DOCUMENT RESUME

ED 033 021 SE 004 530

The Second Ann Arbor Conference on Curricula for Undergraduate Majors in Physics (November 12, 13 and 14, 1962).

Commission on Coll. Physics, Ann Arbor, Mich.

Pub Date Aug 67

Note-47p.

EDRS Price MF-$0.25 HC-$2.45

Descriptors-*College Science, Conference Reports, Curriculum, *Curriculum Development, Educational Objectives, *Physics, Undergraduate Study

Identifiers-Commission on College Physics, National Science Foundation

Proceedings of the third conference of the Commission on College Physics are reported. Its main concern was to consolidate the work of earlier conferences: (1) the Denver Conference, dealing with the curricula of colleges which did not offer the Ph.D. in physics, and (2) the First Ann Arbor Conference, dealing with curricular matters of schools that did offer the Ph.D. in physics. This conference drew its participants from those who had attended the two earlier ones. Part A reports the topics which were discussed, and Part B gives recommendations. Two programs were recommended--(1) the R (research) Curriculum to serve those intending to continue graduate work in physics, and those to work in industry and government as junior physicists and (2) Curriculum S, emphasizing interrelationship of physics with other disciplines intended to serve secondary school teachers, students in other major areas, and those wishing general cultural education with a physics emphasis. (DH)

The Second Ann Arbor Conference on Curricula for Undergraduate Majors in Physics

THE SECOND ANN ARBOR CONFERENCE

ON

CURRICULA FOR UNDERGRADUATE

MAJORS IN PHYSICS

November 12, 13 and 14, 1962

Reported by

H. R. Crane, Project Director

This conference was held in The University of Michigan, and was supported by the National Science Foundation. It was one of a series of conferences planned by the Commission on College Physics.

Preface to the Second Printing

An important early concern of the Commission on College Physics was the curriculum for physics majors. In an effort to obtain some guidance for departments examining their major courses, the CCP, with the cooperation of the AAPT, planned a series of three Conferences on Curricula for Undergraduate Majors in Physics which were sponsored by the National Science Foundation. The first of these was held at the University of Denver to consider curricula for colleges which did not offer the doctorate in physics.[1] One hundred seventy-eight physics teachers representing 174 such colleges attended three one-week sessions in the summer of 1961. The second conference, held at the University of Michigan, considered curricular problems from the point of view of departments which offered the Ph.D. Fifty-one faculty members representing 47 institutions attended this First Ann Arbor Conference in May 1962.[2]

At these conferences, the diverse professional needs of students taking physics, the changes in their preparation brought about by high school curriculum development projects, and the differences in the educational resources which colleges and universities could offer were considered. A final conference was held at the University of Michigan in November 1962; the participants were drawn from the preceding two conferences. They issued a report and recommendations,[3] which attempted to take all of these factors into account, to identify the various classes of students whose needs would or should determine the content of the physics curriculum, and to outline ways to meet these needs. It was the judgment of the participants that no one curriculum could (or should be expected to) meet all of these needs, and their report goes on to suggest two parallel curricular styles.

The primary concern of the profession has been for the student preparing for graduate school and a professional career. For this student a desirable end result in terms of readiness for graduate school was set down to be used as a yardstick. That this yardstick is still a realistic one was confirmed by the participants in the first of a series of meetings the CCP is holding to review the conference recommendations.[4]

These physicists pointed out that the Ann Arbor recommendations, because they specified the level of preparation desired of the entering physics graduate student and not a specific course sequence, left much flexibility in the undergraduate curriculum. They went on to suggest some ways in which the flexibility might be used to advantage.[5]

Experience with a second kind of curriculum, one which meets the needs of students not anticipating graduate work in physics, is still lacking. The definition of Curriculum S, as it is called, was carried further at the Princeton Conference on Curriculum S where three outlines of sample curricula were presented.[6]

Concern with the physics curriculum has not abated; the College Science Improvement Program (COSIP) and the CCP's consulting service in fact offer some means and hope for accelerating modification and improvement. We are therefore reprinting the report of the Second Ann Arbor Conference, the summary meeting of the three conferences, with the confidence that departments of physics which are establishing or modifying their major curricula will find it a useful source of guidance and in the hope that its suggestion of a different kind of curriculum designed for physics students other than those bound for graduate study will continue to encourage innovation. This was, after all, the spirit in which the report was originally written.

