignation of linguistic units to the correct conceptual categories is uncertain. This is why a good deal of illustration from everyday life is necessary. But there are limits to how far this can be done, so that when the learner is trying to codify for himself the relations between various phenomena he is increasingly thrust back upon the purely symbolic operations of the language. The sorts of relationships with which any discipline deals are different in various ways from those of everyday life. This is why we can say with full seriousness that to learn chemistry is to learn the language of chemistry..."

He further comments that the sentences in chemistry textbooks generally fall into two categories; the attributive and the locative. The attributive statement is generally about the physical states and process so that verbs such as "like", "have", or "is", are used to signify attributes. On the other hand, chemical states or changes in the chemical make-up are described by using verbs such as, "make", "yield", "give", "form", "reduce", and "become"--the sentence contains a notion of something existing in space, hence the term locative.

"Matter is made up of very small particles" is an example of a locative sentence as opposed to a sentence such as "lead is dense".

Helping slow readers to understand this distinction in the textbook language of chemistry would be very helpful. Breaking down complex sentences to what the linguists call kernel sentences is another way of ehlping them digest complex, convoluted passages. For instance, take the sentence that begins Chapter 5 of Biological Science: Pattern and Process published by Holt. "Deciding what is living and what is not living is a more difficult task than we first thought." The subject of that sentence is "deciding what is living and what is not living", a difficult mouthful for students used to dinner conversations of monosyllabic utterances of "Give me that", "no", "Shut up". The teacher could rearrange the sentence: "Something is a more difficult task than we first thought" and ask the student, "What?" or begin chronologically, "We first thought something", "Something is a more difficult task", "Someone decides what is living and what is not living". By constructing the external sentences, larger and more abstract units of thought come closer to the student's linguistic accessibility. The passive is easily manipulated by the teacher. A dead sentence like, "The cat was dissected" becomes more vibrant and humorous by transforming it to "Somebody cut up the cat". The point is not to modify the language of chemistry textbooks, but to facilitate and bridge the student's own language, which has been overexposed to narrative modes of discourse and predominance of the active voice, to the point that the students begin to think chemistry which is revealed eventually in their own use of the language. In other words you identify the student's level of language acquisition and you manipulate the content of chemistry so that the student experiences language expansion.

Another step the chemistry teacher can take is to look at those reading skills or strategies that could most easily be developed and taught in a chemistry class rather than in any other particular subject. One can separate reading into three categories: reading the lines, reading between the lines, reading beyond the lines. Generally, the prose in a chemistry textbook should be read very carefully, very literally, as opposed to making inferences between the lines in order to find out the author's prejudice. In chemical problems one has to read so deliberately, so carefully, that each step must be carried out in the correct sequence or the solution to the problem will not be obtained.

Another area where the chemistry and science teacher can help students is in word-attack skills. Words like biosphere, lepidoptera, parthenogenesis, are examples of binomial nomenclature. English teachers try to purge latinisms from students' usage and replace them with shorter anglo saxon words so you can't look to them to encourage students to break down words. Sometimes words become excitingly vivid when broken down etymologically as is the case with a word like parthenogenesis. While discussing a word like telepathy, the teacher can give various forms of the word so that students can see the flexibility of polysyllabic words; telepathic, telepathically, and telepathisizing are some examples. From here the teacher can ask the student to go to the dictionary and look up telepathy and then list all words above and below until they lost the tele- morpheme. In Funk and Wagnall's Standard College Dictionary, published by Harcourt, Brace, there are nine words beginning with tele- until one comes to telemachus and there are 31 below telepathy.

A third strategy that a teacher can use to help students tackle their reading is to point out that chemistry is problem oriented, not chronologically-oriented, like social studies or English. Paragraphs conform to statements of problem or question with sentences that further illustrate or that hint at a solution with a concluding sentence that is generally the solution or answer to the question, or as we saw before, sentences that make up the body of the paragraph are often comparisons or contrasts.

A fourth technique is to encourage the students to use the SQ3R strategy which is nothing more than having them survey whatever they are to read from scanning the table of contents or scanning the subsections of a chapter. Most of the reading strategies advocated by speed reading enthusiasts recommend that the student read nonfiction. Therefore, social studies, chemistry and science are the obvious areas where one can help students develop the SQ3R method. This strategy is developed in the following sequence. After surveying or previewing to identify the author's purpose in writing, have students ask questions based on the materials surveyed, asking where, what, when, how, and why. Then the reader reads the assigned passage: he then recites highlights of what he has read: finally he reviews the passage.

A fifth recommendation is to make available to the students a variety of reading materials on the subject of chemistry or related areas. Periodicals like Science Digest and Scientific American are excellent for slow and able readers respectively. Hooking students on books like the Double Helix or Daniel Cohen's recent publication, Magic Art of Foreseeing the Future, denouncing the current vogue of parapsychology, would be very popular among young readers today.

Another strategy to consider is to read aloud articles on chemistry to students. These articles might be things that you have come across in the Saturday Review or other readings, and you want to use them to share your enthusiasm for the subject. This sharing can rub off on them. Also, it is a good idea with even the most able readers to read aloud material which the students have in printed form in front of them. One educator I have a great deal of respect for says, regardless of the subject or grade, one-fifth of the time in class a teacher ought to read aloud to the students. Many words that are in students' vocabularies are unfamiliar when they see them in print form. An episode in my own life testifies for that. I can remember my brother and I driving around Oakland when I was about in the 10th grade and asking my brother who the famous relative of ours was. He asked me what I was talking about and I said, "Everywhere we go I see signs with 'mortgage'". Even though mortgage was a part of my vocabulary when I saw it in print, my egocentricity led me to think that it was a relative.

Another technique which I am certain many of you, if not all, use though I think it should be stated in order to reinforce the practice, is that you should make obvious connections between illustrations or graphs that are in the text or to make visual representations of information that is in written form.

One problem that is evident in chemistry is that the teacher does not know what a student has been exposed to in science previously, let alone each of the 34 other students in the class. We have wasted too much time trying to articulate subjects from grade to grade. The young mind forgets so much that it would be better if we articulated among teachers having the same students in a day, articulating horizontally, rather than articulating vertically among the grades. When I taught, I usually began my class by having the students try to recall what we did the day before and ask where we are likely to go today. Many students draw blanks when asked, "What did we do here yesterday?" How can they be expected to remember vast sums of information from a class in biology that they took last year. The safest rule to follow on this question is to assume that the students know absolutely nothing and begin anew by getting them to learn the language about chemistry.

Another effective technique is to divide students into working groups, structured deliberately so that one very bright student and one slow student are in each of the groups. Group work affords you the opportunity to listen carefully to the language that the students use. Are they thinking and therefore revealing their chemistry register. Can they talk chemistry? One effective technique is grouping clusters of six, then number the students randomly from one to six. Roll a die to see who is going to take the test or solve the problem for the rest of the group who will share in his grade.

The final technique is to encourage students to study advertising on merchandise that is chemical in nature. Get them to read chemical breakdowns on soda pop labels. Correlate facts of chemistry with their everyday life.

In conclusion I would like to confess that these remedies to help students read chemistry texts did not come down with the last rain. Moreover, each in itself is no panacea, and likewise in concert they are not a panacea. However, reading aloud, illustrating, listening closely to the students' language, organizing the class in small groups, etc., promise to foster a greater degree of students languaging chemistry. As the London Association of Teachers of English suggest as the ubiquitous dilemma of all teachers:

> All teachers irrespective of the subject they teach face a common problem. Among the difficulties found are poor spelling, inability to cope with sentences and punctuation, incompetent note-taking, lack of skill with impersonal writing, failure to read and understand textbooks, and reticence in discussion. All these are problems of language. But language is the means by which we learn, understand and communicate; therefore, language development is the direct concern of every teacher.

## Consonant-Dissonant Relationships in the Teaching of Organic Chemistry

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One of the compelling arguments for the maturity of the science of organic chemistry is the extent to which the large numbers of facts and data, accumulated over the past 150 years have been welded into theories which are not only capable of explaining known facts, but also those which are not yet known. This would include the structural theory, the development of mechanism, and the recent ideas of orbital symmetry. One area of organic chemistry which has resisted unifying theory is synthesis.

Organic synthesis can be devided into two general activities:

(a) Functional group interconversion, and
(b) Assembly of large molecules from smaller ones.

While the former is easily learned by most students, the latter may present difficulties even to many graduate students, unless the problem is trivial. I recall grading an exam while I was a TA at UCLA where the student used a series of five Grignard reactions interspersed with enough functional group interconversions to prepare the product of one Grignard reaction for the next.

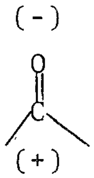
It is this exercise which bears no resemblance to actual practice and accomplishes nothing, save a few points on an exam that has earned synthesis a somewhat unsavory reputation. Based on the performance of the students, and the lack of any unifying theoretical concepts to teach, there has been some well placed criticism of the importance of synthesis by those who teach organic chemistry.

During the last three years, Professor D.A. Evans of the UCLA Chemistry department has developed some ideas which begin to tie together in a framework of theoretical unity some underlying principles upon which syntehsis can be based. I would like to share with you a few of these ideas which we teach our sophomore students, and to do that we will need to take a new look at an old idea.

For a general review of the old idea, I would refer you to a brief, but excellent article published a year and a half ago in J. Chem Educ. 49, 750(1972) entitled: Arthur Lapworth: The Genesis of Reaction Mechanism.

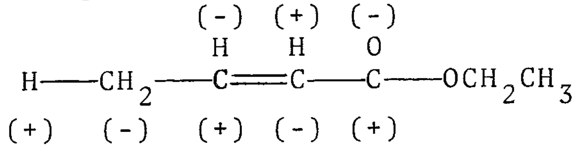
Lapworth was one of the early pioneers in the development of reaction mechanisms, and it is his idea of the "Theory of Alternating Polarities", now largely supplanted by newer theories, upon which we will draw.

Lapworth theorized that reactions could be understood by assigning relative alternating polarities to the atoms of a molecule based on electronegativity differences. Thus in the carbonyl group, on which he did much mechanistic work, the assignments would be:



In modern terms, we teach the chemistry of the carbonyl group using almost exactly this notation. The main difference is that we use the terms electrophilic and nucleophilic.

He didn't stop here, but postulated that like ionic compounds which are in fact made of a series of alternating positive and negative charges, organic molecules can be considered to be made of a series of atoms of alternating positive and negative latent charges. Let me illustrate using ethyl crotonate:

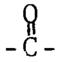


$$\underset{(+)}{H}-\underset{(-)}{CH_2}-\underset{(+)}{\overset{\overset{(-)}{H}}{C}}=\underset{(-)}{\overset{\overset{(+)}{H}}{C}}-\underset{(+)}{\overset{\overset{(-)}{O}}{C}}-OCH_2CH_3$$

Starting with the assignment of a negative to oxygen, we assign alternating negative and positive latent charges along the chain and its branches. The results are totally in accord with the chemistry of this molecule, i.e. both the carbonyl carbon and the $\beta$ carbon bear latent (+) charges and are electrophilic, a fact in complete harmony with conjugate addition (Michael reaction for example) and direct addition (Grignard reaction). Furthermore, the scheme indicates that the $\alpha$ and $\gamma$ hydrogens have a latent positive charge, and in fact, we know that compared to most hydrogens bonded to carbon, hydrogens on these atoms are quite acidic because they yield carbanions on the $\alpha$ and $\gamma$ carbons which are resonance stabilized, and note that both the $\alpha$ and $\gamma$ carbons have a latent negative charge. Lapworth used his alternating polarities to predict site reactivity in aliphatic and aromatic systems.

Now let us take a new look at Lapworth's ideas and apply them instead to organic synthesis. To do this, we will first need to define some terms and assumptions. The definition of functional groups has never been consistent, with some, such as hydroxyl and amino being defined without the carbon to which they are attached: $-OH$ $-NR_2$

while others are defined with the carbon attached such as carbonyl and nitrile:



$-\overset{O}{\overset{\|}{C}}-$ $-C\equiv N$

In order to maintain a consistent definition, we will define a function without a carbon bonded to the heteroatom, thus:

carbonyl becomes $=O$, and
nitrile is $\equiv N$

Again, no carbon is included in the definition of these functions, and the reasons should become apparent shortly.

One of the principles upon which our teaching of organic chemistry is based is that most chemistry occurs at the functional groups because of the ability of these groups to render the reference carbon electrophilic or nucleophilic, it becomes convenient to classify functions according to their ability to render a particular carbon atom nucleophilic or electrophilic. The first group of functions are those which render a carbon atom electrophilic, which we will, for mneumonic reasons, call E-functions, and they are:

$-OR$, $=O$
$-NR_2$, $=NR$, $N$
$-X$, where X = halogen.

The general designation for this class of untions is: $\underset{(+)}{C}---\underset{(-)}{E}$ . Some of the functional groups are obviously combinations of these simple functions, e.g. carboxylic acids.

The second category are those functions which render a carbon nucleophilic. This type of function requires a heteroatom which is less electrophilic than carbon, and these are essentially all metals. The organomagnesium and organolithium reagents are the major N functions which occur in a normal sophomore course. The general designation for this group is: C---N .
(-) (+)

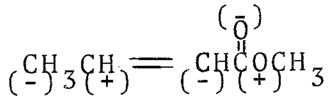
In addition to these two groups, there is a third classification whose members are able to confer both electrophilic and nucleophilic character on the adjacent carbon. These are the A-functions and you can see that this group contains somewhat esoteric functions which usually are not dealt with in the normal sophomore course. The general designation is: C---A
(±)

Using these basic definitions we are able now to generate a charge affinity pattern for any organic molecule containing one of these functions and this charge affinity pattern is nothing more than Lapworth's alternating polarities.

