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Report of the
Committee on Curriculum Content Planning
to the Faculty of the
Massachusetts Institute of Technology
May, 1964

REPORT OF THE

COMMITTEE ON CURRICULUM CONTENT PLANNING

TO THE

FACULTY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

MAY, 1964

Letter of Transmittal

May 2, 1964

To the Committee on Educational Policy:

The Committee on Curriculum Content Planning submits herewith its final report to the Faculty of the Massachusetts Institute of Technology.

Respectfully,

HOLT ASHLEY
P. L. THIBAUT BRIAN
CARVEL COLLINS
MARTIN DEUTSCH
CARL W. GARLAND
FREDERICK D. GREENE, II
WILLIAM L. LETWIN
CYRUS LEVINTHAL
HARTLEY ROGERS, JR.
JERROLD R. ZACHARIAS, Chairman
DAN C. PINCK, Executive Secretary

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# INTRODUCTION

1. The Committee on Curriculum Content Planning was formed in 1962, upon the recommendation of the Committee on Educational Policy, to make an intensive study of undergraduate education at M.I.T. In a report to the Faculty in March, 1962, the Committee on Educational Policy described the goals of the new committee as follows.

"This committee will study the present undergraduate program and the future curricular needs of M.I.T. The first goal will be to obtain a clear understanding of the basic educational objectives and content of each of the core subjects which form the present General Institute Requirements. The interrelationships among these objectives and the opportunities for achieving greater coherence in the overall program will be explored in depth. The committee will also review the present structure of undergraduate education from the point of view of the pace of subject presentation, the magnitude and diversity of a student's academic load, and the degree of scheduling flexibility. It will explore new methods for teaching subjects with very large enrollments and the possibility and desirability of allowing greater time for independent study programs."*

The Committee on Curriculum Content Planning began its work in the fall of 1962. During the academic year 1962-1963 the committee made a detailed study of the existing General Institute Requirements and of the relation of these requirements to the overall educational program and ultimate professional development of our students. The work included an examination of current subjects at the Institute, of new subjects under consideration at the Institute and elsewhere, and of new trends within the professional fields. This work required full time activity on the part of committee members for most of the year. Numerous books and reports were studied. A variety of persons from the Institute, from other universities, and from industry were interviewed or consulted. In an Interim Report, submitted to the Committee on Educational Policy, May 28, 1963, and distributed to the faculty in June, 1963, the committee presented some tentative conclusions and some recommendations in preliminary form. The quantity and quality of resulting faculty discussion, largely stimulated by the Committee on Educational Policy, have been gratifying.

During the academic year 1963-1964, the committee has carefully examined responses to the Interim Report by the various departments, by the Committee on Educational Policy, and by individual faculty members. After much further study and discussion, the committee submits this final report.

2. Our lives as professional scholars and teachers are dominated by the need to live with decisions that are neither black nor white. It is tempting to leave a statement of our educational goals as some shade of gray—especially so because of the vast variety of our students, and especially so because of the increasing diversity of professional fields and continuing growth of knowledge within those fields. We must, however, make clear and decisive recommendations for a program

*Report to the Faculty by the CEP, March 14, 1962 which at the same time helps to prepare those of our students who can do so to reach the frontiers of knowledge early in their most creative years, and helps to strengthen those students who feel the need of a sequential, complete, and formal schooling. None of us was educated in a time when the subject content of any field seemed finite and surmountable. But since our schooling, the growth in every subject seems overwhelmingly greater. How then do we choose which subjects to teach, which to drill, which to point to, which to leave lying about for the student to seize as his own; and how do we, at the same time, allow a clear path for the creative student?

The committee has addressed itself to this and related questions. In the present report, the committee recommends a curriculum in which earlier branching among the core subjects can occur, and it recommends careful and intensive Faculty effort in further development of subjects appropriate to this curriculum.

3. The report is in four parts.

Part I, the Dialogue, presents the committee's recommendations, amplifies in an informal way on them, and relates them to some current Faculty opinions about education at the Institute. The presentation of the committee's recommendations begins with the first speech of Professor M on page 16 of the Dialogue.

The conversation of the Dialogue is fictional. Persons of the Dialogue express general currents of thought and are not meant to be identified with specific individuals. In particular, the Dean of Undergraduate Students is not intended to resemble, or speak for, any one member of the Faculty.

Some of the committee's recommendations will require changes in the Rules and Regulations of the Faculty. In Part II, Recommended Motions, the committee submits appropriate motions for such changes.

Part III, Recommendations and Reports on Specific Subjects, gives further discussion, and some further detail, on laboratory electives, science area electives, engineering electives, humanities and social science, chemistry, mathematics, and physics.

Part IV, Appendix on Elective Laboratories, presents supporting material for the committee's recommendation on elective laboratories.

# I. DIALOGUE

The committee includes in its report the following Dialogue in the hope that it will help relate the report's recommendations to some of the current Faculty opinions about education at the Institute and that it will amplify, in an informal way, the committee's proposals and the reasons for them. As in other parts of the report, a familiarity with Institute nomenclature is assumed. The word course refers to an organized curriculum leading to a specific degree. The word subject, on the other hand, refers to individual classes. A unit of credit is approximately equal to one-third of a semester hour. 360 units are required for a B.S. degree.

## DIALOGUE

| | |
|---|---|
| Dean of Undergraduate Students<br>Engineering Professor A<br>Engineering Professor B<br>Science Professor<br>Professor P<br>Professor M, a member of the Committee on Curriculum Content Planning | M.I.T. Faculty Members |

Guest

Dean: Thank you for meeting today to talk about M.I.T. undergraduate education. More and more questions are being asked about the structure, and the goals, of our program. Discussion by such a varied and representative group as this could be fruitful.

Let me first make some introductions. Except for Guest, we are all members of the M.I.T. Faculty. Professor M, a member of the Committee on Curriculum Content Planning, is here to represent that committee. Frankly, I have found some of the utterances of the Committee on Curriculum Content Planning to have a rather baffling, oracular quality; indeed, if I may make a personal confession, there are gloomy moments when I wonder if they have even considered some of the problems about M.I.T. which I consider important. Be that as it may, we are happy to have you with us, Professor M, and hope you will share with us some of the results of your committee's work.

Guest is not a member of our Faculty. He is a man who, for some years, has viewed M.I.T. from the outside with affection and interest. You are all aware of the technological skill and capacity for industrial leadership which he includes among his many talents. He is, if you like, one of the "consumers" of what we produce at M.I.T. Thank you for joining us, Guest; we hope you will take part freely in our discussion.

I do not plan to say much myself, although I may speak up from time to time to express the views of some of those who are officially concerned with student life outside as well as inside the classroom.

I suggest that we focus primarily on the education of scientists and engineers, and I have invited this particular group with that in mind. Other areas of study at M.I.T. are of vital significance, and I hope that we may return to consider them more directly and make appropriate modifications in whatever conclusions we may reach today.

The only ground rule for our discussion today is that we should speak quite frankly. We might begin by going around the group for each of us briefly to summarize his views on present problems in M.I.T. undergraduate education. Guest, would you begin?

Guest: I'd rather not. You men are the experts on education. I've come to learn. I would appreciate it, though, if some of you would speak about the aims of M.I.T. undergraduate education. My thinking about the Institute has been a little confused on this point and on the related matter of deciding how well you are achieving your aims. I hasten to add that I always think of M.I.T. as a place that does extremely well at whatever it turns its hand to.

Dean: Professor A, would you begin?

Engineering Professor A: Our aims? Well, they have to do with the kind of person we produce as a graduate and the abilities and resources he possesses when he graduates. I don't think we have a single set of aims and I am not sure we should. In fact, one of the things bothering me about our existing program is that it seems rather rigidly oriented, in its speed and content, to just one kind of student.

But to explain my criticisms of M.I.T. education, let me focus on engineering, and on the aims of engineering education that are close to me. I will have to speak in my own personal terms.

Guest: Very good. Just what kind of graduate do you want to see produced?

Engineering Professor A: Well, there are many kinds of engineer, and many different kinds of ability and resource. But there are certain common threads. My own ideal engineer is primarily an innovator. He is able to distinguish important from unimportant facts and to make decisions on the basis of incomplete and approximate information. His mind has a real cutting edge; he can quickly get at the essentials of a complex situation, relate them to practical objectives, and deal creatively with them. He has initiative and leadership. These are the qualities of a great engineer.

Let me be completely honest about my prejudices on this. In my opinion engineering should be, and will be, one of the highest and most demanding vocations in our whole society. Professional engineering education has been much too backward and conservative, and the present public conception of the engineer is poor. But to me, the great engineer is the man of the future. He will be shaping our lives, and M.I.T. ought to be producing him.

Guest: Isn't M.I.T. producing him now?

Engineering Professor A: I think we could be producing more great engineers.

Guest: Would you explain?

Engineering Professor A: Well, two things seem to me wrong. First of all, we might get more of the proper raw material for the educational "process," and second, we might do a better job with the material we get.

Guest: Excuse me for interrupting, but could we consider your two points separately? I expect the second is more interesting, but why don't we start with the first?

Dean: Good.

Professor P. I am surprised at Professor A's first point, about raw material. I thought all indications were that our students are getting better and better. The Admissions Office says the bottom of this year's freshman class would have been in the top half five years ago.

Engineering Professor A: To put it briefly, the admissions procedures place too much emphasis on scholastic achievement in science. In my opinion, we get many students who are essentially bookish and inclined toward theory. They are experts at learning and working with certain set kinds of abstract material, all of which may be fine for science. But I am in engineering. Such students often lack resourcefulness and a sense of practicability, and they lack the instincts and qualities that would make them interested in engineering and successful as engineers. Of course we get many excellent engineering students; I am speaking here only of averages.

Guest: If you are right—and I am not entirely sure I understand the distinctions you are making—why isn't M.I.T. getting more students of the sort you want?

Engineering Professor A: Partly because engineering has undersold itself and has not acquired the glamour of a number of other vocations; partly, at M.I.T., because of a simple feedback effect on our admissions policy from the basic science subjects of the first two years. As the subjects grow more bookish, the Admissions Office must place a greater premium on ability to pass them.

At best we are getting a freshman class somewhat one-sided in its skills and interests; at worst we are getting a group of future super-technicians who lack some of the broader qualities I mentioned before.

Guest: Who is getting the students you would like M.I.T. to have?

Dean: Let me speak to this. The Admissions Office has been greatly interested in various aspects of such questions, and they are questions I have thought something about. I agree that more of the leaders of our society will come from engineering and science. In the recent past, most of the nation's leaders and decision makers have come from liberal arts colleges. This suggests that one approach for M.I.T. to take would be to try to attract students who are headed for the major liberal arts schools by making M.I.T. more like those schools and by aggressive recruiting. But the admissions situation across the country is changing under the increased pressure for college admission. Our admissions criteria and those of the major liberal arts schools have become much more similar, and for better or for worse our entering classes and their entering classes are much more alike.

Across the country present admissions criteria are largely scholastic. But many admissions offices, including ours, are concerned with problems of evaluating the applicants' less easily measured qualities of intellect and character. This problem is being studied, but it is difficult.

Frankly, gentlemen, I don't think we can profitably discuss the matter further at this time.

Engineering Professor A: Just a minute. You can't get off that easily. Sure, I'm willing to drop the topic and I agree that it is much less important than the problem of how we handle the raw material we get, but let me make two parting remarks on the subject.

I have read that one major university is experimenting in its admissions by deliberately gambling on a few freshman with lower test scores who appear to have other redeeming signs of excellence. The point is that we can't experiment in this way because such students might not survive the rigors of our freshman year.

Why don't we try to insure more variety in future professional interest? We could admit students directly to departments, or have a quota system of some sort. I'm not saying I favor this, but it is one alternative.

Dean: Your parting remarks are provocative, though I am not quite sure I fully understand the implications of your second one. Incidentally, I believe the Admissions Office does seek a variety of interests among applicants, though not in any very formalized way. But let's get on to what happens to the student here. Would you give us your views on this?

Engineering
Professor A: Here I have two comments, one on the basic science subjects in the first two years, and the other on the problem of faculty involvement at M.I.T.

For many of our students, including some with good potential for engineering, our basic subjects are just too hard. I am sure that they are fine for a future scientist, but, for the kind of motivation and insight that many engineers need, they move too fast. Various paths ought to be open to students. To be forced into our present single pattern of fast-paced, highly theoretical courses is, for many students, stultifying. They work hard just to stay above water, and they come to the end of their second year in a state of battle fatigue.

Also, M.I.T. has, in my opinion, a problem of faculty involvement.

Guest: What do you mean?

Engineering
Professor A: I mean that faculty members may be involved in many other things besides classroom activities.

Guest: Do you think that M.I.T. differs from other universities in this respect?

Engineering
Professor A: I am not sure.

Professor P. I think we should be clear that at M.I.T. and most other large universities, the primary motivation of the faculty members, and especially the younger and more energetic ones, is towards research and more advanced teaching. And, in my opinion, this is as it should be. It's not just the rewards and promotions by M.I.T. that count. Deeper matters of inner satisfaction, professional reputation, and one's image of oneself are involved.

Engineering
Professor A: And the undergraduate suffers, is that it?

Professor P: Not necessarily. The good research man is often the good teacher. His research sustains the vitality of his teaching throughout his career.

Engineering
Professor A: I should like to ask for a comment from Professor M, who is a member of the Committee on Curriculum Content Planning. I have raised the two issues that I find most significant, and I am not sure how extensively that committee has considered them.

Professor M: I would prefer to wait until we hear from Engineering Professor B and Science Professor before I comment.

Guest: Professor B, what do you think our problems are?

Engineering Professor B: Well, Professor A's comments were very interesting. At an emotional level, I respond to his evident feelings of frustration. But I would describe the situation in somewhat different terms. It seems to me that our aims in engineering education mainly have to do with the quality of the student's intellectual experience at M.I.T. We faculty members are doing our own professional work. We find it open-ended, exciting, and rewarding, both intellectually and emotionally. Our aim is to introduce students to the same kind of experience and reward as quickly and efficiently as we can. If we focus on this, other matters, such as producing "leaders," will tend to take care of themselves. At least I doubt whether explicit consideration of such other matters is worthwhile at the moment. Furthermore, I agree with the Dean about admissions. I think that our raw material is excellent.

Are we achieving the aim I have described? Not so well as we might. First of all, the intellectual experience of the first two years is not as closely related as it should be to the ultimate activity and role of the student. The student finds it, as Professor A says, a kind of battle. He moves from crisis to crisis. The rewards he receives should be better related to the excitement and intellectual satisfaction we would like him to have.

Secondly, although I find the attitude of individual faculty members to be very good, faculty resources should be better mobilized and organized for teaching in the first two years.

Dean: Science Professor, what do you see as our major problems?

Science Professor: I don't quite know how to begin. I am interested and a little puzzled by the remarks of Professors A and B. Perhaps the best thing to do is to tell you what I would have said if you had called on me first, before they spoke. I would have commented on the general atmosphere at M.I.T., and on teaching and learning here.

As to general atmosphere. There is an emphasis by students on the externals of education, on such matters as examinations, grades, and credits.

Dean: This is a common complaint at all universities. Are we really different?

Science Professor: I think that to some extent we are. For one thing, our students have too much to do. This makes it even more difficult to get away from externals.

In the past, before hearing Professors A and B speak today, I have associated this atmosphere with engineering education and its seemingly early vocational specialization, and with the student who appears more interested in qualifying for a particular job than in exploring the intrinsic intellectual excitement and challenge of a given subject.

As to teaching and learning. For the future scientist, M.I.T. shares with other universities several serious faults. One is that the student falls into a relationship with his teacher and subject matter that is essentially passive. He temporarily memorizes information and gives it back on tests and examinations. Matters of routine technique, "handbook" approaches, are emphasized by the student even if not by the teacher. The mental activity of the student is different from what will be expected of him in later professional life; eventually as a good scientist he will have to take an active, creative, almost aggressive attitude toward his subject. Another fault is that the pace of education is sometimes too fast, adding to the emphasis on routine technique at the expense of theoretical insight and motivation. Still another fault is that the student often has too many demanding and serious things to do at the same time. I sometimes wonder how, for example, a sophomore can simultaneously take four, or even three, of our serious scientific subjects and do a decent job at them.

Engineering Professor A: Science Professor, how can you associate these faults of M.I.T. with engineering education? We never see the students until their sophomore or junior year. Almost all the freshman and sophomore teaching is in science.

Science Professor: I don't mean to be blaming anybody. I am, as a first step, trying to describe, in a somewhat impressionistic way, the attitudes which I brought to this meeting—and which I think a number of my scientific colleagues share.

Dean: Why did you begin your comments by saying you were surprised by the comments of Professors A and B?

Science Professor: Mainly because their educational goals as members of the engineering faculty sounded so much like my own. Professor A's description of a "great engineer" was very similar to the description I would give of a "great scientist." A second reason for my surprise was the extent to which they both appear to blame the freshman and sophomore science subjects for the problems they see.

Dean: A study we made in connection with our counselling work supplies some interesting data. Comparing upperclass students in science with upperclass students in engineering, we find substantial and measurable differences. Not just differences in taste and interest, but differences in basic patterns of personality and thought.

Professor P: I have seen some of these data, and they are most interesting. But can one conclude from them that the differences are desirable or natural ones? Undergraduates who enter M.I.T. choose between science and engineering under somewhat artificial circumstances. That the result should show significant differences is not surprising; but to relate these differences to qualities desired in an engineer or scientist may be unwarranted.

Of course, the practicing engineer and practicing scientist are often quite different, but I would attribute much of this to differences in professional experience. The qualities desired in an undergraduate seem to me to be much the same. The similarity of the comments we have just heard by our professors of engineering and of science seems to bear this out.

Guest: I agree with Professor P about this. I find that first-rate engineers and first-rate scientists are much alike in their basic creativity and resourcefulness. But the Dean's data are significant for us in a different way. They show us that the upperclass engineering students with whom Engineering Professor A is most familiar may be rather different from the upperclass students with whom Science Professor is most familiar. This may or may not be desirable, but it is a limitation on our individual experience that must be kept in mind in discussions such as this one. Science Professor, may I ask you several questions?

Science Professor: Certainly.

Guest: You questioned the atmosphere of M.I.T. undergraduate education. Why, in your opinion, does this atmosphere exist?

Science Professor: I am not sure. The faculty seems in some way to be expecting and demanding too much of the wrong kind of effort from the students.

Guest: But aren't you scientists the ones that are doing the expecting? You do most of the teaching in the first two years.

Science Professor: Yes, and I think we do it the way we do because it is expected of us. There is a tradition of difficulty and rigor at M.I.T., a way of doing things. The system is difficult for any one person or group of persons to change.

Guest: What do you think is the solution?

Science Professor: I should like to see some kind of overall relaxation of the M.I.T. atmosphere; a relaxation of schedules and a relaxation of demands within subjects. I should like to see M.I.T. become more like a liberal arts college in this respect.

Engineering
Professor B: I am sympathetic to much you have said, but I am not sure your solution could be made to work. M.I.T., in all its aspects, is a dynamic and intense place. Its metabolic rate is inherently higher than that of many liberal arts schools. I doubt that a free and easy "liberal arts" atmosphere could be brought about. We can't avoid expecting a lot from students and competing for their time in fairly specific ways. What we can do is mobilize our resources better and make this effort with more care and imagination.

Incidentally, I would agree with you on a number of points. We do often give the students too many things to do.