John M. Fowler, Director
Commission on College Physics
August 1967

1 Reported in Am. J. Phys. **30**, 225, (1962).
2 Reported in the "Progress Report of the CCP," Am. J. Phys. **30**, 153, (1962).
3 Am. J. Phys. **31**, 328, (1963).
4 Columbia University, 26–27 October, 1966. Participants: Richard Garwin (IBM Watson Laboratory), M. L. Goldberger (Princeton), Walter Knight (University of California, Berkeley), Norman Kroll (University of California, San Diego), Edward Purcell (Harvard), Allan Sachs (Columbia University) and John Fowler (CCP).
5 "A New Look at Curriculum R," CCP *Newsletter #12* (February 1967).
6 Am. J. Phys. **32**, 491 (1964).

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INTRODUCTORY STATEMENT

The Conference as one of a series

The conference to be reported here was the final one in a series of three.[1] The first one in the series was held in Denver during the summer of 1961, and was reported in the American Journal of Physics.[2] That conference was attended mainly by representatives of institutions which do not grant the Ph.D. degree. The second conference in the series, "The First Ann Arbor Conference" was held in May of 1962 and the proceedings were published in pamphlet form.[3] The participants came mainly from institutions which have programs leading to the Ph.D. degree. The final conference in the series, which took place in November, 1962 and which is the subject of this report, is known as "The Second Ann Arbor Conference". It was attended by about equal numbers of representatives from Ph.D. granting institutions and from non-Ph.D. granting institutions, nearly all of whom had attended one or the other of the previous conferences. (See Appendix I for list of conferees.)

The primary purpose of this, the final conference in the series was to attempt to put together the results of the two earlier conferences, and to arrive at a specific set of recommendations relating to curriculum for undergraduate physics majors, which would increase the overall effectiveness of our system of physics education. It was hoped that in addition, further fruitful discussion would take place on some of the many problems which were left unsolved by the previous conferences.

Organization of the conference

At the opening of the conference the chairman appointed a writing committee, to carry on the work of writing and revising the curriculum recommendations, with frequent checking and consultation with the conference as a whole. The writing committee convened separately for various periods throughout the three days of the conference. Except for these meetings of the writing committee, all the conferees met as a single discussion group throughout. In general a

1. The series of conferences was planned by the Commission on College Physics. The Ann Arbor meetings were conducted under the auspices of the University of Michigan with financial support from the National Science Foundation. The steering committee for the Second Ann Arbor Conference consisted of Walter C. Michels, Bryn Mawr College, and D. M. Dennison, Noah Sherman and H. R. Crane of the University of Michigan. The last named served as Director of the conference. Ralph P. Winch served as "Captain" of the note-takers. Local arrangements were handled by Mrs. AdaMae Newton. The list of conferees is given as Appendix I.
2. American Journ. of Physics 30, 153 (1962).
3. "The First Ann Arbor Conference on Curricula for Undergraduate Majors in Physics". (Available on request to the Physics Dept., University of Michigan.) Additional notes on the First Ann Arbor Conference are included in "Progress Report of the Commission on College Physics, June 1960 through May 1962 (Amer. Jour. of Physics, Oct. 1962).

single topic was taken up in each half-day session. There were few prepared talks. Two note-takers were designated for each half-day session, and they were charged with turning in a written set of minutes. The proceedings, as they will be set forth here are based upon the diligent work of the note-takers.

Form of this report

Inasmuch as the main purpose of the conference was to work out, in collaboration with its writing committee, a set of curriculum recommentations, it is considered appropriate to arrange this report in two sections plus appendices: Part A, the day by day proceedings or minutes and Part B, the recommendations.

PART A: THE DAY BY DAY PROCEEDINGS

Nov. 12, morning. Topic: In what useful way or terms, can we attempt to specify "good undergraduate preparation for a physics major?" Chairman: H. R. Crane. Note-takers: L. Hadley and F. Benedetto.

The chairman opened the meeting by pointing out that, regardless of how widely and interestingly the discussions might range during the three days ahead, a definite product we were expected to come out with at the end was a written description of "good" undergraduate training. With this mission in view, the chairman appointed a writting committee, consisting of Wallace A. Hilton, William Jewell College; Howard Laster, University of Maryland; John I. Lodge, Goucher College; Vernon L. Long, Lewis and Clark College; Walter C. Michels, Bryn Mawr College (chairman); Lyman G. Parratt, Cornell University, and Noah Sherman, University of Michigan. The task this committee bravely agreed to undertake was to bring in each day a new version of a statement on undergraduate training, which would reflect the salient points of the discussion of the previous day or days and which could be torn to bits by the conference as a whole. The idea was that in this manner of successive approximations the conference could get its composite judgment boiled down to a succinct written statement.