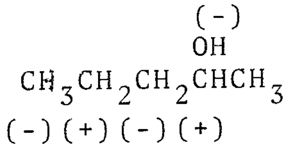
C---C---C---C---E
(-) (+) (-) (+) (-)

Notice that the charge affinity pattern will be the same, regardless of what the actual E function is. One of our essential principles is that problems associated with the generation of a specific atomic arrangement take priority over those dealing with the level of oxidation of either the carbocyclic skeleton or associated heteroatoms.

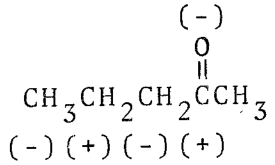
Thus our previous charge affinity pattern fits equally well any of the following molecules:



$\underset{(-)}{CH_3}\underset{(+)}{CH}=\underset{(-)}{CH}\underset{(+)}{\overset{\overset{(-)}{O}}{\overset{\|}{C}}}OCH_3$



$\underset{(-)}{CH_3}\underset{(+)}{CH_2}\underset{(-)}{CH_2}\underset{(+)}{\overset{\overset{(-)}{OH}}{CH}}CH_3$

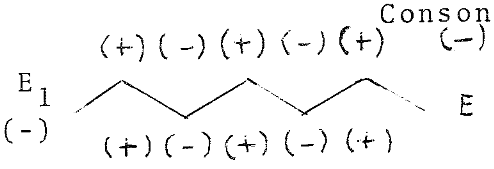


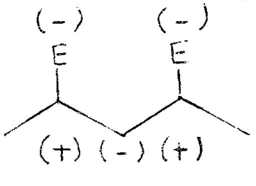
$\underset{(-)}{CH_3}\underset{(+)}{CH_2}\underset{(-)}{CH_2}\underset{(+)}{\overset{\overset{(-)}{O}}{\overset{\|}{C}}}CH_3$

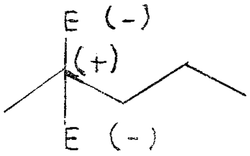
The value of this notation comes when there are two or more functions in the molecule. When this occurs, there are two possible relationships between the charge affinity pattern generated from each function. For simplicity, I will confine my discussion fo E-functions only.

(1) They are in phase with each other, i.e. a carbon which bears a latent (+) charge generated by $E_1$, also bears a latent (+) charge generated by $E_2$. Such a relationship is called "consonant." All 1,1; 1,3; 1,5 etc. di-E functions have consonant relationships.

Consonant Relationships

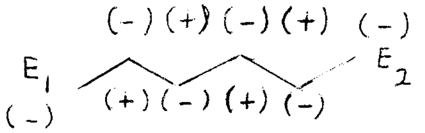


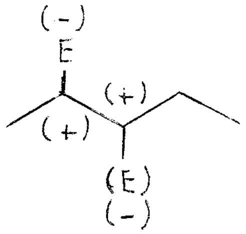




(2) When the charge affinity pattern generated by two E functions is out of phase, i.e. a carbon bearing a latent (+) from $E_1$, bears a latent (-) from $E_2$, the relationship is called dissonant. All 1,2; 1,4; 1,6 etc. di-E functions have dissonant relationships.

Dissonant Relationships





Now we are ready for a concept which students have heard again and again. Opposites attract, and likes repel, i.e. bonds are formed when a nucleophilic atom attacks an electrophilic atom. Or another way, bonds are generally not formed by electrophilic attack on another electrophile or by nucleophilic attack on a nucleophile.

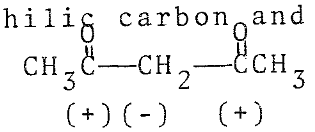
A caution: This works only for polar reactions, but the exlucsion of free radical processes is not a serious problem for two reasons:

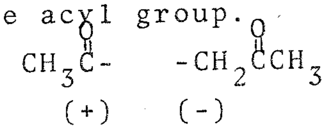
(1) There are only a few viable synthetic reactions which follow a radical mechanism, and

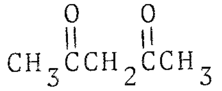
(2) Biological reactions are overwhelmingly polar, in fact, there have been some arguments made that radicals are antagonistic to the biosystem.

Consider the synthesis of the consonant molecule acetylacetone from monofunctional precursors. The synthesis can be accomplished by forming either bonds 2-3 or 3-4 (a degenerate process). By either route, a nucleophilic atom becomes bonded to an electrophile and the only problem is simply defining the source of nucleophilic carbon and the acyl group.

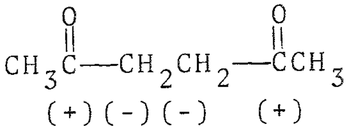
Acetylacetone


$CH_3\underset{(+)}{\overset{O}{\overset{\|}{C}}}\text{—}\underset{(-)}{CH_2}\text{—}\underset{(+)}{\overset{O}{\overset{\|}{C}}}CH_3$


$CH_3\underset{(+)}{\overset{O}{\overset{\|}{C}}}\text{-} \qquad \text{-}\underset{(-)}{CH_2}\overset{O}{\overset{\|}{C}}CH_3$

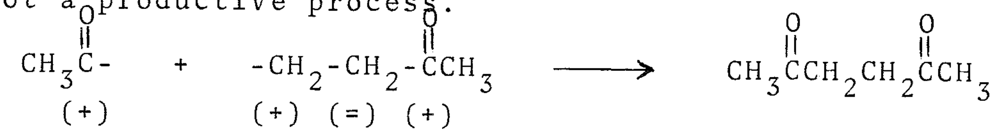

$CH_3\overset{O}{\overset{\|}{C}}CH_2\overset{O}{\overset{\|}{C}}CH_3$

On the other hand, dissonant molecules cannot be synthesized directly by a polar reaction pathway and a single example will demonstrate the validity of this statement. Consider 2,5-hexanedione:

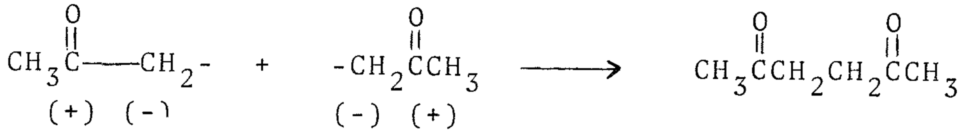

$CH_3\underset{(+)}{\overset{O}{\overset{\|}{C}}}\text{—}\underset{(-)}{CH_2}\underset{(-)}{CH_2}\text{—}\underset{(+)}{\overset{O}{\overset{\|}{C}}}CH_3$

To form the bond between carbons 3-4 requires interaction between two nucleophilic carbon atoms, which does not happen. Alternatively, formation of the bonds between carbons 2-3 or

4-5 requires interaction between two electrophilic atoms, again, not a productive process.



$$\underset{(+)}{CH_3\overset{O}{\overset{\|}{C}}-} \quad + \quad -\underset{(+)}{CH_2}-\underset{(=)}{CH_2}-\underset{(+)}{\overset{O}{\overset{\|}{C}}}CH_3 \longrightarrow CH_3\overset{O}{\overset{\|}{C}}CH_2CH_2\overset{O}{\overset{\|}{C}}CH_3$$

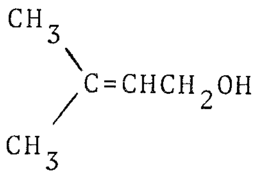


$$CH_3\underset{(+)}{\overset{O}{\overset{\|}{C}}}\text{——}\underset{(-)}{CH_2}- \quad + \quad -\underset{(-)}{CH_2}\underset{(+)}{\overset{O}{\overset{\|}{C}}}CH_3 \longrightarrow CH_3\overset{O}{\overset{\|}{C}}CH_2CH_2\overset{O}{\overset{\|}{C}}CH_3$$

We introduce our students to C,D at a point about half way through the second semester, although I am strongly considering moving it ahead to near the beginning of that semester. Their first use is in synthesis, and after an introduction to the principles I have outlined previously, we classify reactions in terms of the relationships between functions. That is, we list all those which will lead to a 1,2 di-E functions; 1,3 di-E functions, $\alpha$-$\beta$ unsaturated E function, etc, and then we ask the student to think analytically about a synthetic problem.

To illustrate:

Synthesize



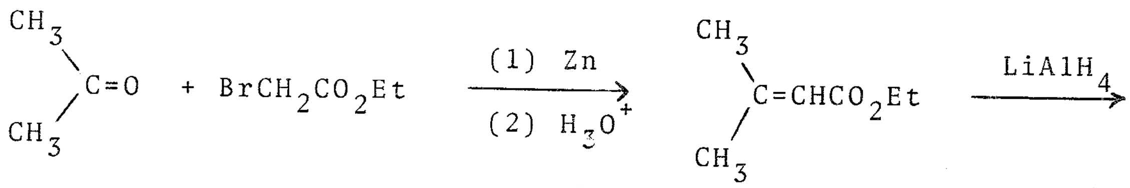
using any mono-functional organic compound with three carbons or less, plus needed inorganic reagents.

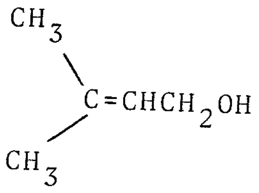
Generally, when a student sees a problem like this, he says,". . . alcohol? Grignard! Even if he reviews all the ways to make alcohols, confusion may set in simply because the reactions leading to alcohols can be classified as:

(a) changes in oxidation level (i.e. functional group interconversions)

(b) reactions which build up the carbon skeleton while simultaneously generating an alcohol.

We try to get the students to think of this molecule not as an alcohol, but as an $\alpha$-$\beta$ unsaturated E function. Now he can look up in his handout all the ways of synthesizing this relationship. He dives into his text, hoepfully, and studies these reactions until he surfaces with a viable pathway and if he did a good job, he may use a Reformatsky reaction.





And now the problem is a simple functional group transformation which can be accomplished with $LiAlH_4$.

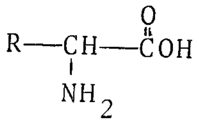
The use of C,D makes a definite improvement in the quality of work when the student makes a conscientious effort to apply the principles and work the problems we assign him.

There are also good applications of the C,D principles in solving mechanistic problems which I will not elaborate on due to time.

The problem of synthesizing dissonant molecules is more than academic, since a large number of biological molecules are dissonant. For example

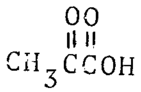
Dissonant Biological Molecules

-amino acids



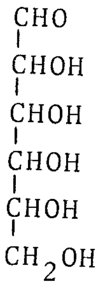
$R—\underset{\mathrm{NH_2}}{\underset{|}{\mathrm{CH}}}—\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{OH}$

pyruvic acid



$\mathrm{CH_3}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{OH}$

saccharides



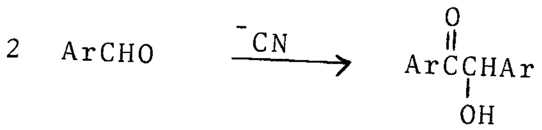
$$\begin{array}{l}\mathrm{CHO}\\ |\\ \mathrm{CHOH}\\ |\\ \mathrm{CHOH}\\ |\\ \mathrm{CHOH}\\ |\\ \mathrm{CHOH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

The methods of synthesis of dissonant molecules are many and varied, but they are not as direct as methods of synthesis of consonant molecules. Of these methods, we teach only the process of polarity inversion.

Inversion operator: a molecule, or molecular fragment which has the potential of inverting the latent or actual charge on an atom.

To see how this works consider the benzoin condensation which, because of its specific requirement for cyanide ion catalysis, baffled chemists for many years.

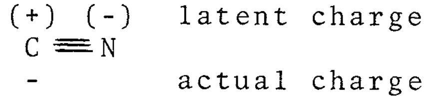
Benzoin Condensation



$$2\ \mathrm{ArCHO} \xrightarrow{^{-}\mathrm{CN}} \mathrm{Ar}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\underset{\mathrm{OH}}{\underset{|}{\mathrm{C}}}\mathrm{HAr}$$

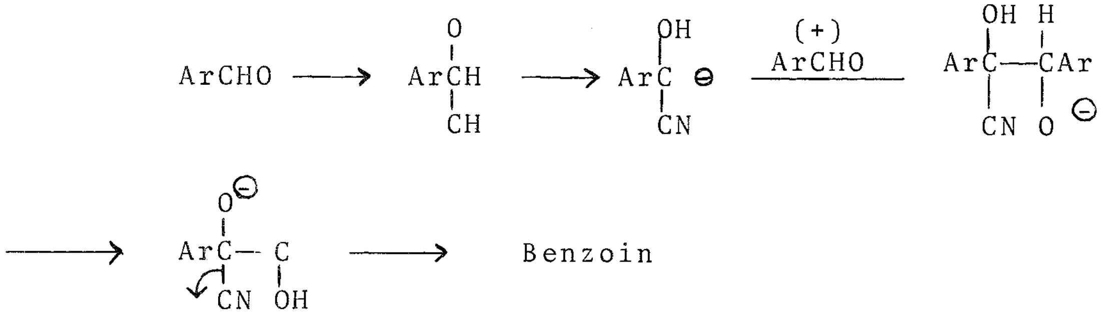
This reaction seems to violate our C-D principles since it requires the coupling of two electrophilic carbons and gives as a product two E functions in a 1,2 relationship.

To harmonize this discrepancy with our theory, let us look first at the nature of cyanide. The nitrile is classified as an E function because of its ability to render the adjacent carbon electrophilic and this should be true whether we deal with a nitrile or cyanide ion itself.