Dean: What would you have us do?

Engineering
Professor B: Most of you are familiar with the sophomore circuit theory course (6.01 - 6.02) in the Electrical Engineering Department. This is one example of how material can be taught intensively, yet in a way that stimulates the student's creative abilities.

Dean: Some faculty members would say, "Life is tough; it involves doing many things at once, 'moving from crisis to crisis', as Professor B put it. A real virtue of M.I.T. is that it teaches this to students early. Many of our undergraduates are proud of this fact. We should not change this aspect of our system."

Engineering
Professor B: They are missing an important point. The issue is not whether M.I.T. education is too intense; it is whether what we do really is closely enough related to the student's later work.

As you know, I think it is not. And I gather that Professor A and Science Professor feel the same way. I think that being able to meet a crisis is important, but we must nourish the other talents and abilities that we would like to see developed.

Dean: Guest, what do you think of the discussion up to this point?

Guest: I have a strong secret prejudice against universities of all kinds. They are conservative organizations, inward looking and resistant to change. And they impose an arbitrary pattern on students which is often harmful, especially for the brightest and most creative. If you ask, "Is there a problem?" I would answer, "Yes." And, I think a solution would be important to M.I.T. I feel this especially when I look at your undergraduates. They are so very talented and able, and I am so impressed with what each can become, given the right circumstances. I sometimes think that any one of them would be better off to come and do research with me rather than go to M.I.T. or any other university. Even if he didn't learn all of his calculus or chemistry right away, he would learn how to attack a problem as an adult, how to find out the things he needs to know. Of course, I am talking about the very bright and the very creative, but that is what I think most of your undergraduates are.

What should your goals be? I was struck by the similarity in the complaints of Engineering Professor A, Engineering Professor B, and Science Professor; and I suspect we would find after resolving some semantic difficulties that they favor very similar things. I myself especially like the way Professor B described his educational aims. The problem is to make the intellectual experience alive and exciting, and this could be done better than at present.

Dean: What solutions do you suggest?

Guest: I am not sure enough to say yet. But I would like to hear from Professor M about the deliberations of the Committee on Curriculum Content Planning.

Professor M: I have no startling revelations to make, but I am happy to tell you about the conclusions we reached and how we reached them.

Let me first briefly outline the committee's work. After several introductory discussions not unlike this one, we decided to look more closely at the specific subjects taught in the first two years. We spent much of the first year doing this. We read texts, talked to teachers from M.I.T. and elsewhere, looked at examinations, heard about future plans, and considered alternative programs. We sought to learn about, and keep in mind, the relation of all these to developments in professional fields and changes in departmental programs. Typically, we devoted several weeks, including our own homework, to a particular subject.

Dean: What did you learn in your study of the specific subjects?

Professor M: As far as attention and dedication on the part of teachers go, and as far as care in administration and organization goes, our findings were most favorable. At the same time, we found some subjects planned and taught in isolation from the rest of the subjects offered in the same department. We found teachers involved in a number of different responsibilities, including, in some cases, a substantial amount of day-to-day administrative work in their subjects. We found that subjects had been changing, but that sometimes the change was largely an acceleration rather than a more fundamental restructuring of material. We sometimes found that quiz practices put too much emphasis on trick questions. Finally, in the isolated universe of each particular subject, we occasionally found rather strong and—to us—not altogether reasonable preconceptions as to which parts of the given subject should be presented and emphasized.

Guest: What did you take to be the aims of M.I.T. undergraduate education?

Professor M: Essentially the aims described by Professor B. We agreed fairly soon on this. Our first concern was the quality of the student's intellectual experience.

Guest: And what conclusions did you reach about that?

Professor M: To be brief here, let me group them under five headings. For want of a better word, let me call them principles—one main principle and four secondary principles. There is, as you will see, some conflict among them, but I shall come back to that.

Our main principle concerns planning. It says, simply, that the Institute should devote more of its resources to the long-range planning of basic undergraduate education. Within the context of the existing core requirements this means that more people should be given more time and incentive for the imaginative preparation and planning of the basic core subjects. Furthermore, this planning cannot be done without even more interdepartmental coordination; for changes in one subject are, and should be, related to changes in another. Under the present system, planning often is done by a teacher who has to cope with so many short-range administrative duties that he finds it hard to be considering, at the same time, radical long-range changes which might be desirable.

Most universities do not recognize as much as they might the high order of intellectual effort such planning demands. Knowledge is growing so rapidly that methods and patterns which served for our own education no longer suffice to bring today's student to the frontiers of knowledge during his early, and often most creative, years. Substantial parts of traditional subject matter must be omitted. New material and new approaches must be devised. New and shorter paths must be built to concepts and insights that are currently important. Proper preparation and planning cannot be mere "scissors and paste" work—the choice of a topic or the choice of a text. It implies fundamental rethinking and reworking of subject matter. It is like composing music, and often as difficult. One is inventing an intellectual experience that is not only new to one's audience, but to oneself as well.

Some of the best subjects are successful chiefly because of the amount of first-class effort which has gone into their design (lectures, homework problems, sequences of topics, and so forth). An example is the subject in circuit theory which Professor B mentioned a while ago.

We on the committee found it a great temptation to cast ourselves in the role of replanners. But we have come to recognize, more and more, the importance of a continuing faculty effort in this respect.

I mentioned four secondary principles which the committee favors, though it is aware that conflicts between these principles at times occur. The first of these might be called the core principle. It asserts that, in deciding on those features, threads, or themes which are to be common for all students, the faculty should be guided by considerations of general future interest and usefulness as well as by technical prerequisites for later professional courses. A possible first criterion to use for this purpose is the following: the core material is the material that every future member of the technological community, as a citizen of that community, should know. This first criterion yields a core that is impracticably large. The problem is more complex: what one student learns in a freshman or sophomore subject another student learns in a professional subject or by independent reading and conversation. What we desire of the General Institute Requirements is that they introduce the student to certain central and fundamental areas of knowledge and kinds of thinking and that, beyond this, they introduce him to enough further areas so he will, by one route or another, eventually fill out the core of knowledge determined by the first criterion above. The program we recommend for the freshman and sophomore years is, in our best judgment, a good way to achieve this end. I should note in passing that we were surprised at the unanimity of the responses of the members of the committee when we looked at possible core material.

A special feature of the core principle is our committee's attitude toward the humanities requirement. We believe that this requirement serves several purposes, of which the last is possibly the most important. It serves in part as a freshman composition requirement. It provides the student with basic knowledge of the humanistic tradition. And it acts as a distributional requirement, guaranteeing that our future citizens of the technological community have substantial knowledge and experience within the areas of humanities and social science.

The next principle might be called the departmental principle. It stresses the desirability of a strong association between an upperclass student and his department. The personal contacts and individual attention which he gets from this association can be among the most valuable features of the undergraduate's education.

The next principle I shall call the flexibility principle. It asserts that various paths for various students are desirable. Our recommendation of project laboratories and science area electives is closely related to this principle.

Finally, there is a concentration principle. It asserts that our students often carry on too many serious academic activities at the same time, and that their programs should be less fragmented.

<u>Dean:</u> What specifically do you recommend?

Professor M: First, that the Faculty express strong support for an increased allocation of Institute resources to planning, coordination, and continued modification of basic subjects.

Dean: What kind of planning?

Professor M: We think the initial effort should be concerned chiefly with the long range planning of content, construing "content" very broadly. Proper and attentive planning would inevitably concern itself with teaching methods, materials, and organization.

Professor P: Isn't such planning of content going on already?

Professor M: Yes it is. During this past year there have been movements for change which go well beyond any in the past decade. In physics, the first experimental classes in the new approach to the freshman subject are being taught this year; a serious laboratory is being developed along the lines discussed in the material on elective laboratories which I shall give you after this meeting; and an intensive study is being made of ways to teach quantum mechanics in the sophomore year. In mathematics the freshman course has been changing markedly, with an increased emphasis on the goals described in the committee's Interim Report, and substantial changes are expected in the sophomore course. In chemistry, experimental subjects will begin this fall with a new approach to freshman chemistry. The Biology Department has introduced an entirely new basic subject, taught by a group of lecturers. In humanities and social science, a thorough review of the core offerings of the first two years has resulted in the new program described at a recent Faculty meeting. Undergraduate seminars have continued to be effective, providing close contact between students and members of the faculty, especially in the engineering departments. Various experiments in electives and laboratories are planned or under way; some of these are described in reports I shall give you after our meeting.

Professor P: Isn't this a sufficiently intensive effort?

Professor M: For the moment, it is very good. But the effort needs to be a continuing one, and a more thorough basic commitment of resources is desirable. Moreover, we would like to see the preparation and planning done in a way which takes into account plans and curricula in other subjects and departments. The Science Teaching Center seems to be a promising vehicle for this. Increasingly during our study, we came to believe that such planning could yield great benefits.

Engineering Professor A: I've seen outlines of the new physics course, and it seems to me that the pace is rather severe.

Professor M: No, that really isn't true. The detailed syllabus shows that a considerable amount of material has been left out, especially on formal derivations and manipulations. You have to take account of a fundamental rearrangement of material and change of tone. Moreover, we believe that sufficiently intensive planning, with attention to feedback, acts as a natural control on pace.

Engineering Professor A: You have been focusing on content, but there are problems of staffing, administration, and organization that seem very important to me—the whole problem of large numbers, of how you handle nine hundred students.

Professor M: These other problems are important, but we believe the first and most urgent need is for intensive planning of the student's intellectual experience in his basic subjects. We recommend that the Faculty give priority to this. Solutions to organizational problems will grow out of such planning. If they do not, the Faculty should turn to a more direct concern with such problems.

Dean: What are your other recommendations?

Professor M: Our second major recommendation concerns the structure of the curriculum. We recommend a common core in science of one twelve-unit subject in chemistry, two twelve-unit subjects in mathematics, and two twelve-unit subjects in physics. In addition, we recommend that every student be required to take a distribution of three twelve-unit science area electives and one twelve-unit laboratory elective. We recommend that the freshman and sophomore requirement in humanities and social science consist of four nine-unit courses in the general pattern recently voted by the Faculty, and that the upperclass requirement of four eight-unit subjects in humanities and social science remain as at present. We recommend that the first- and second-year elective requirement, the "freshman-sophomore elective," remain as at present, except that each student not in R.O.T.C. be required to take six units of elective in engineering.

Engineering Professor B: The reduction of the common core in science is a striking feature of your recommendation.

Professor M: Note that the overall core of science subjects would remain at approximately its present size. The effect of our recommendation is simply to introduce earlier branching within the core framework. The earlier branching which we recommend for science is similar to that recently voted by the Faculty for core subjects in humanities and social science.

Engineering Professor B: Does this earlier branching make sense in terms of subject matter?

Professor M: To begin with, we think the reduction makes sense in terms of existing subjects. A reduced common science core of 5.01, 8.01, 8.02, 18.01, and 18.02, together with science area electives and laboratory electives, should provide an adequate basis on which to build an upperclass program through departmental requirements and elective choice, provided that alternative and independent versions of later terms in the basic science subjects, such as 18.03 and 18.04, are made available at the level of science area electives.

We expect, however, that changes in the common core subjects will occur, both as a result of current planning and as a result of our proposal.

We assume that science area electives and elective laboratories would be made available in limited numbers, and that they would be carefully planned and approved for specific use as science area electives and elective laboratories. Effort and planning on such subjects should be fully comparable with effort and planning on the common core subjects. We have studied possible elective laboratories and science area elective subjects, and, on the basis of faculty interest in such subjects, we believe that an adequate number can be made available as soon as needed. The science area electives would include subjects in chemistry, mathematics, and physics that are presently in the common core, and other offerings from both science and engineering departments.

Engineering Professor A: Perhaps we should wait until a full spectrum of science electives and elective laboratories is in existence before making the changes you suggest.

Professor M: No, we believe that flexibility and elective choice can be profitably introduced now. Furthermore, we believe that they will provide concrete incentive for active development of new subjects, and that earlier branching will stimulate good teaching at all levels in the freshman and sophomore years.

In judging our structural recommendations, please keep in mind that we are urging substantial and continuing change in the content and method of the basic science subjects. Moreover, high school training in the basic sciences is in a state of rapid change. In the near future, we will be able to assume that a large majority of students have had greatly improved high school training. At such time we may wish to require special courses on the part of less well-prepared freshmen. We do not make a specific recommendation regarding this at the present time because we expect that it can be arranged within the framework of the six-unit freshman-sophomore elective and that its specific format will depend on the continued planning in the various subjects.

Guest: Why should there be any common core in science?

Professor M: Ultimately, a common core in science might be unnecessary. We believe that there are several reasons for having a common core at the present time. A common core allows for more concentration of faculty effort in the planning and presentation of basic subjects. It does not require the student to make major decisions about his curriculum before he has first-hand knowledge of university work. And it helps provide a curriculum in which he can postpone choice of professional field until his sophomore or junior year, if he so desires.

Dean: What would a student's schedule be?

Professor M: We recommend that the student's normal freshman and sophomore load be from 45 to 51 units. This means that a student may if he wishes take four major subjects in a given term as a full load—three twelve-unit subjects and a nine-unit humanities and social science subject—or he may take four major subjects plus a six-unit elective, or he can take three major subjects and two six-unit electives. This degree of flexibility under the label of "normal schedule" appears to us highly desirable. We furthermore recommend that each of the common core subjects in science and mathematics be offered in each term. This allows a new dimension of flexibility in the student's freshman and sophomore schedule, and is especially helpful for the less well-prepared freshman.

Engineering Professor B: To what extent could the departments specify a student's freshman and sophomore schedule?

Professor M: We recommend that the departments specify two of the four subjects taken as science area electives and laboratory elective, and that the student be given appropriate faculty counselling in his choice of the two unspecified subjects. In addition, beyond the science area electives and elective laboratory, a minimum of 24 units remains available to the departments in the first two years.

We view the sophomore year as a year of tentative commitment and controlled flexibility for the student. The larger common core currently in existence guarantees that students may shift from one departmental program to another at the end of their sophomore year without undue hardship. The committee believes it is essential that this guarantee be preserved, and that science area electives and elective laboratories be available to assist the student in exploring possible professional specialties.

Dean: Have you any recommendations on upperclass programs?

Professor M: Our third major recommendation is that paths be made available within departments for students who do not want a full professional course. At present, for a student to profit from the association with a department, M.I.T. requires that he study for a professional degree. At a time when many students go on to graduate school, this rigidity is, in our opinion, undesirable. We urge that students be offered less intensive "majors" in various departments, leading to degrees without specification. We do not propose a specific format for such programs; we only recommend that departments be permitted and urged to develop and publicize such programs if they deem them appropriate.

We also recommend that the Bachelor's Thesis be made a departmental rather than Institute requirement.

Finally, and apart from the other structural recommendations which I have summarized here today, there is the question of time for free electives in the upperclass years. The committee feels that it is desirable to guarantee each student a certain amount of free elective time. In our opinion, a reasonable balance of departmental and elective time will obtain if the student is given a minimum of 28 units of free elective time. This provides 144 units beyond the area electives and laboratory for departmental programs.

Engineering
Professor A: We would have to be careful about the number of units of free elective time because the departments would not have so much common core to depend on and would have to require more subjects to compensate for this.

Professor M: We have studied the departmental programs with some care, and we believe that, with appropriate science area electives available in chemistry, mathematics, and physics, almost all of these programs can be adapted to our recommendations with only minor changes. If our proposal is modified for a transitional period to allow for larger departmental programs, we strongly favor having this modification take the form of a decrease in the 28 units of free elective time rather than an increase in departmental specification of science area electives and elective laboratories. Some degree of free choice among the area electives and laboratories is, for us, a fundamental feature of our proposed early branching in the core.

Dean: When do you propose that your recommendations go into effect?

Professor M: We propose that they go into effect for the class entering in the fall of 1965. Thus a full range of elective laboratories and science area electives would not have to be ready until the academic year 1966-1967.

Dean: Have you any other recommendations?

Professor M: We have several further proposals on calendar and schedules, but we do not recommend that these be adopted at the present time. Our final recommendation now is that the Faculty take up these further proposals in a few years' time and examine them in the light of the experience gained from the new programs and curricula.

Dean: What are these proposals?

Professor M: We propose that the Institute adopt a quarter system, with three quarters as the normal academic year and three subjects per quarter as the normal student load. We propose that the unit of "term-subject" be adopted for measuring degree credit, and that all subjects be either unit or half-unit subjects. We propose that overloading for degree credit be restricted to one additional subject per term, and that, except in the case of entering students and transfer students, advanced standing examinations for degree credit be replaced by "independent study examinations" which do not carry degree credit. These further proposals are discussed in more detail in our Interim Report of May 28, 1963.

Dean: We must end this session. Thank you all for your time and interest.

## II. RECOMMENDED MOTIONS

Some of the committee's recommendations will require changes in the Rules and Regulations of the Faculty. The committee submits the following motions to amend the Rules and Regulations.

MOVED:

1. That the Faculty amend Section 14, Paragraph 2, of the Regulations of the Faculty by replacing the words "The General Institute Requirements" by "For members of classes that enter before July 1, 1965, the General Institute Requirements," and by deleting the words "a thesis or project of not less than 9 units (except for students in the Department of Mathematics)".

2. That the Faculty amend Section 14, Paragraph 3, of the Regulations of the Faculty by replacing the words "The General Institute Requirements" by "For members of classes that enter before July 1, 1965, the General Institute Requirements," and by deleting the words "a thesis or project of not less than 9 units.".

3. That the Faculty amend Section 14, Paragraph 4, of the Regulations of the Faculty by replacing the word "Subjects" by "For members of classes that enter before July 1, 1965, subjects".

4. That the Faculty amend Section 14 of the Regulations of the Faculty by adding the following: "For members of classes that enter after July 1, 1965, the General Institute Requirements for the degree of Bachelor of Science are the successful completion of the following: 5.01 (6-6), 8.01 (5-7), 8.02 (5-7), 18.01 (4-8), 18.02 (4-8), 21.01 (3-6), 21.02 (3-6), 21.03 (3-6) or 21.04 (3-6), 21.05 (3-6) or 21.06 (3-6) or 14.003 (3-6), three Science Area Electives, one Elective Laboratory, the first- and second-year elective requirement (including 6 units of Engineering Elective for students not taking R.O.T.C.), the upperclass Humanities and Social Science requirements, the Physical Education requirement as voted by the Faculty, and a total of at least 360 units, excluding advanced Army R.O.T.C.

"For members of classes that enter after July 1, 1965, the General Institute Requirements for the degree of Bachelor in Architecture are the successful completion of the following: 5.01 (6-6), 8.01 (5-7), 8.02 (5-7), 18.01 (4-8), 18.02 (4-8), 21.01 (3-6), 21.02 (3-6), 21.03 (3-6) or 21.04 (3-6), 21.05 (3-6) or 21.06 (3-6) or 14.003 (3-6), three Science Area Electives, one Elective Laboratory, the first- and second-year elective requirement (including 6 units of Engineering Elective for students not taking R.O.T.C.), the upperclass Humanities and Social Science requirements, the Physical Education requirement as voted by the Faculty, and a total of at least 450 units, excluding advanced Army R.O.T.C.