(Anticipating what the reader will find as he goes through the reports of the three days discussions it may be said that the scheme worked well. About half of the time during the three days was devoted to open discussion of the tentative statements brought in by the committee. The work of the committee itself extended into the evenings and even into the small hours of the mornings. At the end of the three days the conference and the committee were in substantial agreement as to the final modifications that remained to be made. The conference thereupon directed the committee to incorporate the final modifications and the conference agreed to endorse, without further debate, the final product.)

Having appointed the writing committee, the chairman proceeded to give a brief review of the situation with respect to defining suitable undergraduate preparation, as it stood at the close of the First Ann Arbor Conference. He made reference to the following "facts of life" which seemed to emerge during that Conference.

(1) Part of the reason it is so difficult to define undergraduate preparation is that there is in fact no sharp interface between undergraduate and graduate work. A student ideally prepared might go to graduate school and be able to begin thesis research after one year, while another, having had less preparation, might not begin his thesis for two years; but the second might turn out to be a better physicist than the first. Any prescription of a course of undergraduate training should be flexible enough to provide for cases such as the one just mentioned.

(2) The problem of directing the right students to the right graduate schools (matching) is intertwined with the question of preparation. A given student might fail in graduate school X where he would have succeeded in graduate school Y (actually a "tougher" school). His success or failure might be due to a multiplicity of factors, only some of

which can be described in terms of "catalog" entrance requirements. This serves to emphasize the impossibility of prescribing preparation rigidly and uniquely.

(3) Two approaches seem to be open, in describing (or prescribing) undergraduate preparation: (a) The work that the student should have covered can be described, or (b) the work that he should be prepared to attack upon entrance in graduate school can be described. In other words the position of the interface can be specified by saying what lies above it. The yardsticks used in describing either (a) or (b) may be well-known texts, detailed lists of topics, and standardized problem lists and examinations. Names of courses are of little value as yardsticks. The opinion at the First Ann Arbor Conference seemed to be that somewhat more precision can be put into (b) than into (a), simply because there seems to be more uniformity over the country in graduate courses than in undergraduate courses. Actually, when the First Ann Arbor Conference got down to attempting to write a description of undergraduate preparation it used the two-prong attack: (a) and (b) together.

(4) Although the reason for it is not crystal clear to everyone, there does seem to be a considerable demand from the small colleges for a detailed statement as to what constitutes adequate, sound, and feasible preparation for a physics major. The colleges evidently want to measure themselves against such a statement, whether they can fully comply with it or not.

(5) In attempting to specify undergraduate preparation for physics majors we should not lose sight of the roughly ninety percent of the majors who terminate their formal course work in physics at that point and end up in jobs in industry or in the school system. Being university people we tend to be myopic about the small segment that is heading for our own area, via higher degrees in physics. (We might with some truth refer to the terminal segment as the ninety percent minority.) Many colleges either cannot afford a multiple-track curriculum in physics or do not have a large enough number of students for it. How can we deal with this problem in trying to formulate a single recommendation that will cover the waterfront?

Having reviewed some of the background for the morning's topic, the chairman opened the meeting for discussion, asking in particular for the airing of ideas and problems which the writing committee should consider in making its first draft. In the discussion that followed, the following points were introduced or emphasized.

The problem of the talented student who finishes college with less than ideal training, came in for extended discussion. He may be in this predicament because courses were not available in his college, or because he is a "late bloomer" and did not get into action soon enough. Such a student is at a disadvantage in applying to one of the "pace setting" graduate school. He needs to find a school that will not only recognize his potential ability but that will give him at least a year's time, with financial support, in which he can close the gap. It was pointed out that the present fellowship apparatus in this country does not cover this need adequately. It was proposed that the Master's Degree program, particularly in the non-Ph.D. institutions, might well be directed in larger measure toward filling this need, rather than toward providing "consolation prizes" for those who are not Ph.D. material, as is often the case. We certainly are not going to be able to eliminate the gap which exists for a large number of promising students by perfecting the curriculum in all undergraduate colleges—at least not overnight; therefore the fellowship-giving agencies and institutions having masters level programs should be urged to do more toward recognizing the problem and toward providing that year of in-between training.