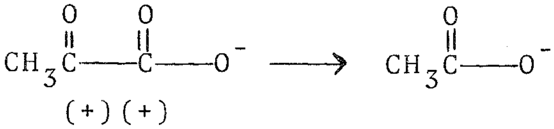


$$\underset{-}{\overset{(+)\ (-)}{C \equiv N}} \quad \begin{matrix}\text{latent charge}\\ \\ \text{actual charge}\end{matrix}$$

But the cyanide carbon has an actual negative charge, it has both electrophilic and nucleophilic potential. Cyanide is an inversion operator. Here is how it works.



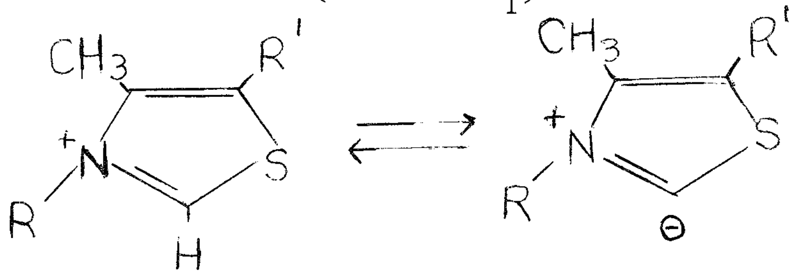
The natural question to ask, then is: Since the body must also synthesize dissonant molecules, are there perhaps biological inversion operators? One of the steps in the metabolism of glucose to carbon dioxide is the conversion of pyruvate to acetate.



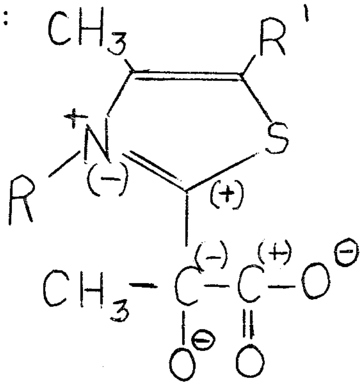
$$CH_3\overset{O}{\overset{\|}{\underset{(+)}{C}}}—\overset{O}{\overset{\|}{\underset{(+)}{C}}}—O^- \longrightarrow CH_3\overset{O}{\overset{\|}{C}}—O^-$$

As this sequence of reactions is presented, I point out that the relationship between the two carbonyl groups is dissonant and that just as we can not directly form dissonant relationships by polar reactions, neither can we break bonds between dissonant functional groups. Since biological reactions are overwhelmingly polar, how does the body accomplish this? Students are now ready to understand the catalytic role of thiamine, vitamin $B_1$.

Thiamine (Vitamin $B_1$)



The carbon between the nitrogen and sulfur is quite acidic due to stabilization of the carbanion by back donation into the low lying d orbitals on sulfur, and a substantial amount of the conjugate base is present under physiological conditions. Generation of a charge affinity pattern shows that this central carbon has a latent positive charge and an actual negative charge. Thiamine is a biological inversion operator. Nucleophilic attack by thiamine on the ketone carbonyl generates the following intermediate:



Inspection of the charge affinity pattern shows that the central carbon has had a polarity inversion and now decarboxylation occurs smoothly in accordance with the established rules of polar reactions. The use of C-D affords an easy explanation for the tortuous mechanistic pathway of what appears to be a simple reaction.

Our final use of C-D, then is in teaching biochemistry, particularly metabolism. The elegant explanation of the role of thiamine is but one example, there are many more.

The idea of consonant-dissonant relationships has been well accepted at four year colleges and major universities all over the country as a valuable tool in research. It was, however, originally devised for teaching undergraduate students (albeit upper division). It also has excellent applications in teaching lower division students and I would exhort you to study this new and exciting application of an old idea and give it a try.

If you would like more information, please contact myself or, better:

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## INNOVATIVE IMAGES

### Chemistry Economics Laboratory

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In the second course of non-science major general chemistry, we introduce chemical economics by asking students to select a consumer good, i.e. cough syrups, and to investigate the contents and price of as many of the varieties as possible. Students compile a report indicating the contents of the product (based on labels) and the action of each ingredient (based on Merck Index). Prices/unit determinations are made and appropriate conclusions based on content and price are included as a part of the exercise report.

Consumer chemistry investigations are done in addition to four to five "wet" laboratories during the quarter. Student response and activity have been very encouraging.

# NUCLEAR POWER

## Nuclear Fusion Research

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Presented to the Symposium on Nuclear Power: Today and Tomorrow at the Forth-Second Two-Year College Chemistry Conference, Houston, Texas, December 6, 1974.

Fusion is a nuclear reaction in which the nuclei of two light elements collide and combine to yield other nuclear particles. In this process, a part of the initial nuclear mass is released as energy in accord with the celebrated relation $E = mc^2$. Such reactions involving a variety of elements are the energy source of the sun and starts.

In the present search for a new source of energy which is capable of meeting mankind's needs for ever increasing amounts of electric power as well as compatible with the preservation of our environment, fusion energy excells both in promises and problems. If fusion energy can be harnessed to generate electricity, its advantages will include:

1. A virtually limitless and inexpensive supply of fuel;
2. No radioactive waste products;
3. No combustion products discharged to the environment;
4. No possibility of a runaway nuclear accident;
5. Reduced thermal pollution as a result of higher power plant efficiencies. Plant efficiencies may exceed 50 per cent using conventional generators, with the additional potential (through direct conversion of fusion energy into electrical power) of advanced reactor efficiencies of greater than 80 per cent. With

direct conversion, waste heat disposal will be essentially eliminated.

6. Fast breeding of fissionable fuel for existing nuclear power plants.

Controlled thermonuclear fusion also has numerous potential application in areas other than power production (see "The Prospects of Fusion Power" by William C. Gough and Bernard J. Eastlund; Scientific American, February 1971), but such considerations are beyond the scope of this paper.

The problems involved in producing electric power from controlled thermonuclear fusion, however, are equally as staggering as its promises. Leaving details until later, to achieve fusion power one must:

1. Heat a small amount of fusion fuel to temperatures of at least 100 million °C - ten times hotter than the interior of the sun.
2. Confine the hot fuel until more energy is released by fusion reactions than was used in heating. Because of the enormous temperatures, no material structure can be used for this confinement.
3. Convert the fusion energy released to a useful form--namely electric power.

Around 20 years ago, research into methods of heating and confinement began with enthusiasm in the U.S., U.K., and U.S.S.R., under a cloak of secrecy. In a very few years both the enthusiasm and secrecy were dispelled; principally because Mother Nature appeared to have an endless assortment of tricks by which to foil every clever attempt to achieve fusion. Disappointment prevailed until around 1968 at which time a breakthrough occurred in the Soviet Union. The Russians, using a fusion device called the Tokamak, announced they had accomplished a major fusion advance. Although the Russian Tokamak performance was substantially short of the fusion goal, it gave renewed optimism to fusion researchers. As a result of further success with tokamak-type devices in the U.S., U.K., and other countries, it appears hopeful that the feasibility of fusion power will be demonstrated in the early 1980's. But rather than belabour the historical aspects of fusion research, let me discuss in somewhat more detail the requirements to achieve fusion power.

## FUSION FUNDAMENTALS

Deuterium and tritium, in a gaseous 50-50 mixture is the proposal fuel for the first generation of fusion reactors. These hydrogen isotopes are favored because they are the least difficult to fuse. Furthermore, deuterium exists in sufficient quantity in the oceanic waters to satisfy any conceivable energy demands for thousands of millions of years. The cost of extracting it by isotope separation amounts to less than 1% of the production cost of an equivalent energy unit of fossil fuels. On the other hand, the tritium supply is small, being comparable to that of uranium. This does not present a fuel limitation, however, since neutrons released by the deuterium-tritium reaction can be used to breed more tritium within the reactor. The more important fusion reactions in a D-T reactor are presented in Table I. Only helium, an inert noble gas, remains after the fuel is expended.

Table I

FUSION REACTIONS

(1) $D + D$ —— $He^{3} + n + 3.25$ Mev

(2) $D + D$ —— $T + p + 4$ Mev

(3) $T + D$ —— $He^{4} + n + 17.6$ Mev

(4) $He^{3} + D$ —— $He^{4} + p + 18.3$ Mev

At thermonuclear temperatures, matter breaks up into a gaseous mixture of free negatively charged electrons mixed with free positively charged nuclei. Matter in this state is called a plasma. The fact that the plasma particles are electrically charged has profound consequences in harnessing fusion energy.

To begin with, for fusion to occur the nuclei must approach close enough for the short range but strong nuclear forces to bind them together. On the other hand, the like charges of the nuclei exert a force acting to keep them apart. To overcome this repulsion force, the nuclei must collide with large velocities. In the context of a plasma, this leads to the unavoidable requirement for enormously high temperatures. This in turn raises the problem of how to contain such hot plasmas. Incredulously, the fact that the plasma particles are charged also provides the solution to containment problem it gave rise to. A charged particle moving along a magnetic field line is constrained to a helical spring-like trajectory. Plasmas therrfore can be guided by magnetic fields. By suitable shaping of the field lines, magnetic bottles can be formed to contain the plasma and isolate it from material surfaces. In an ideal magnetic bottle, plasma would only be able to escape as a result of Coulomb collisions between particles which enable the particles to jump from one magnetic field line to another and eventually jump out of the magnetic bottle. This process would continue until the plasma cooled down to the temperature of the nearest material wall. Mother Nature, however, has a bewildering variety of short-cuts, called instabilities, to speed up the loss of plasma from magnetic bottles. For the past

10 years or more, nuclear fusion research has been to a large measure an endeavor to understand magnetic confinement and to conquer the instabilities which defeat effective confinement. As noted earlier, confinement need only be long enough for a net return of energy. The crucial point then is not that magnetic bottles be ideal, but that they work sufficiently well to satisfy this requirement.

To achieve a positive energy balance, it is necessary that the product of fuel density (n) and energy containment time ($\tau$) exceed a value specified by the Lawson criterion. For a deuterium-tritium fuel at 100 million °C, this value is

$$n\tau \geq 10^{14} \text{ sec cm}^{-3}$$

For economical reasons, tokamak-type reactors are envisioned to operate at a fuel density of $10^{14}$ particles per cubic centimeter so that confinement times of the order of 1 second are required. Different combinations of density and confinement times are applicable to other fusion devices.

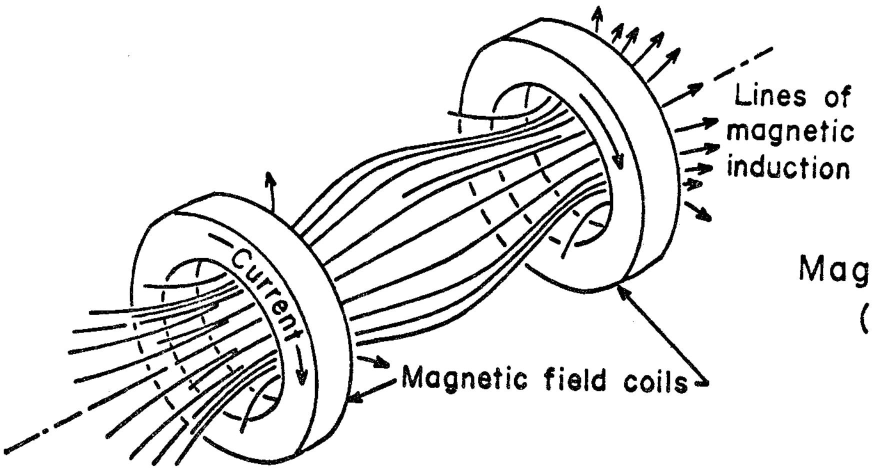
In summarizing the above considerations, to achieve a net return of energy in a deuterium-tritium fusion reactor, fuel must be heated to 100 million °C and be confined for a time such that the product of fuel density and confinement time exceeds $\sim 10^{14}$ $\text{cm}^{-3}$ sec. Now let's see where fusion research stands in achieving these requirements.

## APPROACHES TO FUSION

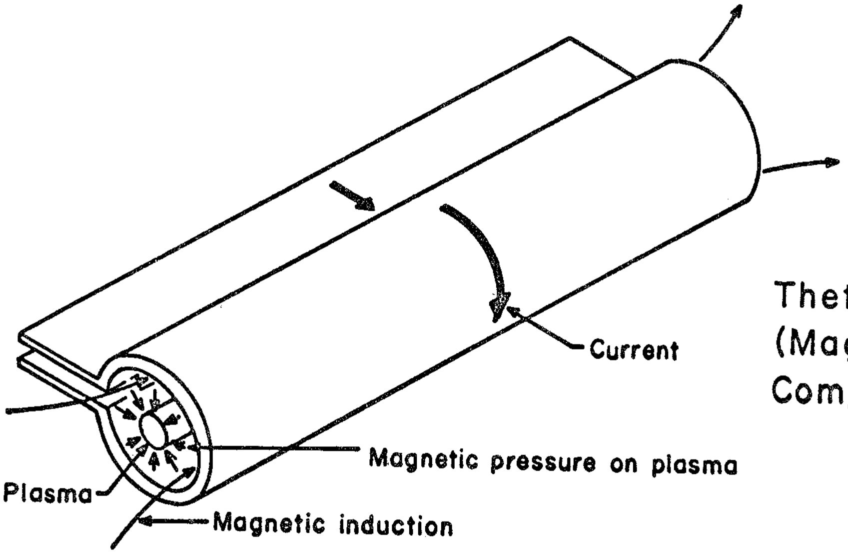
The approaches to controlled fusion are characterized primarily by the search for an effective magnetic confinement scheme. An exception to this is the relatively recent concept of laser fusion. In this scheme, a powerful laser pulse is used to heat a small solid pellet of deuterium and tritium to thermonuclear temperatures. The heating is so rapid that the inertia of the fuel holds it together sufficiently long for fusion to occur. Concurrently, methods of heating the plasma to be confined in the various magnetic bottles have been investigated. An exhaustive review of heating and confinement experiments would be to lengthy, so only a few representative examples will be cited.