"For members of classes that enter after July 1, 1965, subjects taken in the first and second years, in addition to the General Institute Requirements and up to a maximum of 24 units, will be accepted in each Course as part of the stated unit requirements for graduation in that Course. In any Course leading to the degree of Bachelor in Architecture or Bachelor of Science with specification, the Department responsible for the Course may designate two subjects from among the Science

Area Electives and Laboratory Elective required above. All programs for the degree of Bachelor in Architecture or Bachelor of Science with specification shall include at least 28 units of free elective time in addition to subjects used to satisfy the General Institute Requirements for Science Area Elective and Elective Laboratory.

"For members of classes that enter after July 1, 1965, each of the subjects required as General Institute Requirements in the first and second years shall be a 12-unit subject except for subjects in Humanities and Social Sciences, which shall be 9 units, and certain first- and second-year electives which may be 6 units."

5. That the Faculty amend Section 12A (5) of the Rules of the Faculty so as to read:

"Within the limitations of the General Institute Requirements the Faculty delegates to each Department the authority to approve departures by individual students from approved course curricula, and further delegates to each Department authority to establish special curricula for the degree of Bachelor of Science without specification. The Faculty further delegates to the Deans of each School the authority to establish interdepartmental committees empowered to establish course curricula for the degree of Bachelor of Science without specification. Descriptions of these curricula shall be supplied to the Committee on Curricula, and a summary of all departures from all course curricula shall be supplied to the Committee on Curricula each term."

Proposed Regulations of the Faculty

14. To be recommended for the degree of Bachelor of Science or Bachelor in Architecture, a student must have attended the Institute not less than one academic year, which ordinarily must be the year of his graduation. He must have completed satisfactorily a program of study approved in accordance with the Rules and Regulations of the Faculty.

For members of classes that enter before July 1, 1965, the General Institute Requirements for the degree of Bachelor of Science are the successful completion of the following: 5.01 (6-5), 5.02 (6-5), 8.01 (5-6), 8.02 (5-6), 8.03 or 8.031 (5-5), 8.04 (5-5), or 8.041 (5-5) when followed by 8.051 (or 8.05), 18.01 (3-6), 18.02 (3-6), 18.03 (3-6), 18.04 (3-6), 21.01 (3-5), 21.02 (3-5), 21.03T (3-5) or 21.04T (3-5), 14.003 (3-5) or 21.05T (3-5) or 21.06T (3-5), the first- and second-year elective requirement, the upperclass Humanities and Social Sciences requirements and the Physical Education requirement as voted by the Faculty, and a total of at least 360 units, excluding advanced Army R.O.T.C.

For members of classes that enter before July 1, 1965, the General Institute Requirements for the degree of Bachelor in Architecture are the successful completion of the following: 8.01 (5-6), 8.02 (5-6), 8.03 or 8.031 (5-5), 8.04 (5-5), or 8.041 (5-5) when followed by 8.051 (or 8.05), 18.01 (3-6), 18.02 (3-6), 21.01 (3-5), 21.02 (3-5), 21.03T (3-5) or 21.04T (3-5), 14.003 (3-5) or 21.05T (3-5) or 21.06T (3-5), the first- and second-year elective requirement, the upperclass Humanities and Social Sciences requirements and the Physical Education requirement as voted by the Faculty, and a total of at least 450 units, excluding advanced Army R.O.T.C. For students already holding a Bachelor's degree or its equivalent, the required four terms of Physics can be satisfied by two terms of Physics and two terms of Natural Science.

For members of classes that enter before July 1, 1965, subjects taken in the second year, in addition to the General Institute Requirements and up to a maximum of 36 units, will

Present Regulations of the Faculty

14. To be recommended for the degree of Bachelor of Science or Bachelor in Architecture, a student must have attended the Institute not less than one academic year, which ordinarily must be the year of his graduation. He must have completed satisfactorily a program of study approved in accordance with the Rules and Regulations of the Faculty.

The General Institute Requirements for the degree of Bachelor of Science are the successful completion of the following: 5.01 (6-5), 5.02 (6-5), 8.01 (5-6), 8.02 (5-6), 8.03 or 8.031 (5-5), 8.04 (5-5), or 8.041 (5-5) when followed by 8.051 (or 8.05), 18.01 (3-6), 18.02 (3-6), 18.03 (3-6), 18.04 (3-6), 21.01 (3-5), 21.02 (3-5), 21.03T (3-5) or 21.04T (3-5), 14.003 (3-5) or 21.05T (3-5) or 21.06T (3-5), the first- and second-year elective requirement, the upperclass Humanities and Social Sciences requirements and the Physical Education requirement as voted by the Faculty, a thesis or project of not less than 9 units (except for students in the Department of Mathematics), and a total of at least 360 units, excluding advanced Army R.O.T.C.

The General Institute Requirements for the degree of Bachelor in Architecture are the successful completion of the following: 8.01 (5-6), 8.02 (5-6), 8.03 or 8.031 (5-5), 8.04 (5-5), or 8.041 (5-5) when followed by 8.051 (or 8.05), 18.01 (3-6), 18.02 (3-6), 21.01 (3-5), 21.02 (3-5), 21.03T (3-5) or 21.04T (3-5), 14.003 (3-5) or 21.05T (3-5) or 21.06T (3-5), the first- and second-year elective requirement, the upperclass Humanities and Social Sciences requirements and the Physical Education requirement as voted by the Faculty, a thesis or project of not less than 9 units, and a total of at least 450 units, excluding advanced Army R.O.T.C. For students already holding a Bachelor's degree or its equivalent, the required four terms of Physics can be satisfied by two terms of Physics and two terms of Natural Science.

Subjects taken in the second year, in addition to the General Institute Requirements and up to a maximum of 36 units, will be accepted in each Course as part of the stated total unit be accepted in each Course as part of the stated total unit requirements for graduation in that Course. The manner in which such subjects will be fitted into each student's curriculum will be determined by the Department responsible for the Course in which the student enrolls in accordance with the authority granted to departments under Faculty Rule 12A (5).

For members of classes that enter after July 1, 1965, the General Institute Requirements for the degree of Bachelor of Science are the successful completion of the following: 5.01 (6-6), 8.01 (5-7), 8.02 (5-7), 18.01 (4-8), 18.02 (4-8), 21.01 (3-6), 21.02 (3-6), 21.03 (3-6) or 21.04 (3-6), 21.05 (3-6) or 21.06 (3-6) or 14.003 (3-6), three Science Area Electives, one Elective Laboratory, the first- and second-year elective requirement (including 6 units of Engineering Elective for students not taking R.O.T.C.), the upperclass Humanities and Social Sciences requirements, the Physical Education requirement as voted by the Faculty, and a total of at least 360 units, excluding advanced Army R.O.T.C.

For members of classes that enter after July 1, 1965, the General Institute Requirements for the degree of Bachelor in Architecture are the successful completion of the following: 5.01 (6-6), 8.01 (5-7), 8.02 (5-7), 18.01 (4-8), 18.02 (4-8), 21.01 (3-6), 21.02 (3-6), 21.03 (3-6) or 21.04 (3-6), 21.05 (3-6) or 21.06 (3-6) or 14.003 (3-6), three Science Area Electives, one Elective Laboratory, the first- and second-year elective requirement (including 6 units of Engineering Elective for students not taking R.O.T.C.), the upperclass Humanities and Social Sciences requirements, the Physical Education requirement as voted by the Faculty, and a total of at least 450 units, excluding advanced Army R.O.T.C.

For members of classes that enter after July 1, 1965, subjects taken in the first and second years, in addition to the General Institute Requirements and up to a maximum of 24 units, will be accepted in each Course as part of the stated unit requirements for graduation in that Course. In any Course leading to the degree of Bachelor in Architecture or Bachelor of Science with specification, the Department responsible for the Course may designate two subjects from among the Science Area Electives and Laboratory Elective required above. All programs for the degree of Bachelor in Architecture or Bachelor of Science requirements for graduation in that Course. The manner in which such subjects will be fitted into each student's curriculum will be determined by the Department responsible for the Course in which the student enrolls in accordance with the authority granted to departments under Faculty Rule 12A (5).

with specification shall include at least 28 units of free elective time in addition to subjects used to satisfy the General Institute Requirements for Science Area Electives and Elective Laboratory.

For members of classes that enter after July 1, 1965, each of the subjects required as General Institute Requirements in the first and second years shall be a 12-unit subject except for subjects in Humanities and Social Sciences, which shall be 9 units, and certain first- and second-year electives which may be 6 units.

Proposed Rules of the Faculty
12A (5)

(5) Within the limitations of the General Institute Requirements the Faculty delegates to each Department the authority to approve departures by individual students from approved course curricula, and further delegates to each Department authority to establish special curricula for the degree of Bachelor of Science without specification. The Faculty further delegates to the Deans of each School the authority to establish interdepartmental committees empowered to establish course curricula for the degree of Bachelor of Science without specification. Descriptions of these curricula shall be supplied to the Committee on Curricula, and a summary of all departures from all course curricula shall be supplied to the Committee on Curricula each term.

Present Rules of the Faculty
12A (5)

(5) Within the limitations of the General Institute Requirements, the Faculty delegates to each Department the authority to approve departures by individual students from approved course curricula. A summary of such departures shall be supplied to the Committee each term.

# III. RECOMMENDATIONS AND REPORTS ON SPECIFIC SUBJECTS

## 1. ELECTIVE LABORATORIES

The committee recommends that each undergraduate be required to take one twelve-unit subject from an approved list of laboratory electives, normally in his freshman or sophomore year.

In an appendix below (Part IV of this report), we present a collection of reports and suggestions for elective laboratories. This collection is not intended to be in any sense complete. Only a small fraction of the Institute Faculty was asked to prepare such reports; but the responses suggest that the staffs of some departments will probably have to be increased in order to make the teaching of these laboratories possible without overloading the Faculty. In many cases, technical help would greatly relieve the heavy requirement on the Faculty, but even this might not sufficiently reduce the problem.

We are proposing a new type of laboratory in which all freshmen and sophomores would have closer contact with professors and would be dealing with real experiments. This type of laboratory teaching will require significantly more faculty time than the present large exercise-type laboratories. The purpose of the collected reports is to show that such laboratories can be offered for students who do not have extensive background in the area and that, in some cases, laboratories of this kind are now being given.

The staffing of these elective laboratories would be flexible. In some cases one professor might work with four to six students in the professor's research laboratory (as in the case of the experimental studies seminars which Professor Ippen has organized). In other cases, classes of a hundred to a hundred and fifty students might be supervised by two or more professors, several junior staff members, and several graduate students (as in Professor King's physics laboratory or Professor Holt's biology laboratory).

The only restriction which should be placed on these subjects is that the students really spend time working on an experimental problem. We recommend that the subjects be twelve-hour subjects with at least six of the hours spent in the laboratory. Each laboratory would meet for two afternoons a week, and additional hours would be available at the student's option. Laboratories would have "project" rather than "exercise" emphasis; each experimental problem to be solved, or device to be built, would require less than a term but more than a single session for its completion. Emphasis would be placed on the student's own ideas and resourcefulness; he might have a general procedure described for him, but he would not be given exact instructions as to the "right" way of doing the experiment. Although the student would certainly learn individual techniques and methods, the laboratories would not be intended to provide general coverage of basic techniques for later work. (This latter goal would be met by professional subjects in the junior or senior year.) Laboratory subjects might well include a number of lecture or seminar hours, but primary emphasis would be on laboratory work.

These laboratory electives would not be designed to teach specific subject matter or to provide broad coverage of a particular field; rather, they would be intended to give the students some real idea as to what laboratories are and what is meant by solving experimental problems in science and engineering. The laboratories should be essentially professional in flavor. The students should get the feeling that they are working on a problem as a professional would work on it, even though they may be repeating an experiment which has already been carried out and published.

Some of these laboratory electives might require a specific lecture subject as a prerequisite. Others might have no prerequisites, or their prerequisites could be satisfied by one of the common core science requirements. But, in any case, the laboratory should not be directly coupled with a lecture subject.

At the present time, laboratory teaching in the core subjects is primarily the responsibility of the Chemistry Department and to a lesser extent of the Physics Department. These departments would probably still have a large fraction of the teaching of the elective laboratories if they chose to make appropriate offerings. However, many other departments, both in the School of Science and the School of Engineering, would have to offer elective laboratory subjects if the program is to be a success. The proposed suggestions in the appendix below are given to show that elective laboratories are possible in many departments even for students who have not taken theoretical work in the departments. In the elective laboratories indicated in these ten reports from faculty members in ten different departments, approximately five hundred students could enroll in each semester. Other departments have indicated interest in presenting elective laboratories but have not yet made detailed plans of the content.

## 2. SCIENCE AREA ELECTIVES

The committee recommends that each undergraduate be required to complete three twelve-unit subjects from approved lists of electives in the life sciences, physical sciences, engineering sciences, and mathematics. Although they might be taken during the third and fourth years, these electives would normally be scheduled at the first-year or second-year level. Introductory physics, chemistry, or mathematics could be designated as prerequisites.

Our approach to the Institute's core curriculum in science is based on the principles of planning, maturity, and depth set forth in the earlier parts of this report. We espouse science area electives because we believe that flexibility, choice, and early branching are desirable within the framework of the core. Numerous stimulating examples of possible electives have been described to us, some from the current Institute Catalogue, some refined from educational experiments now in progress, some merely as proposals. We have grouped these subjects into areas and present a few illustrative outlines at the end of this section. It is anticipated and urged that certain electives, such as those in chemistry, biology, and psychology, should include integrated laboratory work or demonstration experiments.

Further reasons for this recommendation are that such electives can help the student make a wise choice of professional career; that they will provide early insights into how the scientist or engineer applies fundamental principles toward solving the complex problems which confront him; and that they can contribute to departmental programs. The last reason recognizes the need of many Institute courses for sequences of required subjects that must extend back into the second year. Each department should be able to specify two of the four subjects taken as science area electives and elective laboratory, but should otherwise be restricted from influencing its students' selections.

An appropriate faculty committee, such as the Committee on Curricula, should be charged with judging the suitability of individual subjects offered to fulfill the intentions of this science area elective requirement. Broadly speaking, the criteria of selection are that the material presented should be logically developed from fundamental scientific principles applicable to the field under study, and that narrow or excessive professional concentration should be avoided. The committee's views as to what constitute desirable subjects are best clarified by reference to a collection of outlines and related information assembled as an addendum to this report. These contributions were prepared with thoughtful care by faculty members from most of the science and engineering departments. In addition, a variety of subjects in the 1963-64 Institute Catalogue have been examined and found capable of adaptation to particular elective areas. In the aggregate they would serve to bring many more experienced, senior faculty members into contact with second-year undergraduates.

To ensure adequate diversification, it is recommended that the undergraduate be required to choose his three subjects from among the following six areas: life sciences, chemistry, mathematics, physics, earth sciences, and applied science; and that only one of the three subjects be from each area, except that two subjects might be from applied science. The content of these areas is elaborated below.

The committee gave consideration to putting certain additional restrictions on the science area elective, and it suggests that further examination of three such possibilities may be appropriate. The first, and most important, arises from a conviction in many quarters that the Institute requirements should specifically include applied science material for which insufficient time will be available in core physics and chemistry. Notable examples of such omissions are the application of thermodynamics, mechanics, and Maxwell's equations to matter in the aggregate. Perhaps each student should be asked to take one from a list of subjects designed to meet this need. A second proposed restriction is that one elective be from the life sciences area; the committee was impressed by the vital importance of discoveries currently being made in molecular biology and felt their understanding essential to a scientific cultural background. A third possibility is that one science area elective in chemistry be required, either of all students or of those choosing majors that depend heavily on the chemical sciences. Such a chemistry requirement might be combined or alternated with one focused on properties of matter in the aggregate.

## Areas of Science Electives and Examples

A. Life Sciences. This area would include a subject similar to the present 14.70, focused on physiological psychology. Another example is 7.01T - General Biology, for which the following preliminary outline has been prepared by Professors Levinthal, Holt, and Wall.

### INTRODUCTORY BIOLOGY COURSE

Week 1 What is life? The cell theory. A brief (15 minutes) survey of all living things. Bacterial growth. Chemical description of bacteria, including proteins, nucleic acids, fats, polysaccharides, and small molecules.

Week 2 Physical description of bacteria. Synthetic description of bacteria (very general). Intermediary metabolism. Enzymes, enzyme kinetics, and inhibition. Synthesis of fats and polysaccharides.

Week 3 Energy and entropy considerations relevant to living things. ATP, chemical cycles. Sugar metabolism. Photosynthesis.

Week 4 Genetics. The nature of mutations, genetic mapping, transformation, viral growth, complementation. Only haploid organisms considered.

Week 5 The structure of nucleic acids. How are nucleic acids made? The amount of DNA versus the number of enzymes.

Week 6 How are proteins made? Transfer RNA, messenger RNA, and the code. Protein structure.

Week 7 Membranes, viral and bacterial. Diversity of bacteria and their place in the biosphere. Response of bacteria to the external environment. Enzyme repression.

Week 8 Describe the life cycle of algae in detail. Discuss diploidy, miosis, and mitosis. Mendel and drosophila. The emphasis on chromosome mechanics and the evolutionary implications of diploidy and sex.

Week 9 More complicated properties of single cells. Detailed discussions of amoeba. New properties achieved by cell cooperation. Volvox. Differentiation, hydra, and sea urchins.

Week 10 Evolution. Speciation and the classification of plants and animals. Hybrid vigor.

Week 11 The ascidia, chiroptera, cephalopods, cetacea.

Week 12 Rodents, amphibia, adaptation to high altitudes. Detectors, amplifiers, and effectors of the oxygen supply system.

Week 13 Detectors, effectors.

Week 14 Intracellular environment, extracellular environment. Constancy and variability of internal environment with problems of aging, cycles, and exercise.

Week 15 Detection and analysis of external events. Prediction and memory. Pathology.

Week 16 The origin of life.

Course 7.02 will be given during the second semester of the sophomore year and will be entirely a laboratory course. The laboratory will meet two afternoons per week, with time being allotted for a laboratory lecture and two hours of preparation. It is hoped that the laboratory course can be arranged in such a way that each student will carry out four to six experimental projects during the course of the semester.

B. Chemistry. Among others offered by departments such as Chemistry and Chemical Engineering, this area would include subjects in inorganic and in organic chemistry. A one-term outline for a second-year subject in physical chemistry has also been developed.

C. Mathematics. Many subjects now presented by the Department of Mathematics have been examined which would form the bases of science area electives, building on the common core requirement in mathematics. Examples are 18.03 on analyis and probability, 18.04 on differential equations, 18.20 on linear algebra, 18.10 and 18.18 on probability, and 18.05 on advanced calculus for engineers.

D. Physics. This area would include a version of 8.03 as described in #7, as well as other topics. By way of illustration, the following outline has been contributed by Professor Harald Enge:

Tentative Outline of a Proposed Course in QUANTUM PHYSICS

In spite of what I have said about physics being an experimental science, the selected sequence of experiments to be described is dictated by the buildup of theoretical understanding. By coincidence, this makes the sequence to some extent historical, starting with a short introduction of the so-called "old" quantum theory.