The number of students falling into this category is believed to be quite substantial, and such students are a national asset not to be wasted.

In prescribing undergraduate curriculum it is pertinent to ask if the job of the undergraduate institution is changing, or can change, due to progress made in high school education. Are some elements in preparation being pushed further down the line and into the high school? There are signs of this in mathematics. We have been talking about articulating the undergraduate schools with the graduate schools; perhaps we should also be talking about the articulation of the undergraduate school and the high school. High schools could do a better job if they got more advice and help from the undergraduate faculties, and would be encouraged and stimulated if colleges recognized in some manner good high school preparation on the part of their entering students.

Multi-track programs were discussed; i.e. preparation for teacher training, for industry, and for the professional Ph.D. It was suggested that in all of these programs insight and understanding should be stressed rather than extensive coverage of the field or a mere amassing of factual knowledge. The proposition that the purpose of the four-year course is to show the student how he can get himself educated in the next fifty years was generally subscribed to by the conference.

Getting more students on the track that will lead to teaching was discussed not so much from the viewpoint of undergraduate curriculum as from the viewpoint of the status of the masters degree, the "image" of the teaching profession, the attitude of research-oriented college professors toward teaching, and financial inducements. Masters degree programs are too often looked upon as consolation prizes. The "image" of the teaching profession is poor because of salaries and many factors that are hard to define. The attitude of those college professors who do their teaching with the minimum time, in order to get back to their research, rubs off on the students. Many professors who are genuinely interested in teaching problems fail to "let students in on" that side of their intellectual lives. Financial inducements to careers in teaching are not competitive with those which pull students toward industry. Interesting question: If we were to give high school teachers a much better training in the subject matter of physics, would they just be pirated away by industry to a greater extent than they are now, thus making the effort self defeating?

Finally, the desirability of accompanying any curriculum recommendations with a mechanism for helping with the implementation in the form of visiting committees was raised. Two or more experts in problems specific to a particular undergraduate department might visit the department for several days to appraise the situation and to make recommendations to the local staff and administrators. Such a committee however is not to be either a "rubber stamp" or an "accreditation jury". Here, at the suggestion of Walter Michels, some definite answers were obtained from the group, on the matter of visiting teams. The representatives of the four and five-year colleges were asked if they would value a visit from a consulting team. 90% responded affirmatively. Next the representatives of the Ph.D. institutions were asked if they would be willing to devote about six days per year to making such visits. The response was obtained by passing a paper around for signatures. 26 signatures were obtained.

As a result of the rather strong acceptance of the idea of curriculum consultation teams, as indicated by the above poll, Walter Michels, on behalf of the Commission on College Physics, said that he would explore the problem of what mechanism would be needed to carry out such a program.

The meeting adjourned for lunch.

Nov. 12, first half of afternoon. Topic: What can be done to achieve better matching of physics majors to graduate schools? This requires an improvement in the flow of information about graduate schools and undergraduate schools back and forth between the two kinds of schools. Chairman: Ronald Gebaile. Note-takers: Alvin Hudson and Sherwood Haynes.

H. R. Crane gave a brief statement as to what had been done on this subject at, and as a result of, the First Ann Arbor Conference. With the call to the earlier conference a questionnaire was distributed which asked the conferees for information about their graduate schools, in three main categories: I. Undergraduate preparation desired at entrance; II. Graduate course work required and recommended; III. "Environmental" characteristics of the particular Graduate School. The questionnaire, with collected responses, is reproduced in full as Appendix II of the report of the First Ann Arbor Conference. After devoting a whole afternoon to the discussion of the questionnaire and to the problem in general (see conference report pp 12-14) the First Ann Arbor Conference passed a resolution recommending to the American Institute of Physics "that it consider ways and means by which information of this sort would be collected from graduate departments and made available to undergraduate departments."