Several magnetic confinement schemes and their associated heating mechanisms are illustrated in Figure 1. With simple mirror configurations, hot plasma is injected into the magnetic trap from specially designed plasma guns. Additional heating is achieved by ionizing and trapping of energetic neutral beams injected into a contained plasma. In theta pinch devices, the confining magnetic field also provides heating by compressing an initially cool, dilute plasma into a hot, dense one. The above confinement schemes are known as open magnetic field configurations, since the magnetic field lines extends to regions outside the plasma. In closed magnetic bottles, such as the Tokamak, the magnetic field lines are constrained within the same volume of space occupied by the plasma.

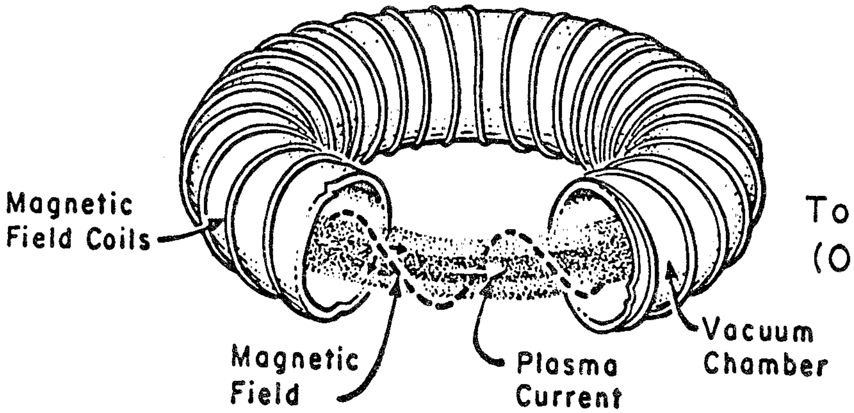
# Examples of Magnetic Confinement and Plasma Heating Schemes.



Magnetic Mirror
(Injection)



Theta Pinch
(Magnetic
Compression)



Tokamak
(Ohmic)

Figure 1

Examples of magnetic confinement and plasma heating schemes.

The plasma in a Tokamak is ohmically heated by passing large electric currents through the gas. Combinations of different heating mechanisms have been applied simultaneously to a given magnetic confined system. For example, in Tokamak plasmas, initial ohmic heating has been supplemented by injection of energetic neutral beams and/or magnetic compression.

The current status and anticipated advanced of typical fusion experiments is illustrated in the so-called Lawson diagram shown in Figure 2. At the present time, near thermonuclear temperatures and n$\tau$ values of $10^{12}$ have been attained. The next generation of experiments scheduled for operation around 1976 are expected to reach higher temperatures and n$\tau$ values of $\gtrsim 10^{13}$. Other experiments at present in the design stage promise to demonstrate fusion "breakeven" by 1980. At the present time, the favored candidate for demonstration of fusion feasibility is a toroidal device of the Tokamak type.

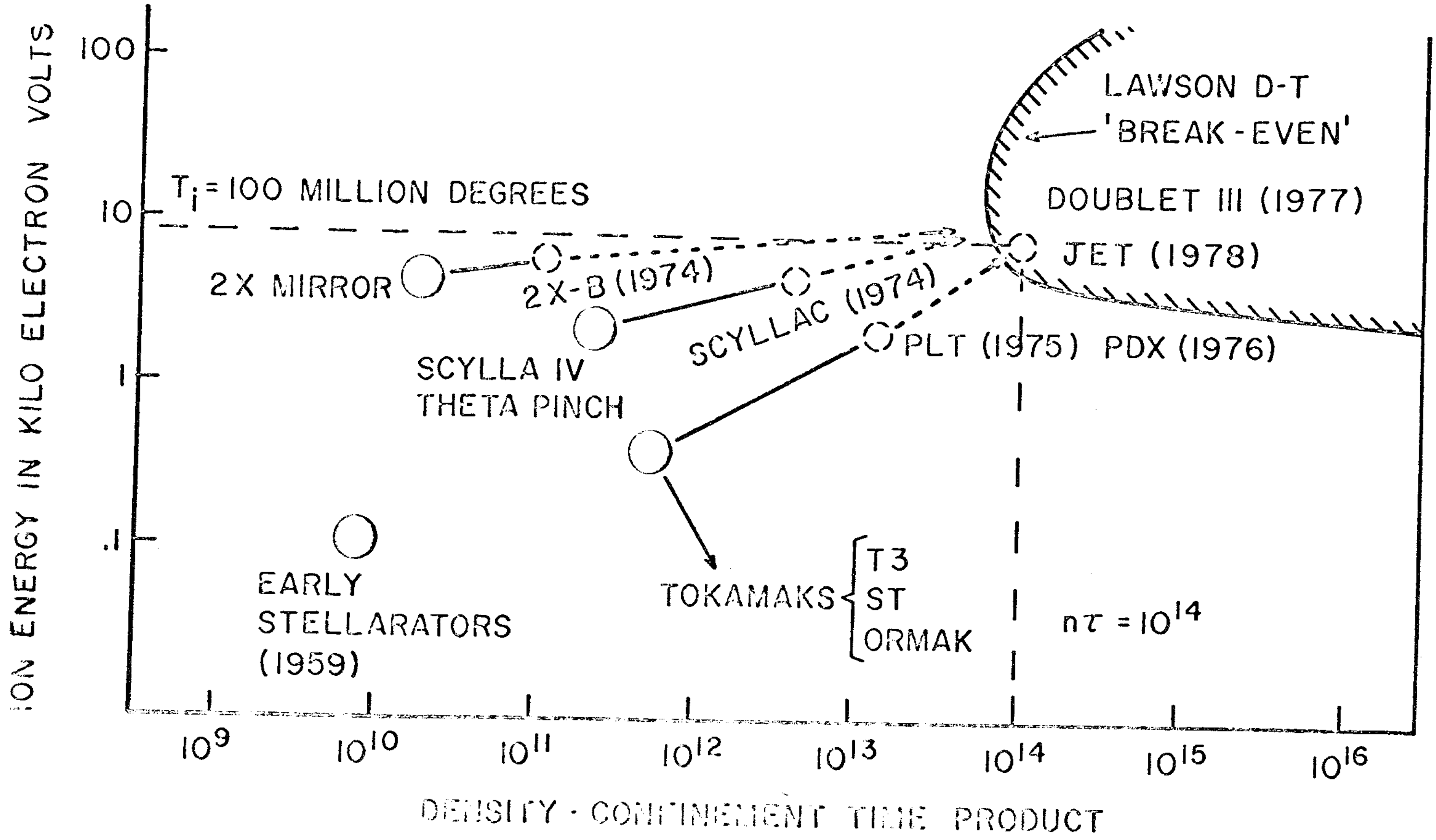


Figure 2

Fusion feasibility requirements and some experimental results.

## TEXAS TURBULENT TORUS

The Russian T3 Tokamak achieved temperatures around 20 million°C using ohmic heating; that is, heating by passing electric current through the plasma. From the physics of plasmas, however, it can be shown that ohmic heating alone cannot produce the considerably higher temperature required for thermonuclear fusion. The concept of the Texas Tokamak is to combine a more powerful type of ohmic heating, known as turbulent heating, with the Tokamak magnetic confinement field. Turbulent heating is produced by suddenly applying a large electric field to an initially cold plasma. Turbulence creates an enhanced e resistance to the flow of plasma current and thus enhances the ohmic heating. As a result, plasma temperatures of more than 100 million°C are attainable in the Texas Tokamak.

The main parameters of the Texas Tokamak were chosen so that the plasma would be similar in most respects to that in the T3 experiment, with the exception that higher temperatures would be reached by applying turbulent heating. The capability for applying turbulent heating distinguishes this device from other existing Tokamaks and profoundly affects the method of construction. A schematic drawing of the Texas Tokamak is shown in Figure 3.

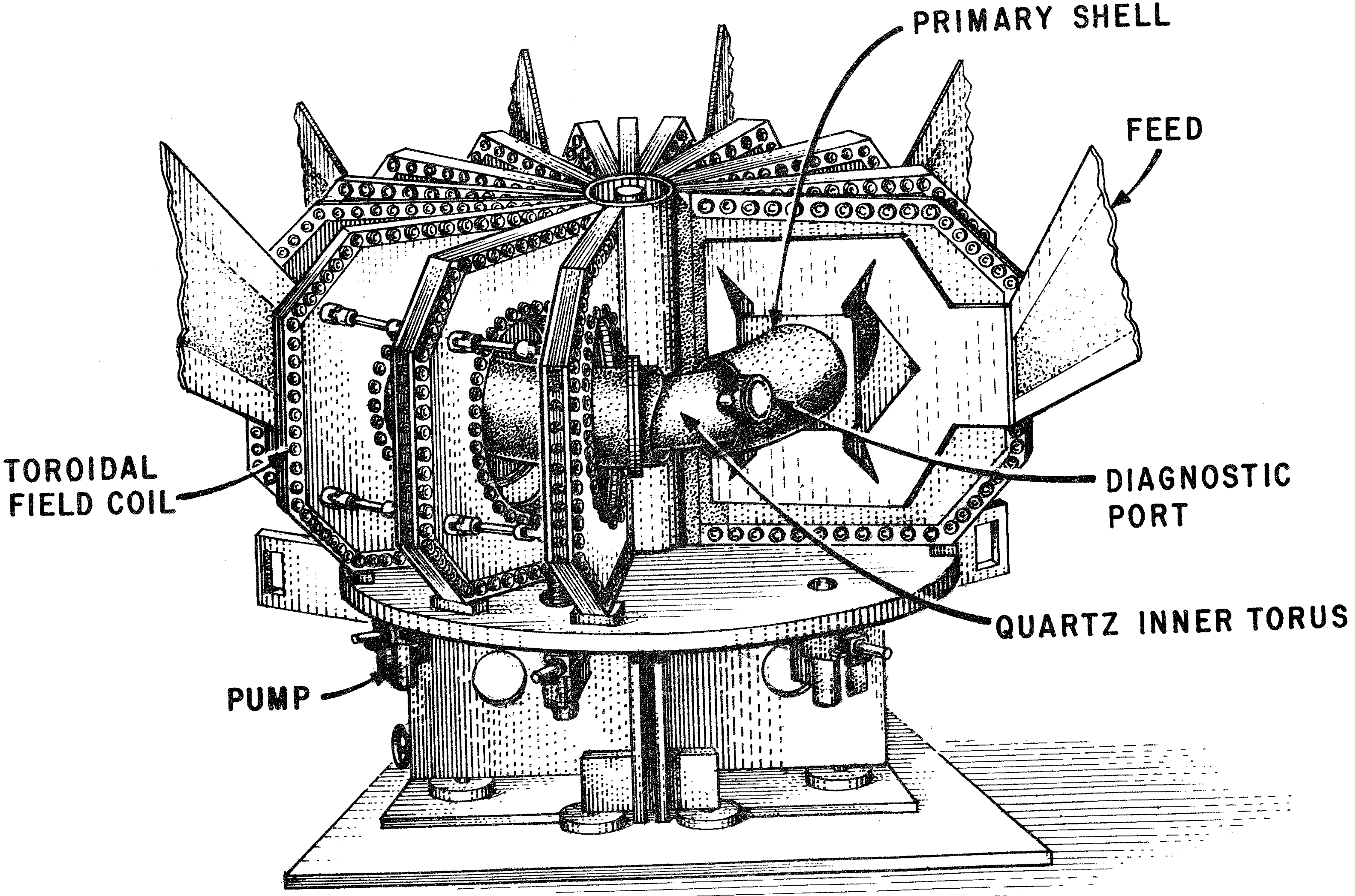
As in conventional Tokamaks, the magnetic bottle results from combining the relatively weak magnetic field due to the plasma current with a stronger toroidal field produced by an external coil. The toroidal field of 12 kGauss is generated by a set of 16 Bitter disc coils having a total mass of 7 tons of copper. The coils are energized from a battery of 360 submarine cells which are connected to supply 12,000 amperes at 400 volts.

The plasma ring having a major radius of 60 cm and minor radius of 9.5 cm is formed inside a toroidal vacuum chamber or torus which is constructed in eight toroidal sectors, each consisting of aluminum shell with a quartz liner on the inner wall. The vacuum seal between sectors is made with silicone rubber gaskets and the interior of the quartz chamber is evacuated to approx. $10^{-6}$ Torr using a turbo-molecular vacuum pump. Before operating the experiment, the chamber is filled with hydrogen gas to a pressure of approx. $10^{-3}$ Torr.

The toroidal aluminum shell and the enclosed ring of plasma form an air-cored transformer. The aluminum shell is the primary winding, the plasma is the secondary and the quartz provides electrical insulation between the two. Electric current is induced in the plasma by connecting the primary to an overhead bank of capacitors through transmission feed lines. The low inductance air-cored transformer arrangement enables the large electric fields necessary for turbulent heating to be applied to the plasma.

Although firing the experiment involves a complex sequence of events, the salient features can be described briefly. A bank of "slow" capacitors is discharged through the primary of

Figure 3



Schematic of Texas Turbulent Tokamak.