Part I. Experiments that can be described satisfactorily or partly by use of ad hoc quantum concepts

a. Black-body radiation
b. Specific heat of solids at low temperatures (briefly)
c. Photoelectric effect
d. Spectral lines from the hydrogen atom (Bohr theory)
e. The Franck-Hertz experiment

Part II. Wave mechanics and experiments illustrating its success

a. Barrier penetration and alpha decay
b. Hydrogen energy levels (in new light)
c. The harmonic oscillator and rigid rotator; molecular vibration-rotation spectra

Part III. Electron spin and the main ideas of angular momentum coupling in quantum mechanics

a. Hydrogen fine structure and hyperfine structure
b. Zeeman effect
c. Molecular beam experiments

Part IV. Many-electron atoms. Pauli's exclusion principle

a. Helium energy levels
b. Hartree's method. The periodic table

My inclination at the moment is to leave out L-S coupling and effects of the residual interaction (Hund's rule, etc.) as too "messy" for this course. A semi-formal treatment of electro-magnetic transitions (perturbation theory) could be included at the end of the course or earlier, whenever the students are ready for it.

The selection of topics has been made so as to give clear illustrations of important principles and methods of quantum physics and not to give a more or less complete course in atomic physics. Very important areas of atomic physics (e.g., x-rays) have not been touched at all.

Since this outline has been made without much knowledge about the prerequisites, please regard it only as one possible point of departure for a discussion of what material ought to be included in a physics course at this level.

E. Earth Sciences. This area would be centered on astronomy and geophysics, and several possibilities have already been reviewed with the faculty of Geology and Geophysics. The following outline was suggested to the committee by Professor Norman A. Phillips of the Department of Meteorology:

Possible Science Area Elective in

METEOROLOGY AND OCEANOGRAPHY

The principal purpose of such a course should be to demonstrate the application of scientific reasoning in meteorology and oceanography. The emphasis is not on the development of general skills or techniques, although some will be acquired. A broad review of meteorology and oceanography is not contemplated either; a relatively small number of specific problems (e.g., four) should be covered in any one offering of the course. The four detailed examples below are drawn from dynamic meteorology and oceanography, but other examples are possible from physical meteorology. The most rewarding examples would be those which illustrate the special features of an observational as opposed to a laboratory science, and some attention must therefore be given to data analysis in each problem.

The effective prerequisite would be mainly mathematical. Fourier series and partial derivatives should be familiar, but only simple "separable" solutions of partial differential equations are necessary. At present this would probably mean a junior year course at the earliest (18.05 being taken concurrently, say).

The following topics should be interpreted as samples rather than as forming a fixed curriculum.

1. Hydrostatics

   a. Theory - (Trivial; ideal gas law, Dalton's law, and expression for pressure force)
   b. Applications
      1. Horizontal distribution of pressure in lower atmosphere
      2. Satellite drag as function of temperatures of ionosphere below satellite (Jacchia, et al.)

2. Propagation of surface waves on the ocean

a. Theory
   1. The simple linear theory in Lamb's Hydrodynamics, with special emphasis on group velocity
   2. Methods of spectral analysis of wave records

b. Application - The detection and location of storms in the Antarctic Ocean from swell recorded in California (Munk). (A beautiful illustration of group velocity)

c. Special features - filtering out of unwanted high frequency noise by location and design of sensors

3. Gravity waves in the atmosphere

a. Theory - As simple as possible, but again with emphasis on group velocity (which is now interesting since it is not parallel to phase velocity)

b. Applications
   1. Interpretation of meteor trail fluctuations observed by radar in the D region (Hines)
   2. Mountain (lee) waves (Sierra Wave Project)

4. Large-scale motions

a. Theory
   1. Coriolis force and geostrophic balance
   2. Vorticity

b. Applications
   1. Weather prediction by hydrodynamical methods
   2. Formation of the Gulf Stream

c. Special features. This topic is well adapted to a triple treatment of theory, observations, and laboratory models. It could easily be expanded to fill the entire semester, to illustrate the effect of rotation on fluid motions of geophysical interest (e.g., Taylor columns, Ekman layers)

5. Possible additional topics would include the global propagation of sound from large explosions, oceanic tides, (maybe) small-scale convection, and the aeronomy of the upper atmosphere.

F. Applied Science. This area could include topics in thermodynamics, continuum mechanics, applied electromagnetic theory, and fluid dynamics, as well as subjects centered around applied solid-state physics, applied chemistry, methods of applied mathematics, and the like.

It is expected that most (but by no means all) of the subjects in applied science would be contributed by the School of Engineering. One important aim would be to illustrate the application of science to realistic engineering problems. The majority of subjects dealing with matter in the aggregate would appear in this category.

Considerable diversity is anticipated, with the foci of individual subjects ranging from circuit theory and system dynamics to continuum theory.

A number of subjects in the current Catalogue show promise of being developed into applied science electives. Examples are 2.01-2.02, 2.25, 2.401, 3.00, 3.09, 6.01-6.02, 16.03, and 16.09. By way of further illustration, the following two outlines are reproduced, one a subject in thermodynamics taught from a metallurgist's viewpoint, the other a continuum mechanics presented jointly by the Departments of Electrical and Mechanical Engineering.

Outline of 3.00-THERMODYNAMICS I

(Prepared by Professor John Elliott)

There is a large class of problems in the chemical and physical behavior of metals and materials which can be treated most effectively in terms of classical thermodynamics. The material in the subject is presented so as to point out the simplicity, power, and limitations in the use of the important thermodynamic (state) properties in analyzing these problems. Emphasis is placed on the use of measurable interactions (work and heat) between the chosen system and the surroundings in determining the changes in the state properties of the system during a thermodynamic process.

The First and Second Laws are presented as postulatory statements of the existence of energy and entropy, respectively, and that they are state properties. Boltzmann's definition is included. The concept of entropy is used to identify reversible and irreversible processes. The Third Law is stated to establish "zero" entropy state.

The other important thermodynamic properties, entropy, heat capacity, the work functions, etc., are also defined. Considerable emphasis is placed on thermochemistry, and on the use of the Gibbs free energy as the criterion of equilibrium in constant temperature-constant pressure processes. The chemical potential is considered in some depth and partial molar properties are developed. Problems and examples are selected to illustrate the application of classical thermodynamics to the behavior of metals and materials.

The attached topical outline shows the sequence in which the subjects are covered. It is to be noted that the chemical potential is treated in greater depth, and fugacity and activity are covered in the next subject, 3.20, Thermodynamics II.

The course consists of two hours of informal lecture and two hours of recitation a week. Approximately five problems are assigned per week. The text is S. Glasstone, Thermodynamics for Chemists, D. van Nostrand. However, there are reading assignments in other texts to provide the student with several points of view on the important topics. We have not as yet found a really suitable text. There are four quizzes per term and a final examination.

## TOPICAL OUTLINE

1. Definitions of work, heat, equilibrium, reversibility, path, process, etc. Mathematical procedures
2. First Law of Thermodynamics and energy
3. Types of work
4. Enthalpy and reference states
5. Enthalpy increment, heat capacity
6. Enthalpy change of reactions, transformation, fusion
7. Temperature dependence of enthalpy of reaction
8. Bond energies, heats of ionization, crystal energies
9. Heat capacities of gases, liquids, and solids
   - The Einstein equation (not derived)
   - The Debye equation and Debye temperature
10. Energy and enthalpy balances
    - Procedure in analysis and calculations
11. Adiabatic reactions, and theoretical reaction temperatures
12. The Second Law of Thermodynamics and entropy
    - The Boltzmann equation
13. Entropy as a concept, reversibility and irreversibility
14. Entropy change of reaction, transformation, fusion
15. The Third Law, zero entropy, and entropy increment
16. Simple statistics, ideal mixing
17. Work functions and free energies
18. The Maxwell relationships
19. Criteria of equilibria
20. Gibbs free energy and equilibrium for constant temperature-pressure processes
21. Chemical potential (fugacity and activity come in 3.20)
22. The reaction isotherm and equilibrium constants
23. Gibbs free energy as a function of temperature and pressure
24. Partial molar properties, partial molar properties of mixing
25. Single-component, multiphase equilibria
26. Discussion of experimental methods
27. Sources of thermodynamic data
28. Techniques for estimation of properties

## Outline of 2.011J - 6.00J-INTRODUCTION TO CONTINUUM MECHANICS

(Prepared by Professors E. F. Kurtz, Jr., and David White)

The course, as presently taught, has each week, two lectures; one tutorial hour; and a fourth hour devoted to examples, demonstrations, movies, and quizzes. The course is intended for M.I.T. first-term sophomores.

The objective of the course is to lay foundations uniformly applicable in the study of the mechanics of broad classes of continua. The variables and laws used in the mechanics of continua are discussed first, and then the use of constitutive relations as mathematical models of real materials is discussed. The application of these concepts to the study of continua is illustrated by considering examples involving elastic solids and viscous fluids.

An outline of the major topics covered in the course is given below:

I. Introduction
   1. Concept of a continuum and continuum variables
   2. Limitations on the validity of the continuum model

II. Force Variables and Laws
   1. Review of mechanics of systems of mass particles
   2. Newton's laws for continua. Momentum density, force density, surface traction, stress
   3. The state of stress, the stress tensor, some fundamentals of tensor calculus for Cartesian axes, coordinate transformations, Mohr's circle, principal stresses, invariants
   4. Surface-force density as divergence of the stress tensor
   5. Restatement of Newton's laws for continua

III. Geometric Variables and Laws
   1. Translation, rotation, and deformation
   2. The displacement field
   3. The displacement-gradient tensor, the strain tensor, and the rotation tensor
   4. Coordinate transformations, Mohr's circle, principal strains, strain invariants
   5. Lagrangian and Eulerian methods of description
   6. Geometric laws, velocity-displacement law, geometric compatibility
   7. The velocity-gradient tensor, rate-of-strain tensor, rate-of-rotation tensor, coordinate transformation, Mohr's circle, principal rates of strain, rate-of-strain invariants

IV. Properties of Real Materials
   1. Solids, liquids, and gases
   2. Elasticity, plasticity, viscosity, other characteristics
   3. Relation of observed behavior to atomic view of matter
   4. The use of constitutive relations as mathematical models of real media

V. Examples for Elastic Solid Continua
   1. Development of constitutive relation, specialized for isotropic media
   2. Statically determinate examples, rods, tubes, tanks
   3. Equation of motion governing displacements in elastic solids
   4. Waves, longitudinal and transverse
   5. Plane stress and plane strain, stress function, biharmonic equation, examples of solutions for Cartesian coordinates, pure bending
   6. Engineering theory of beams
   7. Stress function for cylindrical coordinates, thick-walled tubes, stress concentration, Saint-Venant's principle, boundary layers

VI. Examples for Viscous Fluids

1. Development of constitutive relation, specialized for isotropic media
2. Pressure, the two coefficients of viscosity, compressible and incompressible media
3. Static equilibrium, manometers, buoyancy
4. Nonviscous flows, Bernoulli theorem, pitot tubes
5. Plane shearing flows, Couette flow, Poiseuille flow
6. Laminar boundary layer on a flat plate

## 3. ENGINEERING ELECTIVES

The committee recommends that every student be required to take a minimum of six units of an engineering elective as part of the first- and second-year elective requirement. The engineering elective would be selected by the student from a list of offerings approved for this purpose. Students using two terms of R.O.T.C. to satisfy the first- and second-year elective requirement would be exempted from the engineering elective requirement.

The committee believes that all students should know something about the nature of modern engineering. We feel that the entering freshman often has little understanding of engineering and that such an understanding is essential to an informed choice of department at the Institute as well as to a proper appreciation of the forces which shape modern society.

The committee thinks an engineering elective should be built around a case study of a modern engineering problem. The class would view the problem broadly in terms of the economic and sociological needs which motivate the problem and in terms of the variety of possible ways to solve the problem. Important critical areas would then be isolated, and the class would penetrate deeply into a small number of them. Finally, the class would again focus upon the entire system in the new light of a deeper understanding of the areas studied in depth. Such a subject might be offered as an undergraduate seminar, in which a faculty member works with a small number of students in an informal atmosphere, or it might be a more formal offering to a larger class as in the case of the present subject 2.00-Introduction to Engineering.

Such a subject is difficult to design for freshmen, who have a narrow scientific base upon which to build. Yet the committee feels that it is desirable to interrupt, at an early stage in the student's program, the often unrealistic sequential packaging of his education, and to confront him with challenges for which the preparation has not been neatly laid in a previous semester. To be motivated by a challenging task, to assess fruitful approaches to the task, to identify and fill gaps in his knowledge by independent study, and to apply the newly acquired knowledge to the successful completion of the task constitute an experience which can mature and motivate a freshman just as it does a professional engineer.

The committee believes that a number of the undergraduate seminars currently being offered by the faculty of the Engineering School would make excellent engineering electives. The committee urges that the engineering faculty attempt to design more offerings for larger classes along the lines of 2.00-Introduction ot Engineering.

## 4. HUMANITIES AND SOCIAL SCIENCE

The committee recommends as the Institute requirement in humanities and social science the new program which the Department of Humanities proposes to put into practice with the fall of 1964:

| | |
|---|---|
| Freshman Year: | 21.01 and 21.02 |
| Sophomore Year: | From the following newly designed subjects:<br>either 21.03T (literature)<br>or<br>21.04T (philosophy)<br>and<br>either 21.05T (history)<br>or<br>21.06T (history)<br>or<br>14.003 (social science) |
| Junior and Senior Years: | Four additional subjects in humanities and social science, of which at least three are to be in one discipline. The Departments in the School of Humanities and Social Science should be free, as at present, to impose sequential limitations on these subjects. |

The committee further recommends that the subjects for the freshman and sophomore years be given as nine-unit (3-6) subjects.

The committee believes that studies in humanities and social science are indispensable to the education of every M.I.T. undergraduate. They give him opportunities to develop better understanding and formulation of ideas, to sharpen his sensitivity and judgment in communication, to become more mature in his response to his own and other contemporary cultures, and to acquire more awareness of the human past. They introduce him to forms of disciplined analysis and perception by which he may continue to increase his knowledge of himself and other men and about the heritage of achievements and problems which he shares with them.

To engage the student in a profound way, we feel, such studies should be pursued in depth. For example, a student may in the proper study of a single novel enlarge his abilities in all of the above respects. We believe that a student should be given as much of such study in humanities and social science as is compatible with the other needs of his science and engineering education. We therefore recommend retaining the requirement of eight terms in humanities and social science, four terms in the freshman and sophomore years and four terms in the junior and senior years — as at present.

We support the recent decisions of the Department of Humanities by which the subject in the second term of the core (21.02) will offer greater freedom of choice and the subjects in the third and fourth terms will be history, literature, philosophy, or social science.

## 5. CHEMISTRY

The ~~committee~~ recommends that the common core of science subjects include one twelve-unit subject in chemical principles, ~~the background~~ for which should be the "CHEMS" high school course (see below) or its equivalent.

A second and earlier recommendation — that high school chemistry be made a requirement for admission to the Institute — was voted by the Faculty at the March 18, 1964, meeting.

Two semesters of chemistry are now required of M.I.T. undergraduates. The content of these subjects (5.01 and 5.02) is, roughly: first semester, an introduction to chemical principles, and second semester, application of chemical principles to the correlation of the chemical behavior of the common elements. These two subjects assume no previous course in chemistry because high school chemistry has not been a requirement for admission to M.I.T. At present, 8.5 per cent of students in any entering class obtain advanced placement in chemistry for both 5.01 and 5.02. Advanced placement is not given for the first semester alone. Of those entering with advanced placement in chemistry, approximately 45 per cent go directly into the subject in organic chemistry. Their performance there has been comparable with that of the sophomores who comprise the bulk of the students in that subject.

Although high school chemistry has not been a requirement for admission to M.I.T., a large proportion (99 per cent) of those in the recent freshman classes have had high school chemistry. In addition, high school chemistry training is undergoing considerable improvement with the recent development of better courses such as the Chemical Education Material Study program (CHEMS) and the Chemical Bond Approach program (CBA). Also to be considered is the general improvement of high school courses in chemistry, physics, and mathematics. Presumably the fraction of students entering M.I.T. with the background of the high school CHEMS program will steadily (and markedly) increase over the next two or three years. (It has been estimated that this year between 10 and 15 per cent of U.S. high school students in chemistry are using CHEMS study materials.)

The committee believes that a single twelve-unit subject in chemistry will be of value for all students, including those who take no further chemistry subjects, if it is preceded by a good high school course in chemistry. For the next two or three years the present 5.01, somewhat modified, would, in the committee's opinion, be satisfactory for this purpose.

The Chemistry Department plans to offer a new course (two-semester subject with coupled laboratory work) to approximately fifty freshmen in the Fall of 1964. Development of the new subjects, under the direction of Professor Moore, is being aided by the Science Teaching Center.

The committee hopes that in the current consideration of the effect which the improving situation in high school chemistry, especially the CHEMS program, will have on freshman level subjects at the Institute, a subject can be developed whose first semester might emphasize chemical principles and constitute a reasonable terminal point for some students, as well as a branching point (i.e., starting point to several possible science area electives in chemistry) for others who wish to pursue further studies in this and related fields.

In the expectation that there will be a steady increase in the level of the chemistry background of the entering freshman, the committee believes that a one-semester subject emphasizing the following areas might ultimately be desirable: 1) atomic and molecular structure, bonding, 2) chemical thermodynamics, 3) chemical kinetics -- how chemical reactions occur, 4) determination of molecular structure, a case study.

The outline given below illustrates one form that such a subject might take.

Outline of a One-Semester Course in Chemistry - (five hours per week: three lectures, two recitation sections)

A. Atomic and Molecular Structure, Bonding - 10 lectures

1) Atomic structure: hydrogen atom (emission and absorption spectra, energy levels)

2) Discrete energy levels: description of electron distribution, atomic orbitals, quantum numbers

3) Many-electron atoms, Periodic Table

4) Electronegativity, ionization potentials, dipole moments

5) Molecules: combination of atomic orbitals, hybridization, directed valence, covalent bond

6) Molecular geometry: structure of carbon compounds

7) Bonding in solids: crystals, ionic bonds, lattice energies

8) Crystal structure: X-ray analysis

9) Bonding in liquids: van der Waals forces, hydrogen bonds

B. Chemical Equilibrium - 4 lectures

C. Thermodynamics[1] - 14 lectures

1) Thermodynamic systems, states, characteristics of a function of state, equilibrium states, temperature

[1]The approach outlined here is that of B. H. Mahan in Elementary Chemical Thermodynamics (a monograph currently in use in the second semester of a freshman course for chemistry majors at Berkeley) and of L. K. Nash in Elements of Chemical Thermodynamics (a monograph currently in use in a first semester freshman course at Harvard)

2) First Law of Thermodynamics

   a. Work and heat, pressure-volume work
   b. Enthalpy, Thermochemistry, and Hess's law
   c. Bond energies, enthalpies of formation
   d. Heat capacities, temperature dependence of enthalpy
   e. Ideal gas calculations, isothermal and adiabatic changes

3) Second Law of Thermodynamics

   a. Equilibrium in isolated systems, reversibility and irreversibility, the Carnot Cycle
   b. The concept of entropy, molecular interpretation, evaluation of entropy changes

4) Free energy and equilibrium

5) Determination of free energy changes — electrochemical cell

6) Temperature dependence of equilibria

7) Applications of thermodynamic principles

   a. Phase equilibria, properties of ideal solutions
   b. Chemical applications
   c. Electrochemistry, electrical work, electrode potentials

D. How Chemical Reactions Occur[1] — chemical kinetics - 12 lectures

1) The concept of reaction mechanism

2) Reaction kinetics, measurement of reaction velocity

3) Reaction rate laws, experimental basis

4) Theories of reaction rates

   a. Kinetic-molecular theory
   b. Temperature dependence of reaction rates
   c. Transition state theory of chemical change
   d. Potential energy curves

5) Reaction mechanisms — interpretation of rate laws (detailed consideration of a number of specific examples of special interest and significance)

[1] The approach outlined here is that of E. L. King in How Chemical Reactions Occur ( a monograph for use at the freshman level)

E. Determination of Molecular Structure. A Case Study - 4 lectures (e.g., a detailed examination of how a chemist establishes the structure of a simple compound — isolation, purification, and establishment of structure with emphasis on chemical methods)

F. Molecular Spectroscopy - an alternative to E., which might cover part of the following:

1) Radiation and molecular energies

2) Rotational spectra, size and shape of molecules

3) Vibrational spectra, flexibility of molecules

4) Electronic spectra

## 6. MATHEMATICS

The committee recommends that the common core of science subjects include two twelve-unit subjects in mathematics, normally taken in the freshman year.