The chair next recognized Dr. William Kelley of the AIP, who presented the response of the AIP to the recommendation sent to it by the First Ann Arbor Conference. In introducing this proposal Dr. Kelly indicated that in 1960-61 there were about 10,000 graduate students in physics and that about 5000 Bachelor degrees, 1300 Masters degrees, and 600 Ph.D. degrees were conferred. A study of three large schools indicated that about 50% of those starting for the Ph.D. complete the program. The above figures on the number of graduate students in process give the impression that even the 50% estimate may be on the high side. (It should be cautioned, however, that comparisons between the number of degrees granted and the number of students in the pipeline will soon be affected strongly by the "tidal wave" of war babies that is due to arrive at the undergraduate level within the next few years.) In view of the fact that the drop-out rate in the Ph.D. program is large by any method of calculation, Dr. Kelley asked if this is part a result of mismatch, and if so, if there is a way to improve the situation? He then read a statement which he, together with others at the AIP had prepared as representing a possible course of action. The statement is reproduced as Appendix II.

The main points that came out in the discussion that followed may be summarized as follows:

On the publication of factual material:

Most comments on having a compilation and dissemination of factual materials were favorable. In particular the information on entrance requirements and graduate degree requirements would not only serve for counselling but could also serve as a set of detailed curricular statements to guide undergraduate colleges in their offerings.

Many felt that it was important not only to state normal preparation but also to state whether quality students would be accepted with less than normal preparation and directed into suitable courses.

Some reservations were expressed about the effect such a factual compilation would have, either in homogenizing requirements, or in aiding poor students in finding where it would be the easiest to get the Ph.D. There was also considerable discussion of the AIP's bulletin on Specialties of Departments. Some thought it was not very objective. Several participants felt that the publication of titles of recent publications would give a better picture.

On the publication of "sensitive material:"

The inclusion of various degrees of sensitive material in such a compilation generated much discussion and many opinions.

Need for knowledge of these sensitive factors was frequently voiced but many doubted the possibility of their being effectively presented in any printed form.

It was agreed that student opinion was the most reliable index of many sensitive factors; that the feedback of such information should be encouraged. However, most participants felt that wide dissemination of a few student opinions would give these opinions far more weight than would be warranted in view of the smallness of the sample that would be involved.

On establishing an office of graduate student placement:

Although great need of feedback in these sensitive areas was felt, the methods suggested by the AIP proposal received mixed reaction. The appointment of a full time Director of an Office of Graduate Student Placement was generally thought to incur very serious risks of bias on the part of the Director.

On regional conferences:

Conferences on Graduate Placement in Physics to be attended by faculty representatives of both graduate and undergraduate institutions and possibly by undergraduate students was discussed. Alternative suggestions such as group visitations to undergraduate campuses and regional Physical Society meetings to serve the same purpose were also made.

Resolution by the conference:

At the close of the discussion the following resolutions were moved:

1. We approve in principle the collection and dissemination of factual information on graduate schools especially for the purpose of counselling prospective graduate students and of establishing guidelines for undergraduate curricula. Seconded; Passed without dissent.

2. We support the principle of regional conferences between representatives of graduate and undergraduate institutions as stated in the AIP proposal. Seconded. Tabled for lack of discussion time.

Nov. 12, second half of afternoon. Topic: How can information be collected which will tell whether a change in method or curriculum has been good or bad? Who, among those present, is doing an experiment with provision for evaluation? Chairman, Walter Gordy. Note-takers: Alvin Hudson and Sherwood Haynes.

H. R. Crane pointed out that the question was one which was given a go-around at the First Ann Arbor Conference, with very little constructive result. He emphasized, however, that the problem grows more pressing (and embarrassing) by the year. The amount of human effort and tax-payers' funds that go into making changes in curriculum and teaching techniques is increasing rapidly. Every school is getting into the act. Yet in very few cases is there any provision for drawing a reliable conclusion as to whether the experiment was a step forward or backward. Most evaluation is the subjective opinion of the person who gives the course.

(He recalled that in his youth he made trout flies, and that it took him a long time to realize that he was making them to appeal to himself instead of to the trout.) He urged that the conference make another attack on the problem, and keep on making them even though the chance of a fruitful outcome was small.

Much discussion followed, in which there were some suggestions, but also many comments pointing out that the question is fuzzy and the possibility of a definitive answer remote.

Eric Rogers (Princeton) inserted a preliminary word of caution by presenting an analogy: How would we suggest evaluating the "success" of a course in Shakespeare? Certainly not on the basis of tests and the ability to quote from memory certain passages. Rather, we might prefer to wait a generation later and delegate a traveling team of archangels (sponsored by NSF, of course!) to visit the homes of former students to find out what they were saying to their own children. In other words, perhaps we are not capable of testing students on what we think they should be getting out of our physics courses.