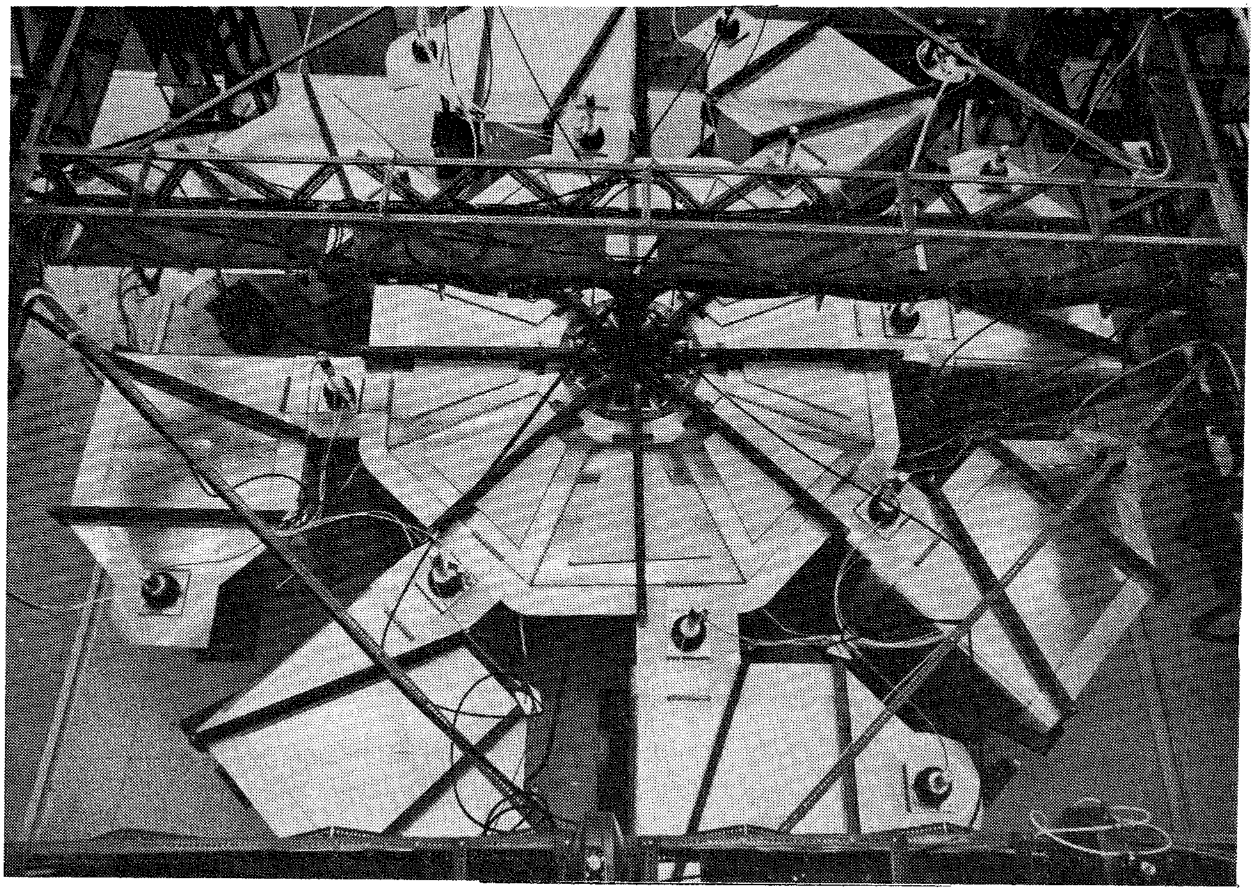
the torus to produce in the magnetic bottle an initial cold hydrogen plasma having a temperature of about 50,000 °C and a density in the range of $10^{12}$ - $10^{13}$ particles per cubic centimeter. A "fast" capacitor bank charged to the order of 40,000 volts is then fired. This fast discharge applies an electric field of 200 volts/cm or more to the plasma and causes the plasma current to rise to 100,000 amperes in less than 1 microsecond. During the current rise, the plasma becomes turbulently heated to temperatures in excess of 100 million °C. After heating, the capacitor banks are crowbarred (isolated from the torus primary), leaving a hot plasma in Tokamak magnetic confinement.

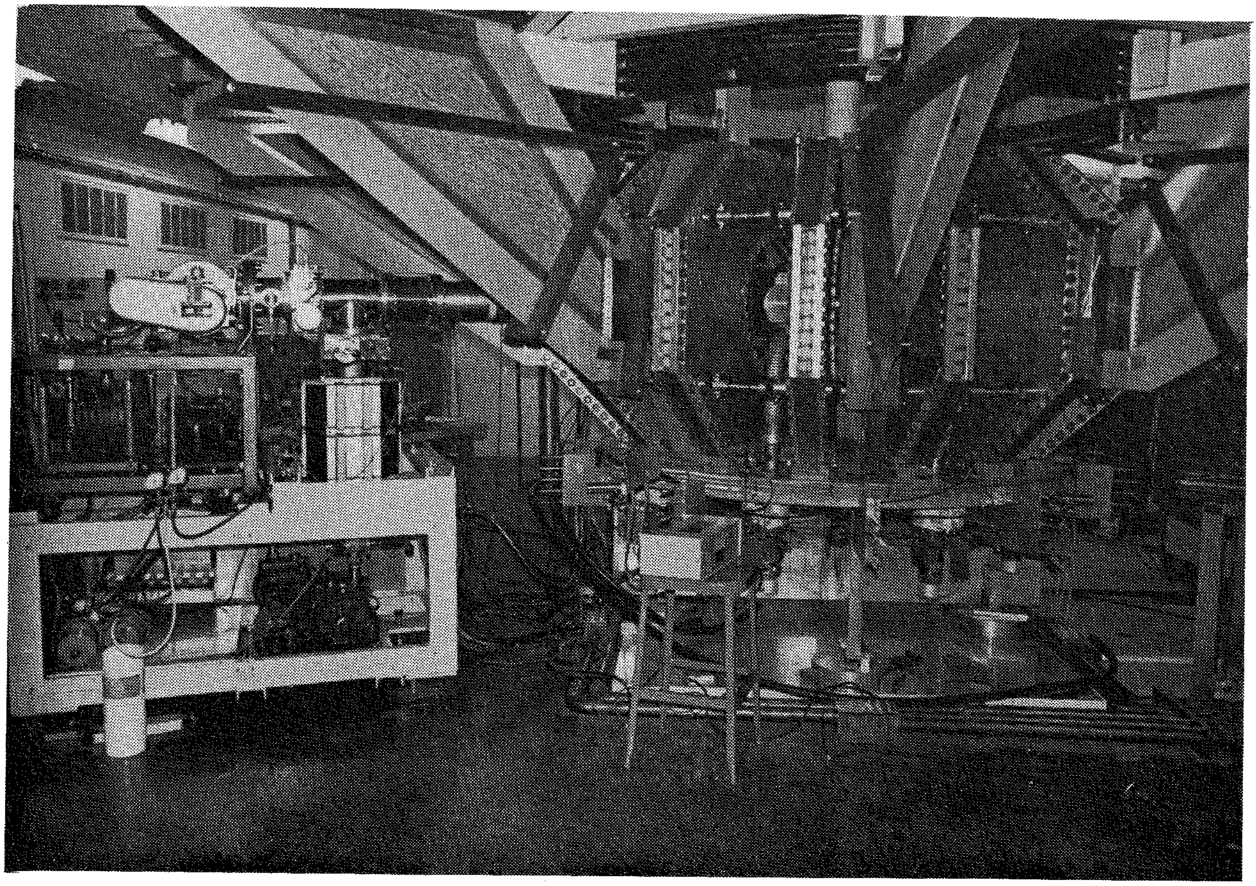
Shown in Figure 4 is the Texas Tokamak (lower photograph) and the eight capacitor bank modules which create the fast turbulent heating discharge.

In order to study the plasma, the experiment is provided with an array of diagnostic devices (see Figure 5) which view the plasma through numerous horizontal and vertical access ports on the torus. In connection with turbulent heating investigations, the more important diagnostics are the microwave interferometer, x-ray detector and charge-exchange neutral particle analyzer. Plasma density is measured using the microwave interferometer. Electron temperature is determined from the x-rays produced when the hot plasma electrons impinge on a small carbon target immersed in the plasma. A typical measurement is shown in Figure 6. Around 0.8 microseconds after initiation of turbulent heating, the plasma electrons have reached a temperature in excess of 100 million °C ( 1keV = 1.16 million °C). An example of the ion temperature obtained from charge-exchange neutral measurements is given in Figure 7. It is characteristic of turbulent heating for a small fraction of the ions to reach temperatures around 30 million °C (3000eV) but for the bulk of the ions have a lower temperature. In future experimental work, the confinement of the turbulently heated plasma is to be studied.

In summary, the encouraging advances occurring in present day thermonuclear fusion research indicate that scientific feasibility may be demonstrated within this decade. Assuming with equal optimism that the subsequent engineering problems will likewise be solved, it is likely that a prototype fusion reactor will be operating sometime in the 1990's with commercial fusion power being available around the turn of the century.

Figure 4

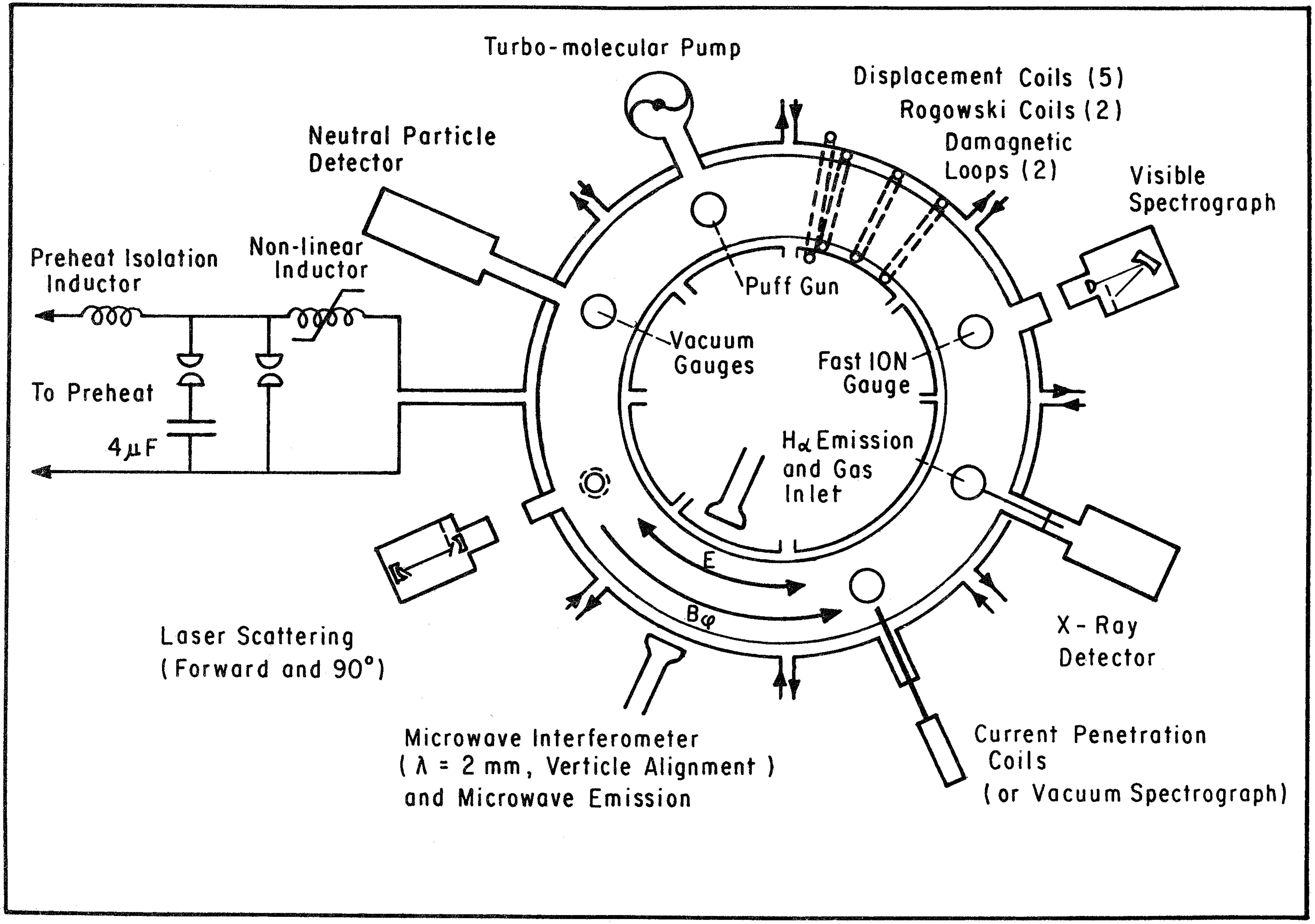




Photographs of Texas Tokamak (bottom) and turbulent heating capacitor bank (top).

Figure 5

Texas Tokamak diagnostics.