The committee believes that, for the immediate future, this requirement would be satisfactorily met by a somewhat amplified coverage of the topics of the first two terms of the present four-term sequence. The increase from nine-unit subjects to twelve-unit subjects implies an increase from one recitation hour per week to two recitation hours per week. This change appears to the committee to be pedagogically very desirable.

The present first term of mathematics is on functions of a single real variable and the differential and integral calculus of such functions. The second term is on functions of several real variables and vector differential and integral calculus. The third term is on linear algebra, series, and probability. The fourth term is on ordinary differential equations.

The committee believes that branching in mathematics could occur in the third term. In particular, one path might lead directly into a modified version of 18.04 on ordinary differential equations, whereas another might lead first into a modified version of 18.03 on elementary linear algebra, probability, and differential equations. Still other paths might lead into subjects in algebra, in probability, and in function theory.

Emphasis in the basic mathematics curriculum has continued in the direction advocated in the Interim Report. The Supplementary Problems for freshman mathematics have been enlarged and published in book form. Joint plans with the Science Teaching Center are being made for exploring the possible development of programmed teaching materials and alternative approaches to basic topics.

The following are excerpts from the discussion of mathematics presented in the committee's Interim Report.

"Science and engineering use mathematical models to analyze and predict real phenomena. In a general technological curriculum, mathematics is the study of such models and of the basic conceptual entities ("mathematical objects") used in the construction of such models. (In a first year of mathematics, for example, such entities are, and should continue to be, functions of real variables and related concepts.)

"Mathematical training should give not only familiarity and facility with these entities but also a sense of their objective reality on which a student can build confidence, resourcefulness, willingness to use any and all techniques to get answers, and ability to work with approximations and to check bounds on such approximations.

"Such training requires that a careful and imaginative course be steered between two extremes: (a) a subject in "handbook" manipulative drill, which leaves the student only able to do problems that exactly fit the drill patterns he has learned; and (b) a subject emphasizing rigorous argument in a context where the student does not yet see the need for it (as in the proof, for example, that a continuous function f between c and d assumes all values between f (c) and f (d)). Subjects of type (a) can be far from easy (and some drill is, of course, vital). Subjects of type (b) provide the student with a sense of objective reality but fall too much into the category of apprenticeship subjects. The ideal subjects should involve a certain amount of rigorous argument and give the student a sense of the nature and necessity of mathematical proof; this might be best accomplished in connection with the combinatorial and algebraic aspects of the subject matter.

"We applaud the recent trends in first year mathematics exemplified by the Supplementary Problems used in 18.01 this year and quote several of these problems as typifying the desired emphasis. We first suggest a possible sequence of topics ..."

"Term 1. Functions of a single variable are presented as basic objects and both algebraic and geometric insights are emphasized. (Careful definition, possibly via set-theoretic notation, should be included.) Differentiation and integration are presented as basic operations on these objects. Elementary functions are chiefly studied. Emphasis is placed on careful work with inequalities and approximations. Throughout the term, problems and exercises require and develop manipulative proficiency.

"Term 2. The term includes functions of several variables, partial differentiation and multiple integrals using vector concepts, Green's Divergence, and Stokes's theorems."

"We conclude with some examples and comments.

"(1). Sample question. How does the number of solutions of the equation $\sin x = ax$ depend on a? Note that this problem falls into no set computational pattern. The student must rely on geometric analysis of the situation. He can get an approximate answer (within $\pm 2$) easily. He can get an exact answer by analyzing points of tangency.

"(2). Working with approximate answers is a good introduction to careful (i.e., rigorous) argument. Proofs can also appear in a more algebraic context; e.g., showing existence of the partial fraction decomposition. (It might even be appropriate to spend time on some simple axiomatized algebraic theory.)

"(3). Mathematical activity is often a mixture of empirical study of cases, conjecture of general theorem, and proof of theorem. Examples illustrating this in simple and meaningful contexts are desirable. The following, though too difficult for a regular exercise, serves as an illustration.

"Let f be a continuous function on the closed interval from 0 to 1, and let p be a real number such that $0 < p \leq 1$. Define: p is a chord for f if, for some q such that $0 \le q < q + p \le 1$, $f(q) = f(q + p)$. Define: p is a universal chord if, for all such continuous f with $f(0) = f(1) = 0$, p is a chord for f. Clearly 1 is a universal chord. Are there any others; if so what are they? A graphical trial and error search shows, for example, that 2/3 is not a universal chord. Proof shows that $\frac{1}{2}$ is a universal chord. (Take any f. Assume $f(\frac{1}{2}) > 0$. Define $g(x) = f(x + \frac{1}{2}) - f(x)$. Then g is continuous on the closed interval from 0 to $\frac{1}{2}$, and $g(0) > 0$, $g(\frac{1}{2}) < 0$. As a continuous function, g must assume all values between $g(0)$ and $g(\frac{1}{2})$, hence for some q, $g(q) = 0$; i.e. $f(q + \frac{1}{2}) = f(q)$.) Full answer to the problem involves construction of examples, generalization of the construction of examples (to get all non-universal chords), and general proof (to get all universal chords).

"(4). Sample question (before student has learned specific integration formula for tan x).

$$\text{Evaluate} \qquad \lim_{a>0} \int_0^a \frac{\tan x}{a}\, dx$$

This question illustrates the desired sense of objective reality and the related ability to work with inequalities.

"(5). Sample question. Let $x = f(t)$ and $y = g(t)$. Find an expression for $\frac{d^2y}{dx^2}$ in terms of the derivatives of f and g.

"(6). Work on partial differentiation gives another opportunity to emphasize resourceful understanding of mathematical objects as opposed to overemphasis either on formal drill or on rigorous proof. A properly trained student will, for example, have no difficulty in keeping independent variables straight in his later work on thermodynamics and will, for example, be able to express a gradient in a new coordinate system without falling back on mere memorizing.

"(7). Eventually, with increased training in calculus on the part of entering students and more time available in the basic mathematics sequence, it might be desirable to introduce more work on the general subject of coordinate transformations. (Work on relativity in physics suggests this.)"

## 7. PHYSICS

We recommend that the common core of science subjects include two twelve-unit subjects in physics, normally taken in the freshman year. We recommend that these subjects be given without laboratory. (See discussion of elective laboratories above.)

In the remainder of this section we describe current planning by the Physics Department for freshman and sophomore physics. This planning is being done independently of our recommendations. We believe that the freshman subjects described below will be appropriate for the common core in physics and that the sophomore subjects described below will be appropriate for science area electives.

The Physics Department and the Science Teaching Center have jointly initiated a substantially new program to replace the present freshman and sophomore physics courses — hopefully to replace 8.01, 8.02, 8.03, 8.04, 8.031, 8.041, and 8.05 with a three- or four-term sequence.

Members of the Science Teaching Center have prepared text materials, lecture demonstrations, problems, tests, and examinations for the first year of this subject, and an experimental group of 55 students has been studying it with Professors Anthony P. French and Jack R. Tessman. These students will continue the experiment next year, and it is expected that they will have finished the topics covered in the outline below.

Some of the materials to be used by these students as sophomores have already been prepared by Professor Edward H. Purcell of Harvard in connection with a physics course being developed by the University of California under the direction of Professor Charles Kittel at Berkeley.

The most novel part of the sequence will be a coherent version of the quantum mechanics, the preparation of which is now under way. Professors Arthur K. Kerman and Louis S. Osborne are presently teaching two small groups of sophomores in order to focus the physicists' attention on the pedagogic difficulties of the subject matter. Professors Kerman and Osborne are being assisted in weekly meetings with a dozen members of the Physics Department. The Physics Department and Science Teaching Center are preparing these materials for general use next year.

A decision has been made to expand this year's freshman experiment to the full entering class next year under the direction of Professor French and with a large supporting professorial faculty.

The subjects for next year will meet five hours per week: two hours for recitation, two hours for lecture, and one additional hour (the hour heretofore allocated for physics laboratory) for lecture, film, or demonstration. The additional hour will be used to help make the backgrounds of the students more coherent than at present.

The Physics Department has also designated the full teaching time for next year of Professors John G. King and Clive H. Perry for the preparation of a laboratory as described in the appendix on elective laboratories.

In barest outline, the proposed sequence of topics for the core subjects in physics is as follows.

| | |
|---|---|
| 1st term: | The particle view of nature (5 weeks)<br>Classical mechanics of particles (9 weeks) |
| 2nd term: | Introduction to special relativity (5 weeks)<br>Mechanical oscillations and waves (9 weeks) |
| 3rd term: | Basic electricity and magnetism (up to Maxwell's equations) (7 weeks)<br><br>Electromagnetism from the viewpoint of special relativity (3 weeks)<br><br>Electromagnetic waves and radiation (4 weeks) |
| 4th term: | Introduction to quantum physics (10 weeks)<br>Properties of matter in bulk, especially gases (4 weeks) |

A fuller description, with references to typical usable source materials, is given below.

At such time as it can be assumed that all students entering the Institute have had a good course in PSSC physics, or the equivalent, it is expected that the sequence of topics above can be covered in three terms according to the following schedule.

| | |
|---|---|
| 1st term: | The particle view of nature (5 weeks)<br>Classical mechanics of particles (5 weeks)<br>Introduction to special relativity (4 weeks) |
| 2nd term: | Mechanical oscillations and waves (4 weeks)<br><br>Basic electricity and magnetism (up to Maxwell's equations) (8 weeks)<br><br>Electromagnetism from the viewpoint of special relativity (2 1/2 weeks) |
| 3rd term: | Electromagnetic waves and radiation (4 weeks)<br>Introduction to quantum physics (8 weeks)<br>Properties of matter in bulk, especially gases (2 1/2 weeks) |

I. The particle view of nature (5 weeks)

Charges and particles

The universal elementary charge; Millikan experiment

Electrons; electron beams; F = ma applied to motion of electron in uniform electric field

Determination of electron mass and charge

The problem of detecting and counting individual electrons; signal versus noise

The electron multiplier and its use as a tool

Atoms and molecules

Formation, detection, and dynamics of beams of neutral particles

Determination of atomic masses and sizes. The concept of cross section

The chemical and physical classification of atoms

Ions and nuclei

The motion of ions under electric and magnetic forces; mass spectroscopy

Nuclei as particles with charge, mass, and size

Randomness; the statistical fluctuations always associated with finite numbers of discrete particles

Radioactive decay; shot noise; Brownian motion

Photons; the phenomenology of photoelectric effect and interference behavior

Extension of the particle concept to include wave properties; the wave aspect of all particles

Big and huge particles — baseballs, planets, and stars

(The above topics comprise Part I of Physics - A New Introductory Course, prepared at the M.I.T. Science Teaching Center. A preliminary printed version exists and is being used as text in the physics course 8.01S during 1963-4.)

II. Classical mechanics of particles (9 weeks)

Kinematics; the notions of instantaneous velocity and acceleration; rudiments of the mathematical description of various motions

Circular motion and centripetal acceleration; circular satellite orbits and $T^2 \sim R^3$ for this case

Frames of reference and Galilean transformations

Force, inertia, and the content of Newton's law

Momentum and energy; collision processes

Conservation principles for momentum and energy; work and potential energy

Use of potential energy diagrams as basis for analyzing motions of constant total mechanical energy

Potentials with minima — $V(x) = Ax^{-m} - Bx^{-n}$; parabolic expansion about the minimum.

The linear harmonic oscillator (free, undamped)

A simple perturbation problem — the pendulum of finite amplitude

Field and potential for a conservative force

The inverse square law; Gauss's law for gravitation

Motion in a central field; polar coordinates and angular momentum

Energy diagrams incorporating centrifugal potential; qualitative analysis of orbital motions

Perturbation of circular orbit in $1/r^2$ field to get closed ellipse

Exact analysis of elliptic motion of high eccentricity

Rutherford scattering with emphasis on dependence of differential cross section on Z, v, and $\theta$

Scattering experiments as a tool for investigating the law of central force

(The above topics correspond approximately to Part II of the experimental course 8.01S and to the printed notes already made for it.)

III. Introduction to special relativity (5 weeks)

The essential ingredients of Newtonian dynamics

Departure from Newtonian behavior — the limiting speed of electrons (film of M.I.T. linac experiment)

Photons — their speed, momentum, and energy (radiation pressure, etc.)

Einstein's box and the inertia of energy; photons from a thermonuclear reaction

Construction of $E^2 = c^2p^2 + E_o^2$ as a general dynamical relation for particles

Motion under a constant force in the new dynamics

Relativity principles in general; the notion of an invariant

Inertial frames and the invariance of $\underline{a}$ in Newtonian mechanics

The need for a revised kinematics

Time dilation (film of muon decay experiment) and length contraction

The Michelson-Morley experiment

Einstein and the universality of c

The relativity of simultaneity

Time and length measurements; the Lorentz-Einstein transformations; space-time

Transformation of velocity, acceleration, and force

Doppler effect and the twin paradox

Relativistic dynamics; photon emission and two-body collisions; thresholds for particle creation; scattering

The force between parallel currents, looked at from the laboratory frame and the rest-frame of the electrons (a first hint of the connection between E and B)

(The above topics correspond to Part III of the experimental course 8.01S. Much of this material was tried out in a freshman seminar during 1962-3, and all of it will appear in printed form during 1963-4.)

IV. Mechanical oscillations and waves (9 weeks)

The forced, damped oscillator; resonance and Q; line width

Two coupled oscillators; normal modes and non-stationary states, superposition

Linear coupled systems of N identical oscillators

Waves in a continuous one-dimensional medium; phase and group velocity

Waves on a membrane with simple boundary conditions

Scalar waves in three dimensions

One example of a non-scalar wave (e.g., seismic waves)

(The above would be drawn largely, with adjustment of level where necessary, from existing sources, first-rate examples of which are:

Slater & Frank, Introduction to Theoretical Physics, Chapters 11-18

Coulson, Waves

Lindsay, Mechanical Radiation)

V. Basic electricity and magnetism (7 weeks)

Conservation, quantization, and invariance of charge

Coulomb's law, Gauss's law, and superposition (but lean on gravitation, Part II)

Discrete and continuous charge; distributions; $\nabla \cdot D = \rho$; energy in the field

Laplace's equation; the curl of a vector field; electrostatic boundary value problems

Steady electric currents; ohmic and non-ohmic media; EMF

Quasi-steady currents; D and $\dot{D}$

Forces between steady currents; the magnetic field and the circuital theorem $\nabla \cdot B = 0$

Non-steady currents; Faraday's induction law; the betatron

Maxwell's equations as a summary of electromagnetism

(Prime source for the above: text material written by E. M. Purcell for Berkeley course project. Other sources at about the right level are electricity and magnetism texts by Duckworth and by Kip.)

VI. Electromagnetism from the viewpoint of relativity (3 weeks)

The force exerted between two charges moving with separate constant velocities (including zero)

Transformation of the force for different inertial frames; identification of electric and magnetic field components

Distribution of lines of force around a moving charge

Electric field of an infinite line of charges with v = const; force exerted by current-bearing wire on a moving charge; force between parallel currents

The law of action and reaction applied to steady-state situations

Effect of sudden velocity change on field pattern of a moving charge; pictorial representation of the radiation field of a pulse

(The content of the above section is based on text materials written by E. M. Purcell for the Berkeley course project and by J. R. Tessman for the M.I.T. Science Teaching Center project.)

VII. Electromagnetic waves and radiation (4 weeks)

Plane wave solutions of Maxwell's equations for free space

States of polarization

Energy flow and Poynting's vector

Reflection and refraction at plane dielectric boundary

Boundary conditions at a conductor; wave guides; standing waves

Interference and diffraction of microwaves and light in simple geometries

(Expected source for much of the above is the continuation of E. M. Purcell's text material. See also good existing treatments of physical optics, e.g.:

Andrews, Optics of the Electromagnetic Spectrum)

VIII. Introduction to quantum physics (10 weeks)

Experimental selection of discrete states — polarized light and various arrangements of polaroids; the concepts of alternative representations and of superposed states

Stern-Gerlach experiments, anelogous to the above

The photon as a dynamic entity; experimental details of the Compton effect (time correlation, dependence on energy and angle); the Duane-Hunt law

The sharp spectral line - how sharp? What shape? Fourier transform

Line broadening; uncertainty principles

The gross energy-level structure of an atom, from the nucleus on out; investigations through emission spectra, inelastic scattering (of nucleons, electrons, and photons), and photo-effects

Heisenberg's principle and its application to the spacings and widths of quantum states

Identical particles and quantum-mechanical symmetries

Time-dependent superpositions of states ($NH_3$ molecule, $K^0$ decay)

Wave mechanics and the Schrödinger equation

Applications of the Schrödinger equation

(The development and organization of the above material, with its experimental documentation, is a prime present concern of the Science Teaching Center. We cannot point to any one existing source that presents the bases of quantum physics in the way suggested above.)

IX. The properties of matter in bulk (4 weeks)

Bulk matter as a huge number of particles possessed of various collective properties — pressure, temperature, elasticity, etc.

The properties of gases; the ideal gas laws and their experimental limits of validity

Data on specific heats, $C_p/C_v$, viscosity, etc., for gases; the use of kinetic theory and quantum theory to interpret these

The statistics of $10^{20 \pm 5}$ particles; the overwhelming probability of the most probable distribution in configuration or momentum space

Temperature and entropy as statistical concepts

Quantum statistics; the electron gas; Bose-Einstein condensation

(A good starting-point for the text material of the above is provided by:

Sherwin, Basic Concepts of Physics, Chapter 7.

Experimental documentation is being collected, or developed ab initio, by the Science Teaching Center.)

# IV. APPENDIX ON ELECTIVE LABORATORIES

This appendix presents a collection of summaries which have been prepared by various members of the Institute Faculty who are now giving or planning laboratory subjects along the lines of those suggested as elective laboratories in the committee's recommendations.

TABLE OF CONTENTS



*Included as part of Professor Ippen's report.

## AN ELECTIVE LABORATORY IN PHYSICS

John G. King
Associate Professor of Physics

We wish to offer an elective physics laboratory course (1-6-2) based on the following kinds of work:

(1) The use of modern instrumentation to study relatively simple physical systems with care and thoroughness.

This work differs from professional experimental investigation only in scope and in the amount of time spent. Given the instruments and ingenious problems to investigate, it is up to the staff to provide guidance in such matters as how to "play the parameters", "distinguishing theory from experiment", "what am I measuring?", etc. The appended list of experiments must be considered as implying a list of apparatus which, if available, would give an unprecedented degree of flexibility to undergraduate physics lab. A few of these experiments are being tried out this term (Spring 1963-1964) with students.

(2) The construction of solder glass vacuum tubes to investigate some of the properties of electrons, ions, and atoms.

Apart from its use in junior physics laboratory (8.09), solder glass was first given a systematic trial last year (Spring 1963) with 33 freshmen. Each one built a high vacuum cylindrical diode, measured its thermionic properties, and, by placing it in a magnetic field, measured e/m for electrons. After this introductory exercise, the students undertook projects of various sorts. The students' descriptions of their work are perhaps most revealing of what was done; a typical student report is attached. We feel that this sort of work is very well suited to this laboratory course. Some of the experiments that might be done are listed, particularly in sections C, D, E, and G.

(3) The investigation of simple solid-state physics problems.

In the Spring of 1962 Professors Cochran and Holden of the Physics Department gave a freshman seminar in solid-state physics. The students grew single crystals of tin, identified the crystal planes by etch pit goniometry, measured resistance in different directions and as a function of temperature, investigated the Hall effect, and measured specific heats.

We wish to accommodate 150 students, who will meet in groups of 25 six times a week for six hours. Each member of a teaching staff consisting of two professors and four instructors (who hold doctorates) will spend two afternoons each a week with the students. The teacher will not need to prepare but will have to give each student and his problem undivided attention as needed. One technician will also be needed, and to permit night work a responsible assistant should be provided. A weekly one-hour lecture will be used to explain or demonstrate new material (for instance, the use of solder glass), to show movies, and generally to provide some unity.

The space now used for the freshman physics lab (4 rooms — 3800 square feet) should be equipped with 150 lockers (5 cubic feet) and storage space which can be high on the wall if the right kind of ladder is provided. One room will be used for solder glass construction, another for solid-state experiments, and the two remaining rooms will contain some of 50 different experimental tables, all set up and ready to go.

## About Fifty Experiments for an Elective Laboratory in Physics

A. Oscillations
   - Acoustical resonance
   - Electrical resonant circuits and cavities
   - Coupled systems (mechanical, electrical, and acoustical)
   - Optical resonance
   - Nonlinear systems (mechanical and electrical)
   - Harmonics, spectra, and noise
   - Transients and Fourier analysis

B. Waves
   - Strings, membranes, bars, and plates
   - Standing waves in gases and solids
   - Doppler effect
   - Dispersion and attenuation
   - Microwave and acoustic optics
   - Radiation pressure
   - Scattering of light
   - Speed of light

C. Electrons
   - Velocity, energy, and momentum of electron beam
   - Shot noise
   - e/m for low (100 eu) high ($\beta$-ray) energies
   - Electron diffraction

D. Kinetic Theory
   - Thermal conductivity
   - Viscosity
   - Speed of sound
   - Specific heat
   - Brownian motion
   - Fluctuations of a vane

E. Atomic Beams
   - Counting atoms
   - Mean free path
   - Velocity distribution
   - Stern — Gerlach experiments

F. Classic Experiments
   - Cavendish
   - Eotvos
   - Faraday
   - Rowland
   - Michelson
   - Fizeau

G. Quanta
   - Franck — Hertz experiment
   - Photoelectric effect
   - Spectra

H. Solid-State
   - Etch pit goniometry

Electric and thermal anisotropies
Low temperature phenomena
Hall effect
Thermionic and field emission

I. Miscellaneous
Heat flow (steady state, transient, periodic)
Diffusion and effusion
Joule experiment
Gas discharges
Piezo — electricity
Solder glass experiments

The following is a final report (less figures) by one of the freshmen, Paul L. Kebabian, in the 12P Seminar in the Spring of 1963:

"The first tube that I built was a cylindrical diode with which I measured the E-I-R properties of the filament and its emission characteristics. I also measured e/m for the electron by using the tube as a magnetron in a magnetic field parallel to its axis. Graphs of the results are attached.

"I next began an investigation of positive ion sources with the eventual goal of constructing a time of flight mass spectrometer, which would use a pulsed accelerating field to give the ions different momenta according to their mass and a fixed field to separate them according to their energies.

"The first type of ion source I tried used a barium getter to supply metal which was ionized by contact with a heated tungsten filament. The main desirable feature of this type of source is that it is extremely clean and easy to construct. Unfortunately, I found that it was too difficult to control the temperature of the getter, with the result that it generally burned out after a short running time. Also, the high atomic weight of barium is a disadvantage for the intended application.

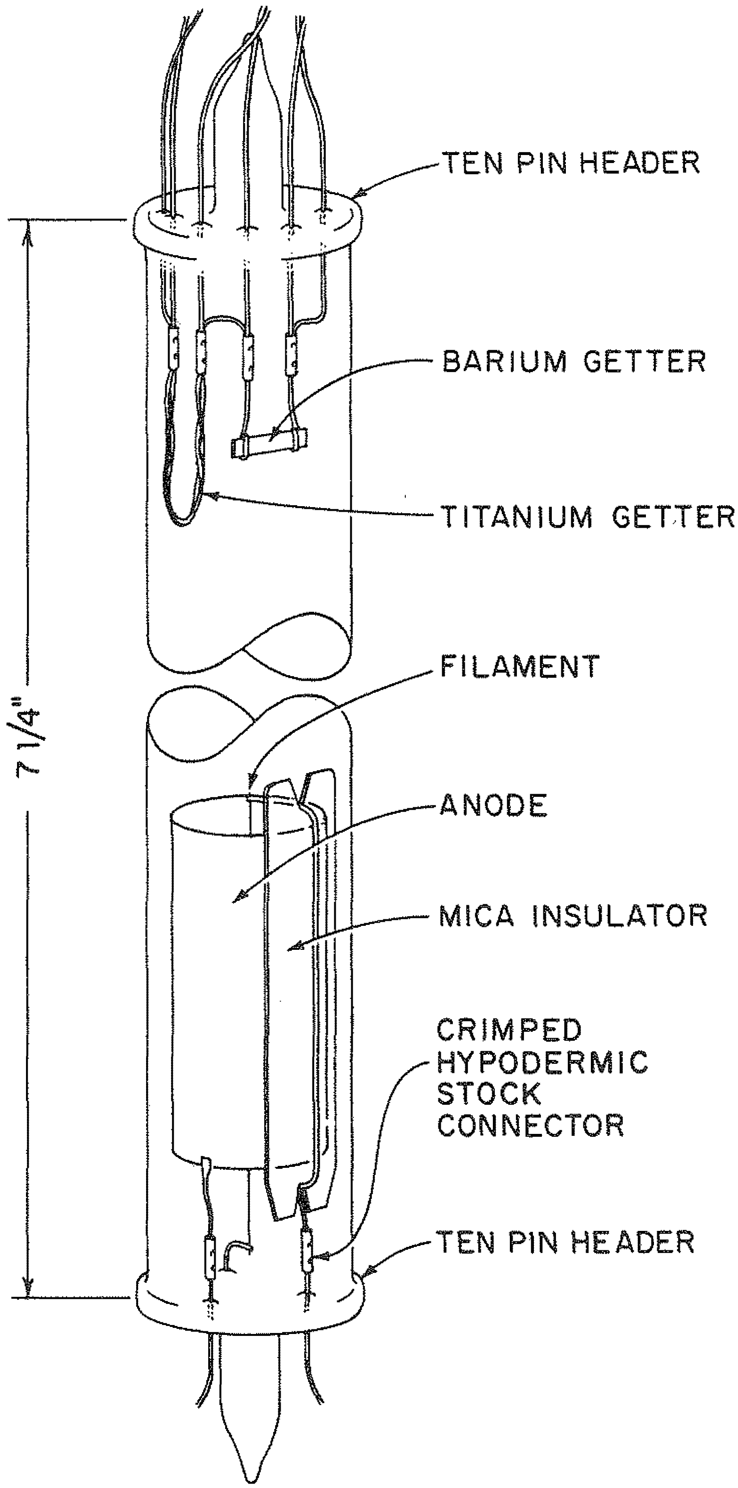
"For these reasons, the final tubes that I built used potassium metal, which was again surface ionized. These worked well, although pollution of the filament, etc., by oxides and decomposition products of the oil in which the potassium was stored were to some extent a problem.

"I found the solder glass technique of making tubes quite reliable, and I did not lose any tubes due to bad solder glass joints.

"The 'electrical' sealing technique, which uses one of the ovens to seal the tubes by fusing the stem while the tube was connected to the vacuum pump, seems to be generally unreliable. Several of the tubes that I sealed this way later developed leaks. Although the use of a torch to seal the tubes, which this method replaces, is somewhat trickier, it is more reliable once mastered.

"I think that it might be worthwhile to look into the possibility of using the headers from ordinary octal tubes in place of the present types. If applicable to solder glass, they would have the advantage that many present types have, rigid support wires extending a useful distance into the tube from the header which would simplify tube construction considerably. They also have smaller stems which would simplify sealing.

"Although the tubes that I built never progressed to the point that I needed internal supports for the plates due to the lack of strength of the lead wires, this need seems to be general for the more complex types of tube. One possible answer to this problem might be the use of glass feed-through capacitors as supports. By using them as indicated in the diagram below, one obtains a rigid and insulated joint. Although the cost per unit is somewhat high (about $.20), a cheaper type can probably be found that will work as well."




INTRODUCTORY DIODE

# AN ELECTIVE LABORATORY IN BIOLOGY

Charles E. Holt, III
Assistant Professor of Biology

## Introduction

The General Biology Laboratory (7.02T), as given this semester, could be adapted for use as a freshman-sophomore elective laboratory. This report describes what has been done in the course and evaluates its possible use as an elective laboratory.

## Description of 7.02T — Mechanics

The responsibilities for 7.02T are divided between Prof. Lettvin and myself. I will be discussing here mainly my own half of the course which has just been completed. There were two sections of 34 students each, and each section met twice a week. In addition, everyone met once a week for a one-hour lecture or discussion. The credit hours assigned to the course are 1-6-2 (lecture-laboratory-study). The staff for this first half of the course consisted mainly of myself and two graduate assistants. Prof. Humphreys supervised one of the projects, and we also had about 12 hours a week of technical help.

## Description of 7.02T — Philosophy

The ideas behind the 7.02T course are essentially those of the CCCP: to provide "real experiments" with a "professional flavor" — to allow the student to develop his "own ideas and resourcefulness" — to give the students an idea of "what is meant by solving experimental problems." A problem that one faces in trying to reach these objectives is that, if the student is truly given freedom to try his own ideas, it is unlikely that the level of work that he attains will be professional in character. The solution to the problem that I used in 7.02T is to begin the course with an experiment that is laid out in sufficient detail that a professional level can be achieved. The students carried out an experiment from the current molecular biological literature — with no compromises made for simplicity in teaching.

This initial experiment, which took six laboratory periods to complete, was followed by a project taking an additional six periods. The students choose their projects from a list of nine. The main principles in laying out these projects were to provide a brief introduction, an object, materials, and methods but to leave the design of the experiments to the students. This now puts the student in the same situation in which a researcher finds himself, and thus allows the student to develop his creativity, critical sense, and work habits.

Thus, the first six periods of the course provided the student with an idea of the nature of a finished piece of research, and the next six periods provided him with an idea of how one attains a finished piece of work.

## Description of 7.02T — Content

The topic of the first experiment was "Inhibition of RNA and protein synthesis by actinomycin D in Bacillus subtilis." From the data and some assumptions it is possible to calculate the fraction of RNA that is messenger, the rate of turnover of messenger RNA, and the number of times that a messenger RNA molecule functions in synthesizing protein. [See Levinthal, Keynan, and Higa, Proc. Nat'l. Acad. Sci., 48 1631 (1962).]

The first period was concerned with properties of bacteria and with techniques of handling bacteria and measuring their growth. The second period was mainly to teach methods of handling isotopes and to introduce the theoretical aspects of interpreting the data. The third period was an experiment to test the validity of the methods used, and the last three periods constituted the experiment proper. In one of these they studied the incorporation of uracil-$C^{14}$ (RNA precursor), in another valine-$C^{14}$ (protein precursor), and in the third they counted the 70 odd samples that they had accumulated (actually, the counting was often done at odd hours).

A list of the nine projects is appended, and also a copy of the mimeographed material for one of the projects.

During the time for these projects, the laboratory was open at least from 1:30 p.m. until 10:30 p.m. on weekdays, from 10:00 a.m. to 2:30 p.m. on Saturdays, and often at other times.

Evaluation of the Approach Used in 7.02T

All involved in 7.02T, students and staff, were overworked. After the application of so much effort it is difficult to be objective in evaluating it. It can, at least, be said that no one regretted the effort and that the students are enthusiastic. I sense that I have taught much more than I did when I gave "exercise-oriented" laboratories.

The first experiment on messenger RNA worked well. Most students obtained fairly good data. In the projects a limited number (I haven't read all the reports yet) obtained results of professional quality. There are all grades from here down, with some not completing a conclusive experiment relevant to their object. My own feeling is that the impact is much greater when good results are obtained and that failure to carry out a conclusive experiment could be excessively discouraging. Nonetheless, most of the students felt they gained by trying, regardless of what they actually achieved.

Adaptation of 7.02T to a Freshman-Sophomore Elective

The approach outlined above would fit in well with the proposed freshman-sophomore laboratory requirement. Various technical matters need to be solved; particularly, we need more space, more technical help, and preferably more graduate assistants. The course, as taught, overran its credit hours badly, but this would be partly solved since 12 hours are proposed for the freshman-sophomore elective. It is probably best to keep 7.01T a prerequisite; otherwise, a great deal of lecturing would have to be added to the course which would be quite inefficient if the same lectures were being given in 7.01T anyhow. If I were to give the entire course as a freshman-sophomore elective, I would probably have one experiment laid out in detail, another in considerably less detail, and finally a project of the student's choice. Time would be divided about equally among the three.

LIST OF PROJECTS IN THE GENERAL BIOLOGY LABORATORY FOR 1964

(1) Sedimentation of Stable and Unstable RNA of B. Subtilis

(2) Fractionation of Components of Rat Liver Cells and Distribution of RNA, DNA, and Protein Among the Fractions

(3) Macromolecular Synthesis in the Early Development of the Sea Urchin

(4) ATP and Actomyosin in Muscle Contraction

(5) Mechanism of Firefly Luminescence

(6) Red Cell Maturation: Correlation with RNA, DNA, Protein, and Hemoglobin Content Per Cell

(7) Red Cell Maturation: Correlation with Hemoglobin Synthesis

(8) Reticulocyte Polysomes

(9) Ribosomal Site of Protein Synthesis

## Sedimentation of Stable and Unstable RNA of B. Subtilis

The results of the experiments that you have just carried out imply the existence of two fractions of RNA: a stable fraction and an unstable fraction. This conclusion depends on certain assumptions about the metabolism of cells in the presence of actinomycin D. The same conclusion is also favored by experiments that do not utilize actinomycin D but utilize density gradient centrifugation to separate RNA fractions on the basis of their sedimentation constants. When a culture of B. subtilis is incubated with uracil for a long period of time, the radioactivity coincides with the various RNA fractions; however, when the incubation is for a short period, the radioactive RNA fraction has a different sedimentation constant from the bulk of the RNA (Levinthal, Keynan, and Higa, PNAS, 48, 1631 (1962); Levinthal et al., Cold Spring Harbor Symposium #28 (1963)).

Object:

Carry out experiments to answer one or more of the following questions:

(1) What are the sedimentation properties of the main fractions of B. subtilis RNA?

(2) Does density gradient centrifugation of extracts of B. subtilis labelled for various times with uracil-$C^{14}$ provide any evidence for the existence of stable and unstable fractions of RNA?

(3) What happens to the radioactivity in unstable RNA when it breaks down? (Incubate briefly with uracil-$C^{14}$; then add an excess of unlabelled uracil.)

(4) Is the fraction of RNA shown to be unstable in the above experiments the same one which decays in the presence of actinomycin?

(5) What is the (very) approximate half-life of an unstable RNA molecule?

Methods and Materials:

The incubations with uracil-$C^{14}$ are carried out as before. The cells are then broken open in $10^{-4}$ M $Mg^{++}$, the RNA is fractionated on a sucrose gradient, and the radioactivity and $OD_{260}$ of each fraction is measured. Observe isotope handling procedures.

After the incubation, chill the sample quickly by adding to crushed ice, and then sediment the cells at about 5,000 g for 5 min. Keep cold here and below. Pour off the supernatant, and add about 10% of the original volume of fractionation medium ($10^{-2}$ M tris-HCl buffer, pH 7.4 and $10^{-4}$ M $MgCl_2$). Resuspend the cells, sediment again, and discard supernatant again. Resuspend in a small volume of fractionation medium. The volume should be at least 2.0 ml so that it can be handled in the next step. If the volume is too large, you will not be able to get enough material onto the sucrose gradient; however, if the solution is made too concentrated, it will not float on top of the gradient.

Rupture the cells by forcing through a small opening on the "french press". (Will be demonstrated.) The press will take about 2.0 to 30 ml with one loading, and the force is brought to 3,000 pounds.

The ruptured cells are spun at 10,000 g for 10 min to remove cell walls. The supernatant from this centrifugation can be applied directly to the top of a sucrose gradient. See separate instructions for running the gradients. Put on a maximum of 2.0 ml onto an SW-25 gradient, preferably 1.0 ml. A 5-20% gradient can be used and, for the SW-25, spin for 6 hours at 24,000 rpm. (The SW-39 head can also be used and a maximum volume of 0.2 ml can be applied; the SW-39 has the advantage of shorter running time — about 3 hours.) The sucrose solutions should contain $10^{-2}$ M tris and $10^{-4}$ M $Mg^{++}$.

Collect fractions for the determination of optical density at 260 millimicrons and of acid-precipitable radioactivity. Use sufficient material to allow both measurements to be made. Note: 1.0 ml of a culture with $OD_{540}$ of about 0.3 has about 0.4 $OD_{260}$ units of RNA. (One "$OD_{260}$ unit" of material is the amount of material that would give an $OD_{260}$ of 1.0 when dissolved in 1.0 ml.)

Partial List of Materials and Equipment

Slants of B. subtilis
TG-20 medium + .01% tryptone
Uracil-$C^{14}$; uracil
Gyrotory shaker
Servall Centrifuge
French press
Equipment for sucrose density centrifugation
Beckman DU spectrophotometer
Millipore filter equipment
Planchette
Actinomycin D

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## DIRECTIONS FOR STUDENTS FOR PROJECT #1

7.02 T                                                                 Spring, 1964

### SUCROSE GRADIENT CENTRIFUGATION
SW 25 head

PREPARATION: to be done in cold room

1. Remove flea from gradient mixer.
2. Wash with distilled water. Squeeze out water with thumb pressure. Wipe and replace flea. Your fingers are 'dirty'; keep out of chambers.
3. Number and set out 1"x3" cellulose nitrate Spinco centrifuge tubes in a rack.
4. Close valve (vertical) and tuck tube up in the tape.
5. Pipette 13.5 ml 30% sucrose solution in right chamber (near outlet tube) and 13.5 ml 15% sucrose solution in the other chamber. Adjust magnetic stirrer so flea (in 30% side) is rotating slowly.
6. Place flexible tubing in cellulose tube with the end touching the wall near the top. (May use cork to keep in place.) Open valve (horizontal).
7. Check that the solution is flowing smoothly down side of centrifuge tube. (Force out air bubbles in chamber with thumb, etc.).
8. Wash out chambers with distilled water when finished. Cover gradients with foil if not using immediately.