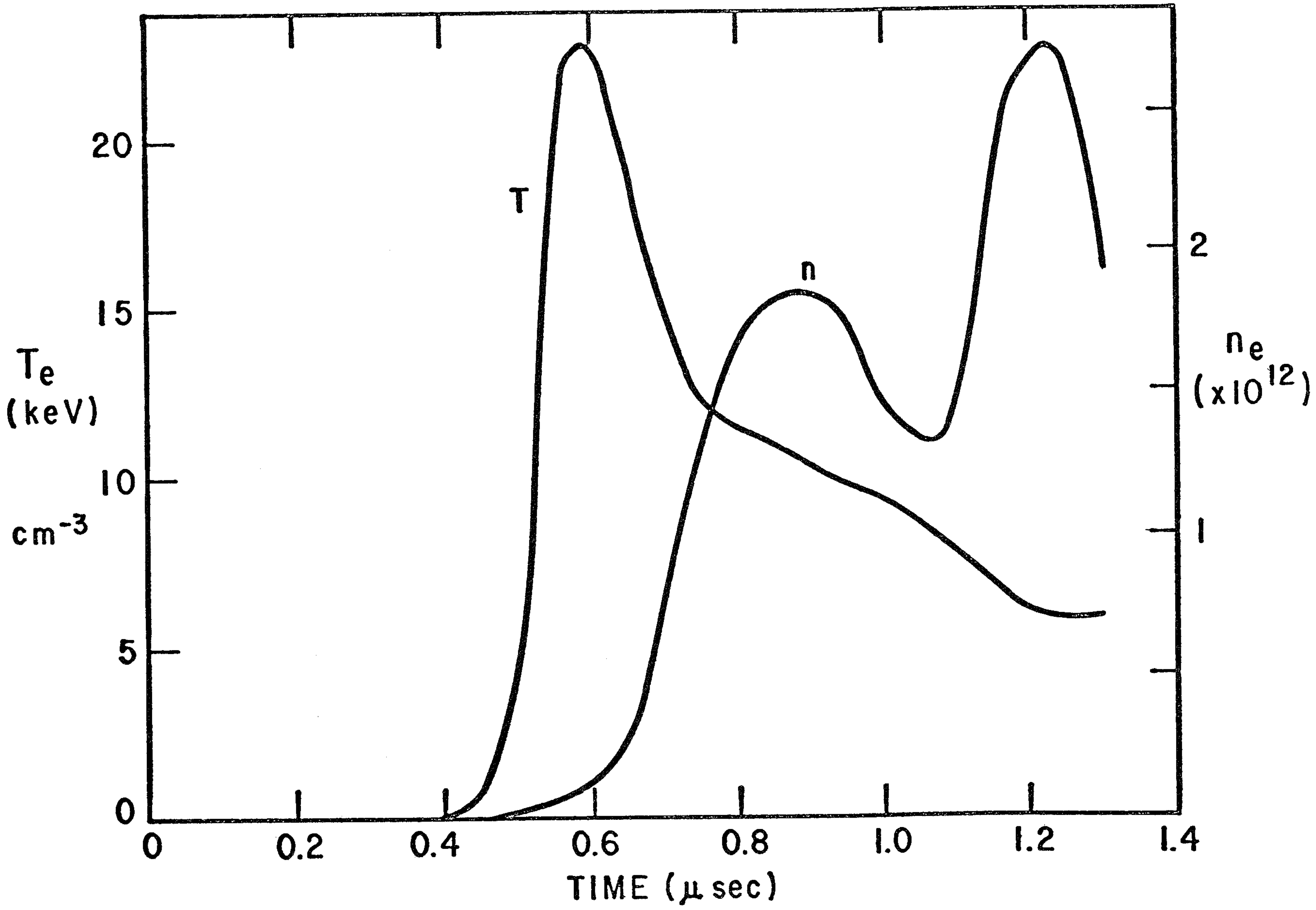


Figure 6

Typical electron temperature measurements on the Texas Tokamak.

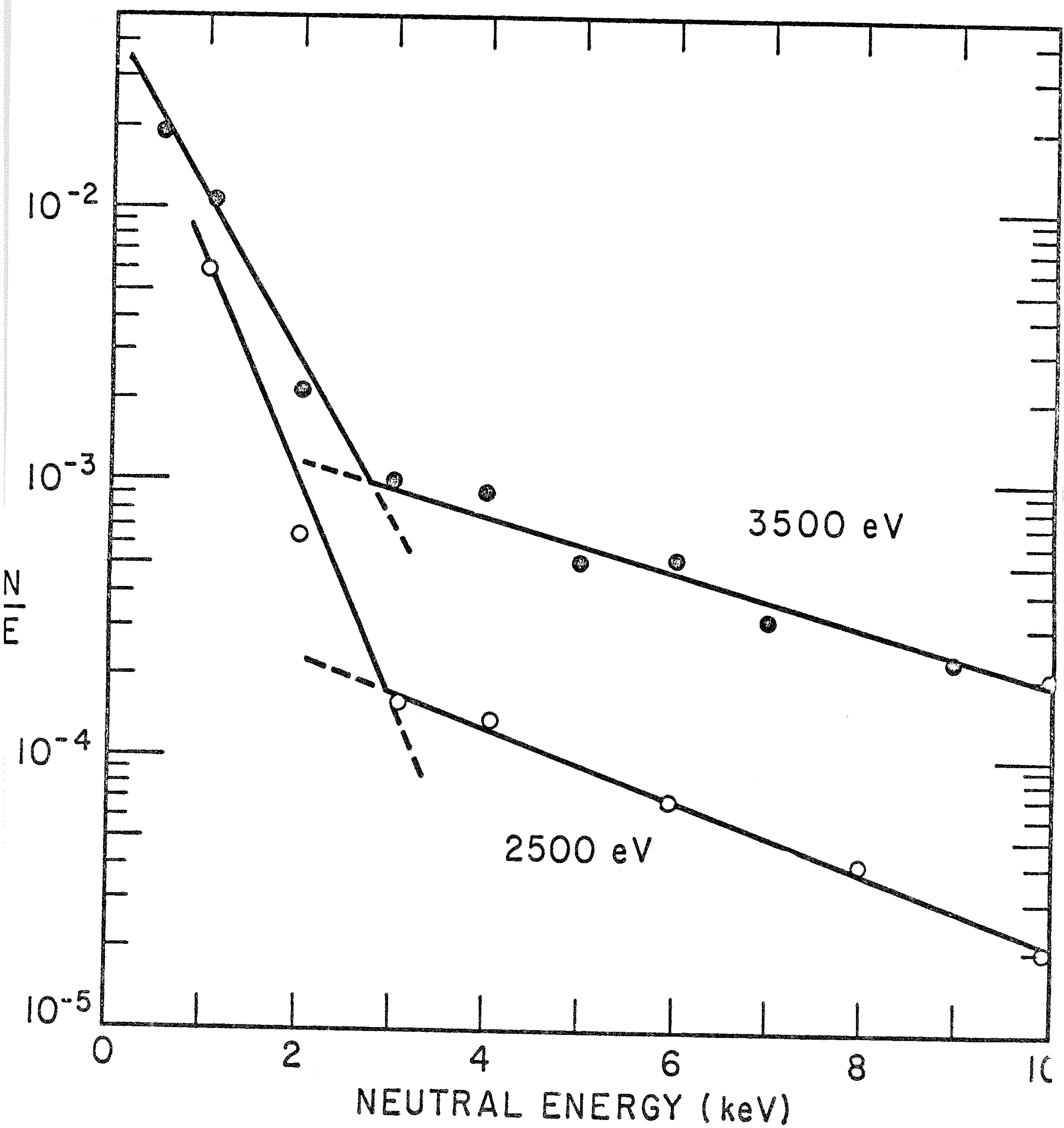


Figure 7

Typical ion temperature measurements on the Texas Tokamak.

# Advanced Energy Concepts

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Presented to the Symposium on Nuclear Power: Today and Tomorrow at the Forty-second Two Year College Chemistry Conference, Houston, Texas, December 6, 1974.

Before discussing Advanced Energy Concepts, it will be worthwhile to know where we are with respect to energy, what sources we use, what we use them for, and in what amounts.

Starting first with our uses of energy, Fig. 1 shows the pattern of energy usage, in the United States in 1968.[1] Note first that our single, largest usage of energy was in transportation which consumed 29% of the energy and that the vast majority of that came from oil as a source. The second largest use of energy was in space heating and was almost evenly split between gas and oil with a small contribution from coal and a smaller contribution from electric energy. The other uses are shown in the figure, but it is worthwhile to emphasize that air conditioning, refrigeration, lighting, and cooking, each consumes a very small fraction of the total.

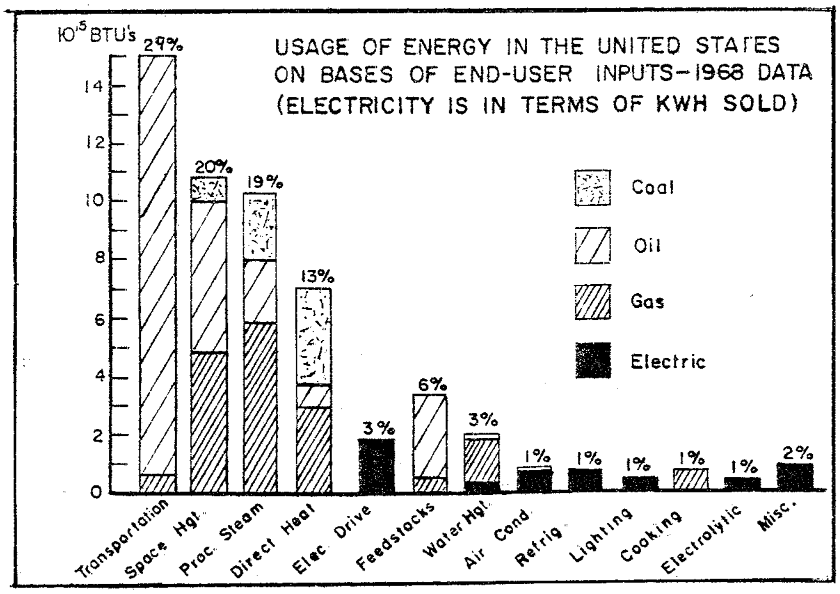

Figure 1

If we turn off all of the lights, it is spectacular, but it does not solve the problem of energy shortage. If we are to reduce substantially our energy use, it has to be in some of the high-use categories indicated in Fig. 1 and we should avoid spending our efforts on cosmetic activities such as reduced lighting.

Figure 2[1] shows a different cut at the fuels consumed and in what sector. This indicates that a major part of our energy has come from coal, natural gas, and oil, with a very small amount from nuclear and hydro. This figure also shows the pattern of usage; for example, transportation used a whole lot of oil and a little bit of natural gas.

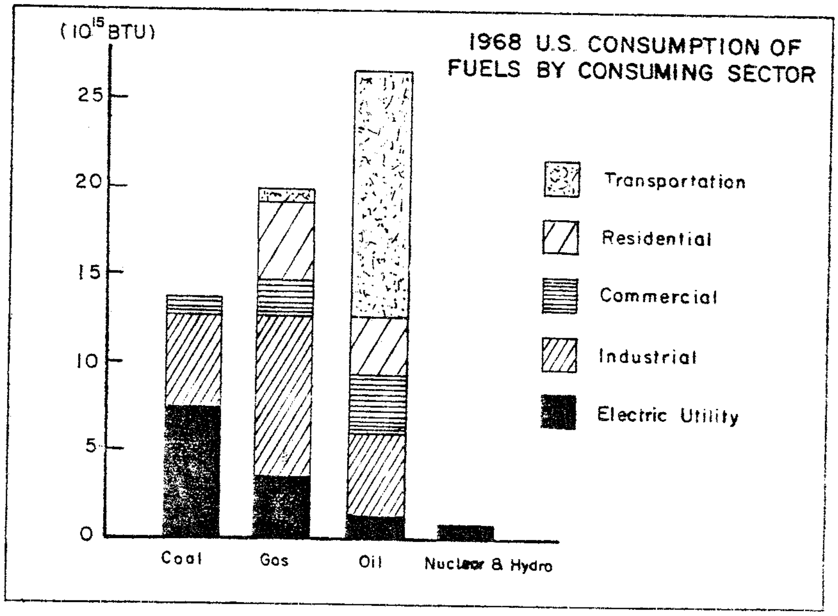

Figure 2

Figure 3[1] shows a combination of the ultimate supply of fossil fuels and the nuclear fission fuel $U_{235}$ for the world and for the world and for the US as well as the relative consumptive use of these different resources for the US and for the world. It is worthwhile noting that the vertical scale on the ultimate supply of fuels is given in units of $10^{18}$ BTU which is abbreviated as a Q. The energy use in the US in 1985 is expected to be between 0.100 and 0.125 Q. Also, in the year 2000, it is expected that the world use of energy will be 1 Q. This gives an idea of how many years supply of energy is in the world's ultimate sources.

The major lesson to be learned from Fig. 3 is that the US and the world have much greater reserves of coal and uranium than they do of oil and natural gas, and yet, the relative consumptive use is such that oil and gas are used much more rapidly than coal. In my opinion this results because the price is low and the environmental impact is low. The concern for air quality has led to the conversion of many power plants from coal to oil. The use rates depicted in Fig. 3 cannot continue and must change either because of realistic pricing or approaching depletion of the valuable resources, oil and natural gas. In my opinion, the work houses of our future energy supply will be coal and uranium.

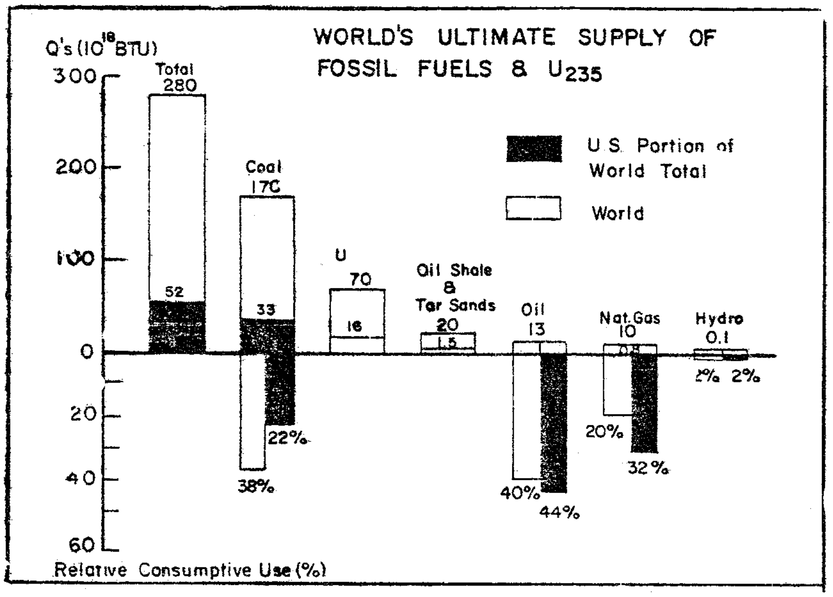

Figure 3

The environmental impacts of the production of coal are those associated with mining, which means the health and safety of miners in underground mines and land restoration for surface mines, both of which can be solved to any degree of perfection desired by developing technology which requires money, people, and time. In my opinion, increased automation will be used to get more people out of underground mines and additional technology will be developed to improve the health and safety of those who must go into the mines.