HANDLE CAREFULLY — DON'T SHAKE

LAYERING: Cold room

Place an open metal bucket from the SW 25 centrifuge head in a 100 ml beaker.
Put in the prepared sucrose gradient.
Take up the material to be centrifuged (less than 1 ml in volume) in a disposable pipette with a rubber bulb. Touch the tip to the surface of the sucrose solution at the side of the tube.

Support your hand. Slowly squeeze bulb to layer solution on top of gradient. Screw metal cap on tight. Place bucket in head, flat side* in, numbers corresponding. Screw tight.
When carrying head, cup hands around the three buckets to prevent swinging.
Hook little finger under stand and take with you.

SPINCO ULTRACENTRIFUGE: Model L

Read section on "operation" in instruction manual.

Ten minutes before using:

Open door (left knob counter-clockwise). Check that chamber is clean (wipe with paper towel). Turn on power, refrigeration, vacuum, brake switches.
Close door (left knob clockwise). Actuate vacuum (right knob clockwise).
Lift up top — check that temperature is +15°F (adjust with big screwdriver). Fill oil reservoir to within 1" of top (Beckman oil).

When ready to use: Turn off vacuum (right knob counter-clockwise). Open door. Line up knobs on base of head with holes in the drive shaft in floor of chamber. Lower head carefully into chamber onto drive shaft. Check that it rotates freely. Close door; actuate vacuum. Wait 5 min. to attain vacuum. SIGN LOG BOOK. Set time dial. Set speed dial at 2 (2000 rpm). Push button far right on console. When speedometer begins to register, increase speed dial to 25.

Stopping: When timer reaches 0, the driving motor stops but it will take 5 min. to come to rest. When at rest turn off vacuum, open door, remove head to stand. Close door, actuate vacuum. Turn OFF refrigeration. After 5 min. shut down (turn off all switches) — This avoids ice condensation in the chamber.

COLLECTING FRACTIONS:

1. Prepare a rack of test tubes (about 30 per 28 ml gradient) in a tray of ice.
2. Set the finger pump to deliver 1-2 drops per second, and run iced water through the tubing for several minutes.
3. Clamp the cork tightly in the ringstand with the needle vertical. Pump the tubing dry. Wipe off water around needle point. Turn off pump.
4. Carefully center centrifuge tube in holder over the needle point. Press down firmly onto needle and clamp tube holder.
5. Turn on pump and start collecting fractions, with a constant number of drops per test tube. Note the number of drops collected into the last tube.
6. Save the centrifuge tube if it is radioactive or contains a pellet you wish to investigate.
7. Pump water through the tubing at least 10 minutes to wash out.

*If the flat side is left out, the bucket will break off when the centrifuge is running.

# A LABORATORY ON THE STRUCTURE AND PROPERTIES OF MATTER

John Wulff
Professor of Metallurgy

The proposed freshman-sophomore laboratory elective, which I should like to give, is based on past experience in the freshman lecture elective 3.09, laboratory elective 3.10, freshman seminar, and 3.14 junior course which I now give — all on the same or related subjects.

I regard the proposed course as a continuation in depth of certain topics started in 5.01. It is focussed on solids and, in order that the student be prepared for his one-project experiment per term, he does seven weeks of six-hour experiments which concern technique as well as the subject matter of the lectures and recitation seminar. Thus, crystallography, crystal growing, alloying, microscopy, X-ray diffraction, tensile testing, and the like are better learned early so that the eventual project need not be slowed down for want of technique. Both lectures and laboratory in the first seven weeks of the term are probably not needed for ten percent of the class, but experience in the freshman seminar and 3.09 has convinced me that they are most worthwhile for that ninety per cent of the class who are, at first, handicapped by lack of laboratory, problem solving, and library skills.

The recitation-seminar section of one hour per week and the laboratory for the last eight weeks of the term would be devoted to one experimental project. Thus, in arranging laboratory and seminar-recitation sections at the beginning of the term, students would go into one of three groups — A, B, and C. The A section would be for students who elect to specialize in courses such as I, II, XIII, and XVI; the B section for students who elect Courses VI or VIII; and the C section for students who elect III, V, and X. Each recitation section would have its own project experiment during the last eight weeks of the term, so that the recitation-seminar section hour could be devoted exclusively to the subject of this experiment. Thus, with a maximum of ten sections, no more than ten different experiments would be carried out in the last eight weeks of the term. At present we average two six-man teams on the same experiment. One group would focus more on one phase of the same project than on another.

The main lecturer in the course would continue with his two lectures per week covering the relation of properties to structure. He might, in the last ten lectures of the term, cover most of the properties taken up by the various laboratory sections; whereas the seminar instructors would only discuss the subject of their particular laboratory project. They would, in seminar, guide by discussion both experimental work and outside reference reading. In this way, the seminar instructor would acquaint the student with primary and secondary references to his laboratory experiment. He would also instruct him in writing his report, demand written introductions to the report for correction in the first two weeks, and check illustrations before the final report is handed in at the end of five weeks.

Space and Equipment: We have sufficient space and staff to carry out this course but insufficient equipment for 120 students.

Text: Elements of Material Science, by Van Vlack, will be used, or our own text which will be in print next September.

Reference Texts: Introduction to Solids, by Azeroff; Metallography, by Kehl; Physical Ceramics, by Kingery; Physical Metallurgy, by Chalmers; Polymer Chemistry, by Billmeyer; and Introduction to Chemistry, Nature of Chemical Bond, by Pauling.

SUGGESTED LABORATORY PROJECTS FOR PROPOSED
FRESHMAN-SOPHOMORE STRUCTURE OF MATTER LABORATORY
(three outlined in some detail, the others listed)

1. Magnetic Properties of Ferrites

   a. Press and sinter a ferrite toroid.
   b. Study microstructure; relate to equilibrium diagram.
   c. Slowly cool one toroid — ordered spinel.
   d. Quench one toroid — disordered spinel.
   e. Determine degree of order with X-ray diffraction.
   f. Measure magnetic properties in an A.C. circuit — impulse coil and pick-up coil on same core.

2. Aging

   a. Cast end-chilled plates of aluminum-4.5 per cent copper alloy.
   b. Examine structure to extent time permits (dendrite arm spacing, amount of nonequilibrium second phase, etc.).
   c. Homogenize. Again examine structure to extent time permits.
   d. Compare amount of second phase with that predicted by theory.
   e. Age. Make hardness vs. time of aging curves for different temperatures.
   f. Determine mechanical properties. Relate properties to structure and processing history.

3. Study of Cube Texture in Recrystallized Copper

   The (100 [001] texture can be made extremely sharp in rolled and annealed copper sheet; essentially a pseudo-single crystal may be formed. A unique aspect of this texture is that its intensity can be evaluated rather precisely by simple metallographic analysis of annealing twins, by etch pitting, and by elementary X-ray diffraction techniques. In addition, the polycrystalline copper having such a texture has interesting plastic properties.

ADDITIONAL LABORATORY PROJECTS FOR PROPOSED
FRESHMAN-SOPHOMORE STRUCTURE OF MATTER LABORATORY

1. Precipitation-hardening
2. Crystallinity and Cross-linking in Polyethylene
3. Orientation and Mechanical Properties of Polystyrene
4. Sintering and Grain Growth in Ceramics
5. Magnesium-lead Phase Diagram
6. Crystal Growing
7. Cold Work - Anneal Cycle of Alpha Brass
8. Tensile Properties of Copper Single Crystals
9. Lead-Antimony Alloy Magnetization Curves at Liquid Helium Temperature
10. Activated Sintering of Tungsten
11. Hall Effect of Germanium
12. Determination of BxH Product of a Permanent Magnet Material such as Bismanal
13. Variation of Modulus of Elasticity of Cast Iron with Composition
14. Beta Phase Tungsten Compounds as Superconductors

15. Curie Point Measurement in System Cu-Ni

16. Intergranular Corrosion and Embrittlement of 18:8 Stainless Steel Due to Slow Cooling Through the 750°C Range

17. Etch Pits in Lithium Fluoride

18. Deformation Texture in Drawn Wire

19. An Evaluation of the Stretching Capacity of Deformable Solids

20. Strength (Hardness) vs. Grain Size Relationships

# A LABORATORY IN EXPERIMENTAL HYDROMECHANICS

Justin E. Kerwin
Associate Professor of Naval Architecture

In response to your request, I have prepared an outline of a possible freshman-sophomore laboratory elective. This course would be an expanded version of two Undergraduate Seminars, "Experimental Ship Hydrodynamics" and "Sailing Yacht Tank Testing." (The latter was not as specialized as the title might indicate.) Although the laboratory projects would be carried out at the Ship Model Towing Tank, the topics would hopefully be of interest to non-naval architects.

I have indicated that we could possibly accommodate about forty students per term provided some additional space adjacent to the towing tank was made available. This would require some additional staff and auxiliary equipment.

## Experimental Hydromechanics

Prerequisite: 8.01, concurrently

Hours: Two one-hour lectures per week to whole group
Two three-hour laboratories per week for groups of four and five
One one-hour seminar per week for groups of four and five

Organization: The lectures will cover both experimental techniques and some elementary fluid mechanics. Both areas will have to be developed simultaneously in order to back up the laboratory program. It should be mentioned that coverage of fluid mechanics will be difficult in a freshman-sophomore level course. The presentation will therefore be somewhat qualitative, with particular emphasis on scaling.

The laboratory projects fall in two categories, a series of basic experiments to be carried out during the first ten weeks, and a special project to be completed in the remaining five weeks. The latter should be a "realistic" problem of sufficiently narrow scope to be covered in detail.

A preliminary list of lecture and laboratory topics is as follows:

Lecture Topics

1. Experimental Techniques
   a) Methods of measuring force, displacement, velocity, and acceleration.
   b) Recording and analysis of experimental data.
   c) Sources of experimental errors.

2. Elementary Fluid Mechanics
   a) Physical properties of fluids.
   b) Forces acting in a fluid — pressure, viscous, gravitational, surface tension, inertial, etc.
   c) Hydrostatic forces and moments — buoyancy, stability.
   d) Scaling laws — non-dimensional parameters, Reynolds and Froude numbers, etc.
   e) Dynamics of free-floating and fully submerged bodies — restoring and exciting forces, damping, virtual mass.

Laboratory Projects

1. Basic Experiments
   a) Hydrostatics — buoyancy and stability.

   b) Bernoulli equation — the pitot-static tube — drag of a disc normal to flow.

   c) Gravity waves — period, celerity, wave length, group velocity, particle paths, drift. Velocity-wave length relationship as an example of Froude scaling.

   d) Boundary layers — drag of a flat plate — laminar and turbulent flows — transition — boundary layers on three-dimensional bodies — separation-wakes — Reynolds Number.

   e) Lift — deeply submerged hydrofoils — near-surface effects — effect of separation on lift.

2. Examples of projects
   a) Wave excitation forces on a surface ship.

   b) Dynamics of a free-floating buoy in waves.

   c) Scale effects on ship and hydrofoil models.

   d) Prediction of sailing yacht performance from model tests.

   e) Design of a velocity meter.

Space, Staff, and Equipment:

At the present time, two Undergraduate Seminar groups with five-six students each can be accommodated at the towing tank. However, the number could be increased greatly if additional space (and some equipment) immediately adjacent to the tank were acquired. While the tank is presently kept busy forty hours per week, the carriage itself is only running a small part of the time. Most of the time is spent setting up and checking out equipment prior to a test. At the present time, there is neither staff nor space for more than one (or at the most, two) project to be underway simultaneously, and this is not enough to keep the carriage in continuous use. Consequently, it is believed that the addition of a well-lighted and quiet area for setting up and checking out experimental set-ups would allow several lab groups to work simultaneously. In this case, possibly a total of forty students per term could be accommodated.

Staff requirements are difficult to estimate at this early stage. Certainly at least an additional instructor and laboratory technician would be required for a group of forty.

## AN EXPERIMENTAL ENGINEERING AND DESIGN LABORATORY

Robert W. Mann
Professor of Mechanical Engineering

The forwarded material on student involvement in design and laboratory project activities is characteristic of a freshman-sophomore laboratory elective which we would be prepared to offer under the provisions of the recommendation on elective laboratories of the Interim Report of the Committee on Curriculum Content Planning.

On the basis of some examples of student performance in subjects we have and are offering now at the freshman, sophomore, and junior levels, we are certain that an effective Institute-wide offering could be organized within the framework of the first two-year program envisioned by the Committee on Curriculum Content Planning.

The subject would borrow heavily from our design-laboratory experience and the freshman seminars in subdividing the students into small (perhaps six-man) groups, each prosecuting a major inquiry throughout the major part of the semester. The subject of the laboratories' attention would, to a maximum extent, be related to and draw upon the interest and research of each laboratory leader. We have found that quite junior people can be most effective in this role, especially as they derive dual benefits from their student contact — both experience in teaching and "help" on their own projects. Thus the staff requirement might be one instructor per two six-student laboratory groups.

The students' own project efforts would be supplemented by a continuing lecture series which could range from the philosophy of inquiry to writing a good report and which would include a graded series of introductory exercises to provide coordination between laboratory groups and accelerate their individual efforts.

The space and equipment of the Design Division of Mechanical Engineering and the Engineering Projects Laboratory are well suited to the program proposed and could probably accommodate up to a hundred students, depending upon other commitments. Staff to handle a group of this size could probably be recruited.

To provide an indication on the character and variety of projects which might constitute the student investigations, the following list is abstracted from design and experimental engineering projects of the past several years proposed by Mechanical Engineering faculty and undertaken by freshmen, sophomores, and juniors. Obviously, more planning must be undertaken before a detailed program is evolved.

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## A LIST OF DESIGN AND EXPERIMENTAL ENGINEERING PROJECTS

Design of a "Zero-Reaction" Astronaut Tool

Feasibility Study of a Stair-Climbing Wheel Chair

Design of an Artificial Limb

Design of a Solar Cooking Oven for Domestic Use

Utilization of Solar Energy for Irrigation Purposes

Feasibility Study of Low Temperature Distillation of Sea Water

Mobility Aid for the Blind

Air Lift Pump

The Stability of a Liquid Annulus in a Tube at Zero Gravity

Compensation for Thermal Expansions in a Thermoelectron Engine

Measurement of Forces Occurring in an Impact

The Yaw Stability of Moored and Towed Vessels

Develop a Push-Pull Testing Machine

Determination of the Smallest Quantity of Fuel Which Will Ignite by Compression in Injected and in Premixed Form

Electrochemiluminescence

Blind Man's Cane

Design of Low-Cost Tape Transport

Pressure and Force Measurements in the Human Stomach

Stress-Strain in a Moving Perforated Tissue Paper Web

Electrostrictive Bearing

Dynamic Super-Charging of Internal Combustion Engines

Speed Control of a Power Absorbing Electric Dynamometer

Design of an Air Regulating Valve for Skin Diving Equipment

Mechanical and Optical Sensory Probes for the Blind

Remote Manipulation

Simulation of Space-Environmental Conditions

Development of a Blood Pump-Oxygenator (Heart Lung Machine) Without Moving Parts

Feasibility and Optimization Study of a "Ducted Fish Tail" Pump for Boat Propulsion

Roll Pressure Distribution Study

Food Container Conveying

Instrumentation of a Remote Manipulator with a Stress Optical Touch Transducer

# A POSSIBLE LABORATORY SUBJECT ON THE TOPIC: COMPLEX LIQUIDS

Edward W. Merrill
Professor of Chemical Engineering

Based on experience with four successive freshman seminars (Seminars 11, 12) I can foresee the practicality of offering a subject to freshmen and/or sophomores having, per week, six hours of laboratory work, one hour lecture or discussion, and two hours outside preparation.

The general framework would be the topic Complex Liquids and would involve the student in the following areas:

1) elementary fluid mechanics of Newtonian and non-Newtonian liquids
2) elementary physical chemistry
3) polymer physics and chemistry
4) surface chemistry
5) some engineering design problems aimed at requiring the student to bring together basic knowledge, estimation, and practical judgment

In the laboratory, the students would work, in part, with doctoral candidates on various advanced problems (e.g., model flow of blood, turbulent flow of polymer solutions, film forming properties of surface active liquids). The overall direction and coordination of laboratory work would be the responsibility of the instructor and a teaching assistant. We would require that each student submit, before the three-hour laboratory sessions which he attends twice a week, a report on what he proposes to do in his experiment and what he expects to observe. After he has carried out the experiment, which would usually be incomplete and often would produce nothing, we would require a written report which we would evaluate with a letter grade. This report would be turned back to the student in the following period and discussed with him.

In previous freshman seminars I have had the assistance of a particularly effective senior who is interested in a teaching career. The senior actually gave several one-hour lectures and directed the laboratory report work, as well as part of the experimental program. In observing the relations between the freshmen and the senior, I was constantly struck by the extent to which the freshmen would confide in the senior regarding their problems, their lack of understanding, etc., and the extent to which they asked the senior about his experience at M.I.T. in other years. The possibilities of using selected upperclassmen in our instructional program has probably been considered from time to time, but it occurs to me that in the proposed program, because of its informality, the double opportunity exists for qualified upperclassmen to gain experience as teachers and for undergraduates to experience a new kind of teaching.

Naturally, this proposal is based on the assumption of financial support for the teaching assistant (or assistants) and for materials and minor equipment needed for the laboratory operation.

In the present laboratory facility, this seminar can accommodate twelve students; with additional space, we could instruct from twenty to twenty-five students.

## A NEW FRESHMAN LABORATORY PLAN: "EXPERIMENTAL STUDIES"

Arthur T. Ippen
Professor of Civil Engineering

In the Freshman Seminars SEM 11 conducted as Experimental Studies over the past two years, students are introduced, at an early point in their careers, to a variety of experiments conducted by many different faculty members representing many of the departments at the Institute, including Civil, Mechanical, Nuclear, Chemical, and Electrical Engineering, and Geology, Aeronautics and Astronautics, and Geo-Chemistry. During a student's first year at the Institute he is introduced, with more than a superficial glance, to the spectrum of research laboratories and research facilities at the Institute. During the Fall Semester of this past year, 43 M.I.T. professors participated in the Experimental Studies seminars for 59 freshmen. In the seminars students in groups of from four to six study with a professor for three continuous weeks. Thus, freshmen perform work in four different laboratories each semester, with as many professors, for three to four working periods. Although it is granted that the logical sequence of a more methodically planned laboratory in a single field may be lost, and that close co-ordination with theoretical instruction may not be possible, there are, nevertheless, many advantages and outstanding opportunities for students to do creative work in this seminar program. Several advantages of the Experimental Study program are:

1. The experiments are more meaningful because they are done in context with or, at least, in close proximity to actual research carried out.

2. The components and instruments employed will cover a much greater variety of basic principles and of types of measurements currently in use in scientific exploration.

3. Matters of precision and accuracy, of responsibility for methodical and logical procedures in relation to more complex systems, will be more apparent in the actual research environment.

4. The repetitious nature of the experiments performed by group after group and over a number of years is greatly reduced. Most laboratories can provide a great variety of experiments and will change their set-ups from year to year.

5. Students will have an opportunity to meet a number of instructors for a sufficient time to establish a basis for future consultation with those to whom they feel attracted either personally or with respect to their professional interests.

6. Most of all, students will gain an appreciation for the scope of activities at M.I.T., for the nature of the work in the various fields, and the professional spirit which motivates most of the faculty. They may thus be greatly influenced by their experiences under this plan in the final choice of their professional careers.

There are, in addition, certain advantages accruing to the faculty and to the various departments of the schools:

1. The faculties of many departments, but primarily those of the Schools of Science and of Engineering, will gain a certain appreciation of the capabilities of the first-year student and a direct connection with the educational program of the freshman year.

2. The planning of departmental programs in later years may be facilitated by their early and direct experiences with these students, especially as the background of the entering class changes with improved training in high schools.

3. There will be ample opportunity for interdepartmental exchanges through involvement of faculty members from most departments in this program. A certain element of competition is automatically introduced.

4. The program will require less time of the individual faculty member participating, since the material for which he is responsible is limited to one or two experiments and the students will work in his normal work area. He can inject as much new material during any semester as he wishes and need not prepare material for the entire semester, as is the case with other courses.

In summary, the experimental project seminar, seeking to exploit the unique opportunities existing at M.I.T. for a more effective integration of the Undergraduate School with the advanced activities in science and engineering, has thus far, on the basis of student and faculty interest, succeeded in its purpose.

The following is a discussion of laboratory experiments performed by freshmen in one of the Experimental Studies seminar series. This seminar, conducted by Professor Erik L. Mollo-Christensen of the Department of Aeronautics and Astronautics, introduced students primarily to concepts and viewpoints rather than to examples of engineering practice.

DESCRIPTION OF FRESHMAN LABORATORY EXPERIMENTS PERFORMED IN THE FRESHMAN SEMINAR SERIES

A Report by Professor Erik L. Mollo-Christensen

## 1. The Acoustic Response of an Enclosure

The experimental arrangement consisted of a noncircular cylinder made out of lead roofing sitting on the table. A horn driver tweeter was connected to a rubber hose, and the end of the rubber tube excited a standing sound field in the enclosure of a wave length smaller than its size.

The students were asked to describe this sound field. They were given a microphone, an oscilloscope, and a voltmeter. After some discussion and experimentation, they discovered that there were nodal surfaces in the sound field, and that these nodal surfaces had vertical generators over the lower half of the enclosure. They therefore put a piece of paper at the bottom of the enclosure, moved the microphone around until they found a node, and made a pencil mark on the bottom. They thus mapped out the nodal lines. They did this for several frequencies.

What they discovered in the discussion and examining the results were:

a. the relation between frequency, propagation speed, and wave length;

b. an understanding of standing waves in several dimensions.

They also used a scope and a signal generator for the first time.

On the suggestion of one of the students, we then put a stack of sponges in the middle of the enclosure and found that there were fewer nodal lines and that those which were left were much less distinct. One of the students concluded his report with the remark that "if you spend several hundred dollars on a hi fi set, I guess you should really spend several times that on the room you put it in."

## 2. Observation and Description of a Stream of Lead Pellets Falling into Water

The experimental arrangement consisted of a salt shaker filled with tiny lead shot. The salt shaker was fastened to a doorbell. Turning on the doorbell shook the shaker, and the shot would be shaken out. This gadget was hung over a plastic barrel full of water. As the shot fell into the water, they set up a streaming motion in the water, and in the first laboratory period the students were asked to describe the flow. They used air bubbles to observe particle trajectories. In the second laboratory period they were asked to try to describe quantitatively a stream of lead shot falling. They all knew the laws of a single falling body. They quickly found that describing or computing the location of each lead pellet as a function of time, although informative, did not lead very far. After some discussion I managed to get one of them to suggest that we should perhaps label the pellets by giving the height of each pellet at a certain time $t_1$. From this we managed to develop the Lagrangian continuity equation, and from there we went on to an Eulerian description of the streaming field. The students seemed to grasp the concepts of continuity and of Lagrangian and Eulerian frames when they finished the session. Also, they seemed to appreciate how one forms a continuum of statistical measure. This experiment has been repeated twice since with other groups of freshmen.

The following is a list of the men who conducted Freshman Seminars in Experimental Studies in the Fall of 1963:

| Faculty Member | Experimental Topics |
| --- | --- |
| Dr. Martin A. Abkowitz<br>Prof. of Naval Architecture | "Modeling the Behaviour of Ships in Waves" |
| Dr. Harris J. Bixler<br>Asst. Prof. of Chemical Engineering | "Desalination by Reverse Osmosis" |
| Dr. Eugene E. Covert<br>Assoc. Prof. of Aeronautics and Astronautics | "Experiments in Vorticity" |
| Dr. William H. Dennen<br>Assoc. Prof. of Geology | "Spectrochemical Analysis" |
| Dr. Philip A. Drinker<br>Asst. Prof. of Civil Engineering | "Internal Waves in Stratfield Fluids" |
| Dr. Peter S. Eagleson<br>Assoc. Prof. of Civil Engineering | "Self-Excited Vibrations" |
| Dr. Lawrence B. Evans<br>Asst. Prof. of Chemical Engineering | "Separation of Azeotropic Mixtures" |
| Dr. Lawrence B. Evans<br>Asst. Prof. of Chemical Engineering | "Desalination of Sea Water by Freezing" |
| Dr. Robley D. Evans<br>Prof. of Physics | "Biological Application of Nuclear Physics" |
| Dr. Morton Finston<br>Prof. of Aeronautics and Astronautics | "Natural Convection Phenomena in Fluids" |
| Dr. James G. Gottling<br>Asst. Prof. of Electrical Engineering | "Electrical Properties of Thin Metal Films" |
| Dr. David Greenewalt<br>Inst., Geology and Geophysics | "Electrical Properties of Rocks and the Measurement of these Properties from the Earth's Surface" |
| Dr. Raimo J. Hakkinen<br>Assoc. Prof. of Aeronautics and Astronautics | "Measurements of Probability of Velocity Fluctuations in Turbulent Flow" |
| Dr. Robert J. Hansen<br>Prof. of Civil Engineering | "Buckling of Shell Type Structures" |
| Dr. John W. Hearle<br>Assoc. Prof. of Mechanical Engineering | "Study of Visco-Elastic Properties of High Polymers" |
| Dr. Harry M. Horn<br>Asst. Prof. of Civil Engineering | "How Firm is the M.I.T. Foundation?" |
| Dr. William D. Jackson<br>Assoc. Prof. of Electrical Engineering | "Waves in Electrically Conducting Fluids" |
| Dr. Russel C. Jones<br>Asst. Prof. of Civil Engineering | "Solid Matter: Minerals, Metals, Plastics" |

| Faculty Member | Experimental Topics |
|---|---|
| Dr. John F. Kennedy<br>Assoc. Prof. of Civil Engineering | "The Formation of Sand Dunes" |
| Dr. Edward M. Krokosky<br>Asst. Prof. of Civil Engineering | "Solid Matter: Minerals, Metals, Plastics" |
| Dr. T. William Lambe<br>Prof. of Civil Engineering | "How Firm is the M.I.T. Foundation?" |
| Dr. David D. Lanning<br>Assoc. Prof. of Nuclear Engineering | "Use of the M.I.T. Reactor for Neutron Activation Analysis" |
| Dr. Jean P. Leinroth, Jr.<br>Assoc. Prof. of Chemical Engineering | "Separation of Azeotropic Mixture" |
| Dr. Jean P. Leinroth, Jr.<br>Assoc. Prof. of Chemical Engineering | "Desalination of Sea Water by Freezing" |
| Dr. Ulrich Luscher<br>Asst. Prof. of Civil Engineering | "Pressure Waves in Soils" |
| Prof. Frederick J. McGarry<br>Assoc. Prof. of Civil Engineering | "Solid Matter: Minerals, Metals, Plastics" |
| Dr. Aidan B. McNamara<br>Asst. Prof. of Mechanical Engineering | "Study of the Visco-Elastic Properties of High Polymers" |
| Prof. Charles L. Miller<br>Head, Dept. of Civil Engineering | "Man-Machine Communications — Computer Languages and Time Sharing" |
| Dr. Erik L. Mollo-Christensen<br>Prof. of Aeronautics and Astronautics | "Description of Streams of Particles" |
| Dr. Gordon C. Oates<br>Assoc. Prof. of Aeronautics and Astronautics | "Flow Over Bodies — Forces and Flow Patterns" |
| Dr. Emmanuel Partheniades<br>Asst. Prof. of Civil Engineering | "Wave Action and Sediment Transport on Beaches" |
| Mr. Frank E. Perkins<br>Instr., Civil Engineering | "Man-Machine Communications — Computer Languages and Time Sharing" |
| Dr. William H. Pinson, Jr.<br>Assoc. Prof. of Geology | "Experimental Geo-Chronology on Rocks and Meteorites" |
| Dr. S. Curtis Powell<br>Assoc. Prof. of Naval Architecture | "Cavitation of Ship Propellers" |
| Dr. Norman C. Rasmussen<br>Assoc. Prof. of Nuclear Engineering | "Nuclear Radiation Detection" |
| Dr. Brandon G. Rightmire<br>Prof. of Mechanical Engineering | "Mechanical and Electrical Behaviour of a Solid-Solid Interface" |

| Faculty Member | Experimental Topics |
|---|---|
| Dr. Arthur C. Smith<br>Assoc. Prof. of Electrical Engineering | "Some Experiments in Solid-State Physics" |
| Dr. Kenneth N. Stevens<br>Prof. of Electrical Engineering | "Sound Measurement and Analysis" |
| Prof. Edward S. Taylor<br>Prof. of Aeronautics and Astronautics | "Low Velocity Measurements in Fluids" |
| Dr. Jay R. Walton<br>Asst. Prof. of Civil Engineering | "Computer Simulations of Transportation Models" |
| Dr. David R. Whitehouse<br>Assoc. Prof. of Electrical Engineering | "Experimental Approach to Plasma Physics" |
| Dr. John W. Winchester<br>Assoc. Prof. of Geo-Chemistry | "Neutron Activation Analysis of the Atmosphere" |

The following are excerpts from letters to the co-ordinator of the program from men who have taught the seminars:

> "I felt that the three sessions of three hours each were very worthwhile and significant. We were able to follow a schedule which brought the freshmen directly in contact with some of the same material and ideas which we are now teaching at the graduate level.
>
> "They were able to work experimentally, computationally, and conceptually with some of the information feedback system aspects of their own educational program. I feel this gave them some insight into the process in which they are taking part. In addition, through the formulation of systems structure and numerical simulation (both by hand and on the 7090 digital computer) of the system characteristics, they were able to see some of the characteristics of oscillation, stability, damping, periodicity, and growth, which they will encounter again in a more formal way as they advance in their undergraduate program.
>
> "It is my feeling that no subject is too difficult to discuss meaningfully with students of this type if the faculty member is able to see the implications of his own work free from the complexities of mathematics and vocabulary within which it is usually entrapped." (Jay W. Forrester, Prof. of Industrial Management)
>
> "I found working with the freshmen interesting and beneficial. I think the students I had enjoyed the rather simple experiments we had them perform and discuss. They at least left with some understanding of, and enthusiasm for, chemical engineering.
>
> "In our experimental problem the students performed all of the work themselves although I had a couple of graduate students looking over their shoulders when precision instruments were being used. They appreciated this chance to <u>do</u> things and indicated that this was not the case in some of the other experiments. I would gather (and agree) that fancy experiments in which the students spend a great deal of time watching rather than doing are not favorably received." (Harris J. Bixler, Asst. Prof. of Chemical Engineering)
>
> "In response to your memorandum of January 10 regarding the Freshman Seminar course "Experimental Studies," please put us down as enthusiastic supporters of this effort. Our experience indicated that the boys involved responded to it in a very positive and valuable fashion, and I certainly believe that it should be continued." (F. J. McGarry, Assoc. Prof. of Civil Engineering)

## LABORATORY RESEARCH IN PSYCHOLOGY

Peter H. Schiller
Lecturer in Psychology

During this spring term, with the assistance of one graduate student in the department, I am giving a course, limited to ten students, whose aim is to acquaint students interested in psychology with the methods and procedures of psychological research. For the 1964-1965 M.I.T. catalogue it is described as follows:

Bulletin Format

9.50 Research in Psychology
Prereq.: 9.00 and any two subjects in psychology
Year: U (2)

Laboratory research in the areas of perception, learning, and memory. Each student will carry out an original study in the area of interest to him. Survey of problems specific to research topics, design and conduct of experiments, written presentation of results.

The course is designed for advanced students who have had three or more courses in psychology; it is possible that with some modifications a similar course could also be given to freshmen or students without previous acquaintance with psychology. These modifications would, in essence, put less emphasis on original work and would thus employ replication experiments or experiments in which minor modifications are made on previous studies. Students would be more closely supervised than in 9.50, and more time would be spent on basic experimental methods. The choice of problems would be more restricted, exploring perhaps only one area in contrast to the three in 9.50 so that all students would be exposed to similar training. The exact procedures involved in such a course would need further study and thought.

The subject, 9.50, is designed to cover three specific problem areas:

(1) Interference with short-term memory:

Attempts to gain better understanding of the physiological processes underlying learning and memory have resulted in numerous experiments on animals employing electrical stimulation, chemicals, etc. to interfere with memory. This is an area where numerous experimental possibilities exist using simple experimental techniques. Equipment is available for this work, as several members of the staff are engaged in this sort of research. The animals used will be rats.

(2) The perception of illusions:

Recently, considerable interest has been generated by experiments showing a relationship in the perception of illusions in different modalities, particularly in vision and touch. These findings have generated a number of interesting experimental possibilities. Some of these will be carried out by the students in this course. Equipment is available for a number of illusions (Poggendorff, Muller-Lyer, Horizontal-Vertical).

(3) Visual masking:

When two visual stimuli are presented in rapid succession, an interference in their perception may be observed. The kinds of interference, the mechanisms underlying this phenomenon, and the general implications for perception have long interested and puzzled psychologists. There are a number of experiments to be carried out in this area which are both important and rewarding to students. Equipment for this work (tachistoscopic programmer and viewing boxes) is available.

A number of faculty members and I are actively engaged in these areas. For this reason, equipment for the course is directly available. For additional expenses (laboratory animals, new equipment, etc.) one can draw on certain grants for research in the department. Space for the experimental work has been provided for on the first and second floors of Building E-10. The lectures, to be held twice weekly during the first phase and once weekly later, will be given in Building E-10. The time devoted to research will vary, but students will be expected to spend an average of seven hours per week in the laboratory and about two hours weekly reading assignments. Thus this course is essentially a "1-7-2".

After becoming familiar with the nature and significance of the problems in the three areas, students will choose the area in which they would like to carry out their experimental work. Each student will work in one area. Students will be paired off, so that during the course always two will work on the same problem. This will provide for desired collaboration and will also add reliability to the experimental procedure and results.

# ELECTRONIC PROJECTS

Richard D. Thornton
Associate Professor of Electrical Engineering

## Introduction:

This subject has four concurrent objectives:

1. To introduce important electronic components
2. To show simple combinations of components as the basic circuit building blocks
3. To introduce important electronic measuring instruments
4. To explore methods, techniques, and interpretation of electronic measurements

The term is divided into five three-week projects, each associated with a specific part of an oscilloscope. Each student would build a small oscilloscope from a kit and study its operation in considerable detail in these five projects. The oscilloscope would have a maximum sensitivity of 1 μa/cm and 1 mv/cm with a rise time of less than 0.1 μsec and a size and quality suitable for dormitory experimentation as well as for general laboratory use.

## Nature of Projects:

Each three-week project would introduce one or two electronic components and investigate the operation of a simple circuit utilizing these components. Each project would also require the student to become familiar with the operation of one or two important electronic instruments and would introduce some pertinent measurement techniques. Typically the first week of each project would be devoted to studying component characteristics; the second week would explore the operation of the circuits; and the third week would include analysis relating component and circuit properties and the writing of a report to summarize the three weeks of work.

## Organization:

Each student would be assigned one bench one day each week and would be expected to spend about six hours in the laboratory between 9 a.m. and 9 p.m. Formal problem assignments due at the end of each laboratory day would emphasize the important points and enforce preparation and/or reflective thought. A short report at the end of each three-week period would give practice at explaining ideas and tie the work together. Also, there would be one oral report per term on any one project. Two one-hour lectures each week would introduce important new ideas and provide experimental demonstrations. Extensive notes would explain theoretical aspects and typical experimental results and problems. Total student time would be ten hours per week with two hours for outside study. The student's grade would be based 10 per cent on each three-week project, 10 per cent on the oral report, 20 per cent on assigned problems, and 20 per cent on subjective evaluation by his instructor.

## Staffing and Facilities:

One experienced faculty member would give the lectures, read selected student reports, and listen to the oral reports. One instructor and teaching assistant would be assigned to each group of 20 to 24 students. Typically there might be three twenty-man sections requiring three (1/3 time) instructors, three (1/2 time) teaching assistants, and one (1/2 time) professor in charge. These 60 students would require three days per week in a laboratory with 20 benches. Each bench would require an oscilloscope, signal generator, and power supply, and each student would require a take-home laboratory kit and an oscilloscope kit.

Project Outline:

A typical set of five projects might be as follows:

1. Probes, attenuators
   a. Components: resistors, capacitors, coaxial cables
   b. Circuits: RC combinations
   c. Instruments: square-sine, signal generator, oscilloscope for repetitive signals, ac bridge
   d. Measurements: frequency, gain, frequency response
2. Rectifier circuit
   a. Components: rectifier diode, transformer, electrolytic capacitor, power resistor
   b. Circuits: rectifier
   c. Instruments: voltmeter, ammeter, ohmmeter
   d. Measurements: incremental impedance, v-i plotting, appreciation of the "ground"
3. CRT and high voltage power supply emphasizing
   a. Components: vacuum diode, CRT
   b. Circuits: oscillator, CRT biasing
   c. Instruments: phototube
   d. Measurements: high voltage, light intensity, linearity, resolution
4. Deflection amplifier
   a. Components: transistor, zener diode
   b. Circuits: differential amplifier
   c. Instruments: curve tracer, oven
   d. Measurements: temperature dependence, incremental gain, rise time
5. Sweep circuits
   a. Components: high speed diodes
   b. Circuits: trigger circuit, integrator
   c. Instruments: pulse generator, oscilloscope for pulse measurement
   d. Measurements: pulse properties, diode recovery

## MEMBERS OF THE COMMITTEE ON CURRICULUM CONTENT PLANNING

HOLT ASHLEY
Professor of Aeronautics and Astronautics
(September 1962-May 1964)

P. L. THIBAUT BRIAN
Associate Professor of Chemical Engineering
(September 1962-May 1964)

CARVEL COLLINS
Professor of Humanities
(September 1962-May 1964)

MARTIN DEUTSCH
Professor of Physics
(September 1962-May 1964)

CARL W. GARLAND
Associate Professor of Chemistry
(September 1962-May 1963)

FREDERICK D. GREENE, II
Professor of Chemistry
(September 1963-May 1964)

WILLIAM L. LETWIN
Associate Professor of Industrial Management
(September 1962-May 1963;
March 1964-May 1964)

CYRUS LEVINTHAL
Professor of Biology
(September 1962-May 1964)

ELTING E. MORISON
Professor of Industrial Management
(September 1963-March 1964)

HARTLEY ROGERS, JR.
Associate Professor of Mathematics
(September 1962-May 1964)

JERROLD R. ZACHARIAS, Chairman
Professor of Physics
(September 1962-May 1964)

DAN C. PINCK, Executive Secretary
(September 1962-May 1964)

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