Uranium mining has the same kinds of environmental impacts as coal mining and requires similar attention. In addition, uranium ore refining and fuel fabrication must be done in environmentally acceptable ways. In my opinion, this also requires additional technology which means money, people, and time.

## NEW ENERGY SOURCES

Figure 4[1] shows estimates of the amounts of new depletable energy sources of the world yet to be used. These resources are uranium for fueling the fast breeder reactor and deuterium to power a fusion reactor. The uranium isotope $U_{235}$ which is the fissionable material consumed in presently-operating thermal reactor, constitutes 1/140 of natural uranium, the rest being $U_{238}$. A fast breeder reactor consumer $U_{238}$ and hence the energy production capability of our uranium resources is expanded by a factor of 140 in a breeder reactor. Furthermore, in a breeder reactor the fuel cost is negligible, hence the energy source given in Fig. 4 is noted as "regardless of cost of mining". For emphasis, the 420,000Q is roughly four million times the expected US energy use rate in 1985 or 420,000 times the world energy use rate in the year 2000. Thus, it is clear that breeder reactors can provide an enormous supply of energy for the world, and, in my opinion, the development of both the liquid matal fast breeder reactor (LMFBR) and the gas cooled fast breeder reactor (GCFR) should be completed as rapidly as possible. The development should include adequate concern for reactor safety, radiation release into the environment, radioactive waste handling, storage, and disposal, the environmental effects of thermal discharge.

NEW ENERGY SOURCES OF THE WORLD
YET TO BE TAPPED

Depletable

| | |
|---|---|
| Liquid Metal Fast Breeder Reactor* | 420,000Q |
| Fusion ($D_2$ from Oceans) | 1,000,000,000Q |

*Regardless of cost of Mining

Figure 4

The basic fuel for fusion reactors will be deuterium, a heavy isotope of hydrogen which occurs in all the water of the world. The amount of deuterium from the ocean, when converted to energy through the fusion process, is indicated in Fig. 4 to be 10,000,000,000 Q. Deuterium can be extracted from water at a small fraction of the cost of fossil fuels for an equal amount of energy. Hence, the fuel cost for fusion energy is negligible. Practical fusion power remains to be developed, but there is optimism in the scientific community that it will be, and when it is, there will be enough energy available to satisfy the energy appetite of the world. I believe fusion will be successfully developed as an economical energy source; that it will be the primary energy supply that will maintain the quality of life for the whole world for the indefinite future.

Figure 5 indicates estimates of new, non-depletable energy sources of the world, yet to be tapped. Geothermal energy can be used where it is economical to develop. This occurs in limited regions; thus, geothermal sources can provide a limited amount of energy for the whole world as indicated by the

0.009 Q of Fig. 5. As an example, the most attractive geothermal resource in the US at the moment is the dry steam resource at The Geysers in California. Electric energy from this resource is economical to produce and is being developed as rapidly as possible for use by the system of the Pacific Gas and Electric Co. Even with vigorous development, the geothermal capacity will never amount to more than 10% of PG&E's total installed capacity. Hence, it is important enough to be developed, but is not large enough to solve the whole problem, even for the company in its vicinity. There are other geothermal sources around the world of different sorts, and, in my opinion, they will have local importance, but they will not make a measurable contribution to the global energy supply. The same can be said for wind energy and tidal energy. As indicated in Fig. 5, the amounts of these are limited and, in my opinion, the capital costs of equipment to develop them will be so great that they will be non-competitive except in very special situations.

NEW ENERGY SOURCES OF THE WORLD
YET TO BE TAPPED

Non-Depletable ( Per-Year-Basis )

| | |
|---|---|
| Geothermal Energy | 0.009Q |
| Wind Energy | 0.003Q |
| Tidal Energy | 0.09Q |
| Solar Energy | 5,190Q |

( World Energy Consumption Rate in 2000=1Q)

Figure 5

As given in Fig. 5, solar energy worldwide amounts to bery large resource. For example, as stated in this figure, the world energy consumption rate in the year 2000 is expected to be 1 Q, whereas the solar energy received by the earth is over 5,000 Q. Solar energy is a very diffuse source and as such may require very expensive equipment to develop in large amounts. I believe that solar energy will be applied in special situations to be descrived later, but it will make small, but significant local contributions to the energy supply, but it will not provide the bulk of the world's energy needs, ever.

In my view, we must exploit every source available to us, but on the whole, between now and the year 2000, the work horses will be coal and nuclear fission, and in the longer term, say beyond the year 2050, the work horse will be nuclear fusion.

CONVERSION SYSTEMS

The energy from primary sources is normally consumed after it has been converted to some other form. For transportation, most energy is converted to mechanical form by internal combustion engines. For most other energy uses, the energy is converted to thermal energy by combustion of a fossil fuel or by fission reactions. The thermal energy is then used directly as process or space heat, or converted to thermal energy in steam. The steam is used directly as process steam or to drive a steam turbine to produce mechanical gy. The mechanical energy is used directly or converted to electric energy by a turbine-driven generator.

The combustion of fossil fuels produces gases and particulates that can reduce ambient air quality. Natural gas burns the cleanest, which is one reason it is so desirable as a fuel. Proper combustion produces nitrogen oxides which can be dispersed from stacks to cause little degradation in ambient air quality.

Depending on its composition and impurity content, a liquid hydrocarbon can produce unburned hydrocarbons, carbon monoxide, nitrogen oxides. Emission controls can reduce the degradation of air quality to any degree desirable depending on the time, money, and effort available for the task.

When coal is consumed it produces ash particles which are removed from the stack gas by precipitators, and, if the coal contains significant sulfur, sulfur oxides are produced that can be removed from the stack gas by scrubbers. Stack gas cleanup systems need substantial improvement which is a technological problem that can be solved in time.

When nuclear fuel is consumed, radioactive wastes are produced in the fuel rods from fission products and nuclear activation of other materials. During this fissioning process, no significant amount of radioactivity is released to the atmosphere in a well designed reactor. When the reactor is refueled, the radioactive material can be safely transported and processed in such a way that it is kept out of undesirable situations.

The energy conversion processes from primary source through thermal energy to steam that drives a turbine generator to produce electric energy are illustrated schematically in Fig. 6. In such a system it is necessary to condense the steam in a condenser and this is usually done with cooling water as illustrated in Fig. 6. This cooling water comes from lakes, ponds, or rivers to which the heat is transferred, or it comes from a cooling tower in which the heat is rejected to the atmosphere by heat transfer to the air and by evaporation of some of the water. The heat rejected can have either beneficial or harmful effects depending on how the thermal discharge is managed. There are successful operations in which oysters, shrimp, and catfish have growth rates enhanced substantially by appropriate use of thermal discharges from electric power plants. In my opinion, the thermal discharges from power plants can continue to be managed with acceptable environmental impact and they will increasingly be put to beneficial use.

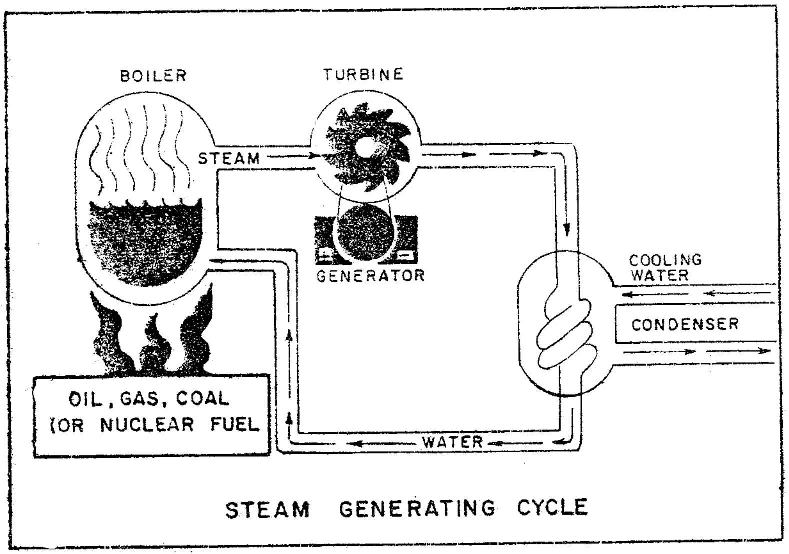

Figure 6

ADVANCED ENERGY CONCEPTS

The first advanced energy concept to be presented is that illustrated in Fig. 7[2] which shows schematically the system under operation in St. Louis by the Union Electric Co. for burning municipal solid waste to generate steam and electric power. As the figure illustrates, this is a fairly sophisticated process that involves several steps of extraction and processing that finally ends with a pelletized fuel that is mixed with coal and burned in a power plant. It is the estimate of experts that as much as 5 to 10% of the electric energy supply in a large urban area can come from municipal solid waste burned with coal in power plants. It is also said by experts that this method of consumption of municipal solid wastes provides more of a solution to the waste disposal problem than it does a solution to the energy shortage although it makes a significant contribution to the energy supply.

Another advanced energy conversion technique that will have increasing importance as time progresses is the production of synthetic fuels, gaseous and liquid, from coal. Pilot plants are under construction or in operation for a number of different synthetic fuel processes. There are synthetic gas plants that produce pipeline-quality gas that can augment our dwindling reserves of natural gas. There are also processes that produce so-called low-BTU and medium-BTU gas that can be burned to drive combustion gas turbines or to raise steam in utility or industrial boilers. This is one advanced energy concept that extends our ability to use coal, our most abundant energy resource.

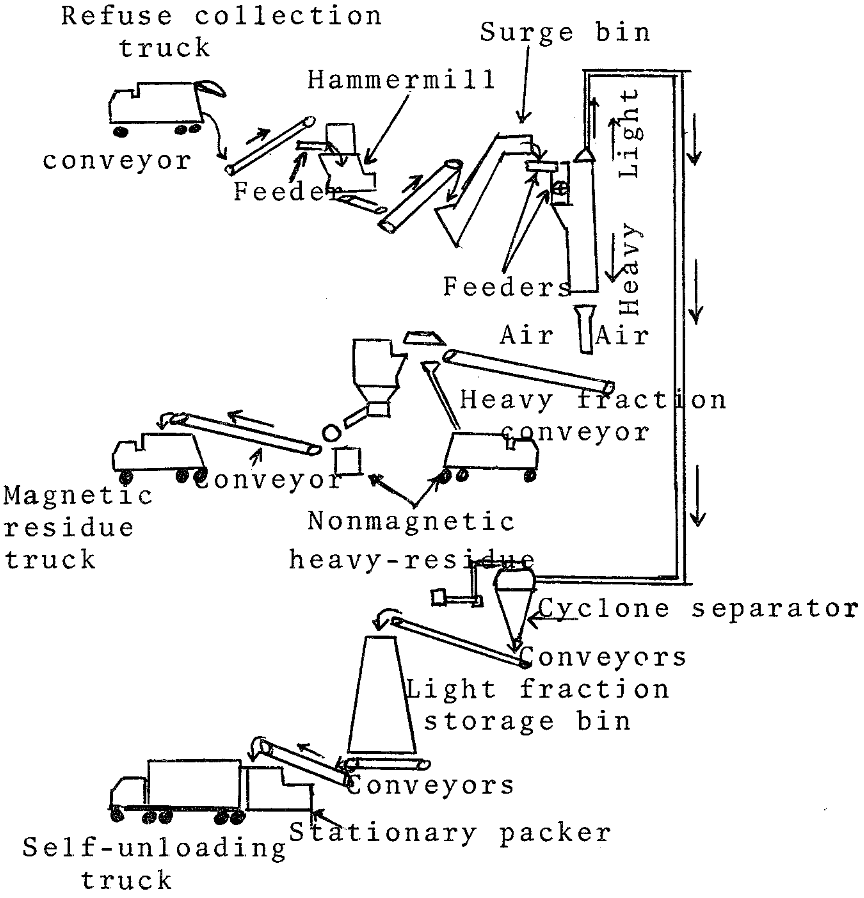

Figure 7
Preparing Municipal Refuse for Burning in a Fossil Fueled Power Plant

Figure 8[3] illustrates a magnetohydrodynamic (MHD) generator. This particular concept is proposed as a way of geting an increased amount of energy out of a given supply of fossil fuel and doing it with little impact on the environment. The principle of the scheme is that a hot gas, seeded with an easily ionizable material (such as potassium), is a good enough electrical conductor that when it flows through a magnetic field it can generate an electric current directly.

That is the part of Fig. 8 shown with the magnet and electric field. The exhaust gas from such a device would still be so hot that it can be used to generate steam in a conventional steam cycle. This is proposed as a way of extracting much more energy from the fuel; but by combusting the fuel at a higher temperature than in other systems, more nitrogen oxides are formed as well as any sulfur oxides from sulfur in the fuel. The need in this sytem for cleaning of the effluent gases is so great and the chemical processing problems so difficult that in my opinion the development cost is too great to be practical. An alternative to MHD is the gas turbine-combined-cycle system in which the fuel is burned, expanded through a gas turbine and exhausted into a boiler. The scheme can do almost as well at fuel efficiency as is claimed for the MHD system at an order-of-magnitude less development cost. In summary, although the MHD concept is attractive in principle, in my opinion, the development cost will be so great that it will not prove practical. This is not to say, however, that research should not be continued on the concept, because it might be successful after all.

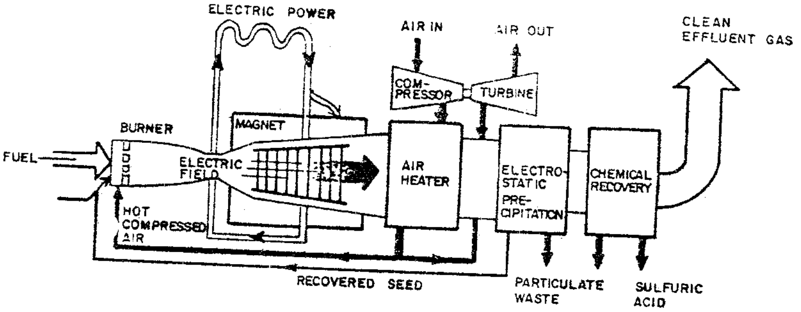

Figure 8
Magnetohydrodynamics (MHD) Generation of Electricity with Environmental Controls

A new source of energy in the US is the oil shale deposits of the Western US, mostly in Colorado. The oil can be removed from the shale by retorting and this can be done either by mining the oil shale and hauling it to a processing plant, or by processing it in place. To make the environmental impact of strip mining and waste disposal acceptable may require expensive measures. The opinion of most experts is that oil produced from oil shale will have a relatively high price and will be available in limited amounts. If the price of oil gets high enough this can be an important source, but it is doubtful that it can be produced at a high enough rate to be a major supply of oil in our system.

Hot dry steam fields provide geothermal energy at Lardarello, Italy and the Geysers, California. In such fields, individual wells produce steam that is piped to power horses where it drives turbine-generator sets to generate electricity. Geothermal energy is not without its environmental impacts in terms of air quality and esthetics. In fact, the steam at the geysers contains hydrogen sulfide which causes an air quality problem in the vicinity.

Geothermal energy, which is essentially thermal energy from the hot core of the earth, can be obtained not only from dry steam as described earlier, but also as hot brine, geopressured deposits of brine and fresh water, and from hot dry rocks by use of a suitable working fluid. In these systems there are the environmental problems of air quality degradation caused by dissolved gases, noise from steam flow, disposal of spent brine, and land subsidence due to draw-down of reservoir. Nonetheless, localized areas of economical geothermal energy will continue to be developed and make important local energy contributions. But, in my opinion, geothermal energy will never contribute a significant fraction of the US or world energy consumption.

Solar energy can be used in a variety of ways, depending on how one wants to collect it and use it. The most attractive use, in my opinion, is for heating and cooling of buildings. For this purpose only low quality heat is required. Low quality is defined as low temperature and low pressure. In order to collect solar energy and make low quality heat only inexpensive collectors are required. As depicted in Fig. 9[4] an inexpensive solar collector can heat water which can then be used to augment the fossil-fueled heating system as indicated in that figure for a Junior High School. In my opinion the low quality heat required for heating and cooling requires inexpensive enough technology that it can be made economical in the very near future. Solar cooling is especially important in the south and southwest where the electric utility systems experience a summer peak caused by the air conditioning load. The use of solar energy for cooling would not only save fuel for producing the electric energy that would otherwise be used for air conditioning, but it would also save the capital cost of the equipment needed to supply the peak load.

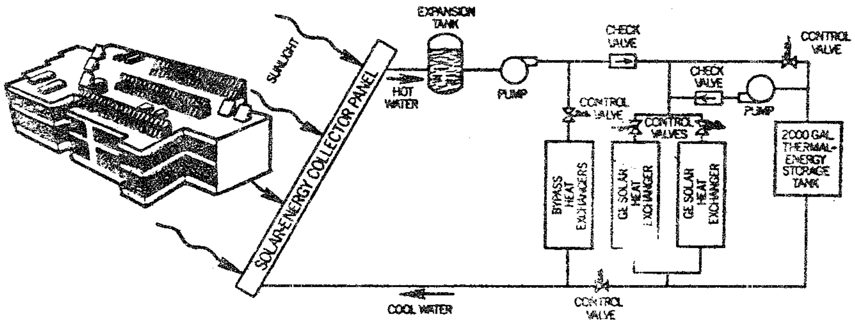

Figure 9

Schematic for Heating a Building with Solar Energy

Another system for collecting and using solar energy is so-called solar-thermal conversion. In such a system the solar energy is concentrated to produce high enough temperatures to boil water and produce steam to drive turbine-generators and produce electric energy. These systems, usually considered in the size range of modern fossil and nuclear-fueled central station generating plants, require a steerable concentrating system that can track the sun across the sky. One of the most attractive systems consists of a boiler on top of a tower surrounded by a large number of flat mirrors on the ground whose positions are controlled to reflect the solar energy onto the boiler. This concept is being studied at the University of Houston by Dr. Hildebrand. Whereas this system and other solar-thermal systems are technically feasible, it is my opinion that their capital costs will be so high that they will not be economically feasible.

In Stillwater, Oklahoma, a windmill is operating at the airport with a belt-driven generator for the production of electricity.[5] This windmill was designed and built under the supervision of Professor Highes at Oklahoma State University. In my opinion, windmills will be useful in local situations where the wind intensity and duration are great enough to make the system attractive, but windmills will not make significant contributions to the world energy supply.

Figure 10[6] is an artist's conception of a solid-state junction which is the esential element in a photovoltaic solar cell. These are the kinds of cells that converted solar energy in our space program. This concept at the present time is too expensive by a factor of approximately of 100 to be economically competitive with alternative power generation schemes on earth. Even though there are thoughts that evolutionary processes can bring this cost down in time, it is my opinion that an invention is needed. We should continue research trying to stimulate that invention, but we should not depend on it's success for future energy supplies.

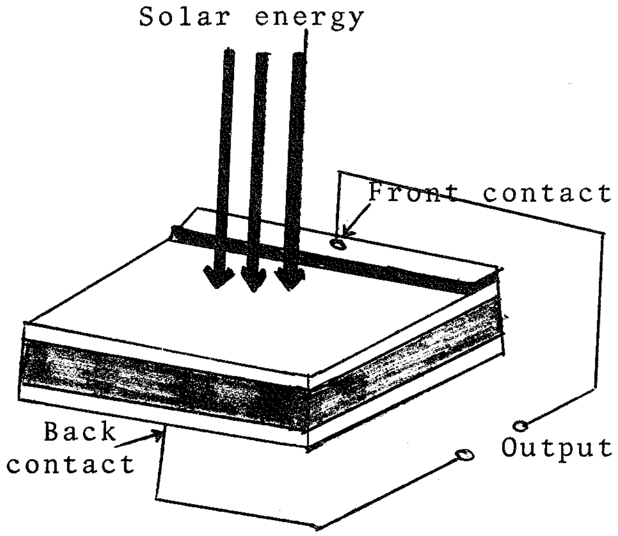

Figure 10

Solar Cell for the Direct Conversion of Sunlight to Electricity

One concept for application of solar cells is one in which a synchronous satellite carrying solar cells collects solar energy as direct-current electric power, converts it to microwaves, and beams it to the earth, where it is collected by a receiving antenna and converted to 60 cycle power and fed to the grid.[7] While every aspect of this system is technically feasible, it is economically infeasible by a large margin and there is substantial doubt in my mind that it will ever prove practical.

Figure 11[8] shows the functional block diagram of the system which is proposed to convert temperature differences in the ocean to useful energy. This is one manifestation of solar energy, although subtle. There are areas of the world like off the east coast of Florida where substantial temperature differences of the order of 20 degrees centigrade exist over a vertical distance of a few hundred feet. It is proposed to use that temperature difference to vaporize a working fluid like ammonia and use a Rankine cycle to drive a turbine-generator and produce electric power. It is my opinion that the attractiveness of this scheme to researchers is caused by the fact that the energy is continuously available and requires no storage or backup like other solar conversion schemes. In my opinion, it will never be economically practical because of the vast amount of equipment it takes to convert a substantial amount of energy from such a small temperature difference. Nonetheless, research work on such concepts should continue.

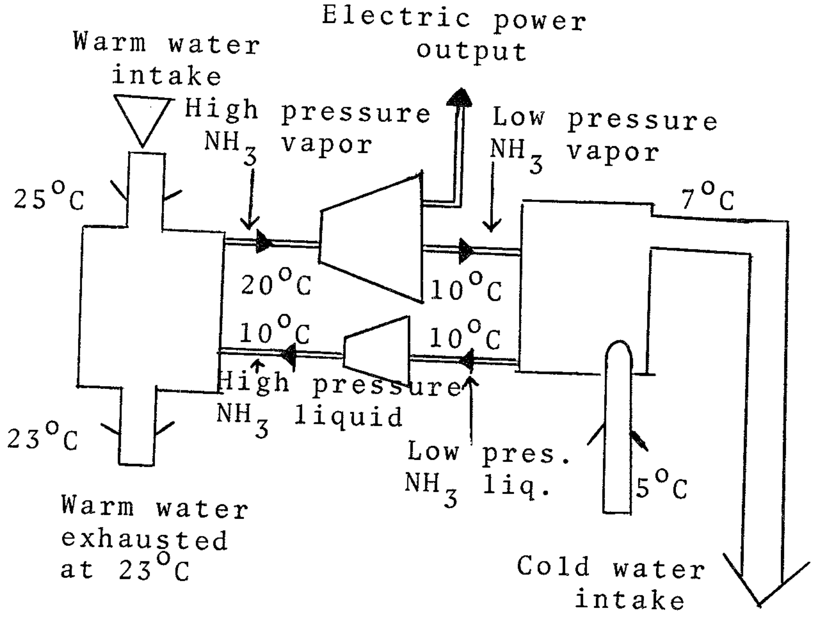

Figure 11

Schematic of Power Plant Operating from Ocean Thermal Gradients

Summarizing solar energy conversion concepts, it is my opinion that solar heating and cooling can be made economically practical and should be pursued vigorously as a fuel saver. This will become increasingly important as the cost of fuel continues to increase and it becomes more scarce. Other systems proposed to collect and convert solar energy will not be economically practical. Research should be continued on these, but we should not make optimistic predictions and then depend on them for our future energy supply. To do so, will likely put us in an untenable, energy-short position in the future.

Figure 12[9] shows the essentials of a hypothetical fusion reactor. Fusion energy, in my view, will really be the ultimate work horse energy supply for mankind. In Fig. 12, the center, labeled plasma, is where the reactants are heated and made to react and produce energy. The energy comes out as charged particles and energetic neutrons. The blanket catches the neutrons, extracts their energy, and breeds additional fuel for the reaction. The rest of the system is simply apparatus needed to make the reactor function properly. In my view, this is the concept that will make the enormous amount of energy cited in Fig. 4 available from the inexpensive source of deuterium in the oceans of the world and will provide mankind with an unlimited, inexpensive supply of energy.

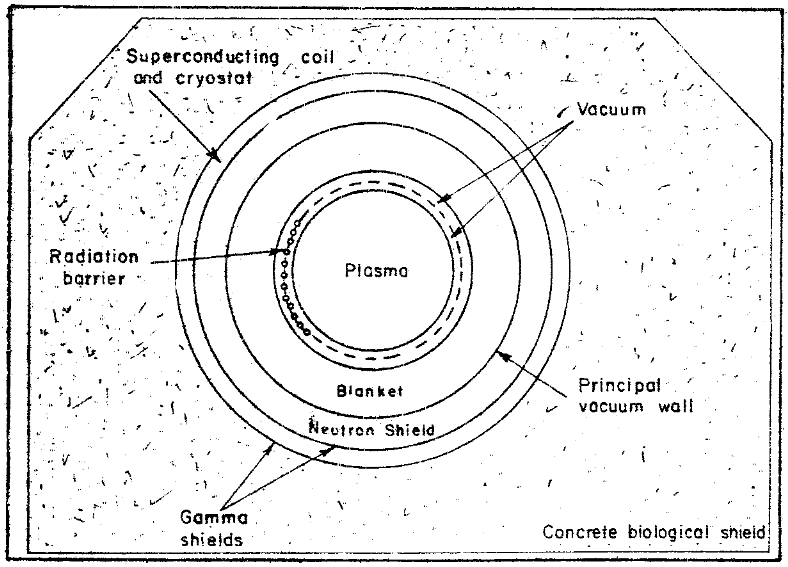

Figure 12

Elements of a Fusion Power Reactor

Other advanced energy concepts that I would like to mention relate to secondary energy supplies. For example, at the moment a large part of our energy supply, and an increasing part, is used by the consumer as electric energy. The electric energy is simply a secondary form of energy that is convenient to transport and use. We simply take a primary source like fossil or nuclear energy and convert it to large amounts of electrical energy and then the electrical energy is distributed to a large number of ultimate consumers each of whom only needs a small amount. In my opinion, as time goes by, electric energy use will grow until we reach the limits of the capacity of our technology to transmit and distribute the amounts we need. At that time, I believe the secondary energy source for transmission will become chemical. A large energy source like a nuclear reactor will be used to produce a chemical fuel like hydrogen or methane which will then be piped underground through pipelines to the ultimate consumer. Electric energy needed inside cities can then be generated locally by either fuel cells, if they become practical, or by combustion turbines driving generators.

## SUMMARY

In summary, it is my opinion that from now until 2025 to 2050, the work horses of our energy supply will be coal and nuclear fission. There will be local and important contributions from geothermal and solar energy, but these will not provide the bulk of the energy needed by society. Over the longer term, it is my opinion that fusion energy will become practical and will be the ultimate long term supply for mankind.

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