Other comments are classified for convenience, as follows:

A. Questions to Assist in Clarifying the Problem:

(1) What qualities are "good" and "bad" in curricula? How does one define these qualities? Are changes, per se, of value if we don't have clear criteria by which to judge the effectiveness of curricula?

(2) Do not changes in the level of students over the year and other changing factors make testing and comparing results extremely difficult?

(3) Can one conduct valid evaluation experiments in education? (Implication: No.)

(4) What is the half-life of experimental courses?

(5) Would the larger universities be willing to band together and divide themselves into various trial groups to improve the statistics?

By far, the most recurrent and perplexing questions raised during this discussion were: "Just what are we trying to measure? What criteria do we use to judge the worth of a new program?" No clearcut answers emerged, though several diverse proposals of a fairly specific nature were made.

B. Suggested Criteria for Judging the Effectiveness of Curricula:

(1) Records of CEEB and GRE test scores might be kept and compared.

(2) The percent of the student body that we can attract into being physics majors may be a valid criteria.

(3) An "oscillation" technique of returning to old programs every several years to see if we can detect corresponding changes in our students may be a helpful technique.

(4) The percent of our students which survive to the Ph.D. degree is a good criterion of the effectiveness of matching students to appropriate graduate schools.

(5) Our ability to increase the numbers of that large, overlooked source of majors: women, is a good test of our effectiveness.

(6) Very informative and revealing sources of information are reports from former students—particularly after a time lapse of a few years.

(7) A method of improving and strengthening good curricula would be to identify and recognize outstanding teachers earlier in their careers so they may be more properly rewarded in both money and prestige—thus more teachers will become conscious of the worth of efforts in improving teaching. An inspiring teacher is a most important factor in any program; this is too often overlooked.

C. Some Cautions and Comments.

(1) The small numbers of students involved frequently make the statistics suspect.

(2) Physics is different from other subjects in certain characteristic ways: it is a peculiar mixture of the tight logic of philosophy with the freer aspects of an experimental science. Do we get this difference across and, in particular, how does one test in a subject in which reasoning plays such a big part?

(3) Whatever tests we come up with, they must not be structured so rigidly that the really creative individual is ruled out. The requirements for a career in physics are very high and we need both intelligence and creativity. Too often we place too many impediments in the paths of the brighter students.

(4) Since NSF is spending large sums of money in fostering new programs, we'd better find ways of measuring the effectiveness of these new programs.

D. Consolation Prize

Several people expressed the hopeful opinion that even though it is almost impossible to evaluate curricula, it is valuable to try experimental courses because the stimulation to both staff and students of partaking in such an experiment is beneficial in itself—under these circumstances both groups try a bit harder than normal. Even though we may not be able to demonstrate objectively the worth of new programs, confidence was expressed that we all knew "in our house" who were the good teachers and when courses were successful.

The chairman next called for examples of curriculum experiments that had been made, with provision for evaluation of the results. Two experimental programs were described in some detail.

R. G. Fowler (University of Oklahoma) mentioned one experiment he conducted with students in a junior course in electricity and magnetism. He noted that students who were good in mathematics generally did well in E and M. However, extra tutoring in mathematics (of the poorer students) did not subsequently produce improved performance in the physics course.

Marsh White (Penn State) related an experiment he carried out about two years ago with 600 students in the introductory course for majors. The class was divided into three groups which received differing proportions of large (150-200 students) demonstration lectures and small (20-25 students) recitation sections.

Group I: 3 large lectures and 1 recitation section per week.

Group II: 2 large lectures and 2 recitation sections per week.

Group III: 1 large lecture and 3 recitation sections per week.

All students took the same final examination. On the basis of scores achieved in this examination, there were statistically significant differences which pointed in favor of the larger numbers of smaller recitation sections.

Nov. 13, Morning, first half. Topic: This session was devoted to the consideration of the first preliminary draft of the statement on "good undergraduate preparation", which was distributed in multilith form. Chairman: D. M. Dennison. Note-takers: Alfred Romer and Robert Little.

Walter Michels, Chairman of the writing committee introduced the draft by describing some of the thinking that had been going on in his committee, some of the boundary conditions the committee had tentatively adopted, and some ideas as to the general form the statement might take. He attempted to give the current thinking of the committee on the following questions:

Can a single curriculum be recommended? He characterized as boundary conditions those conditions within separate institutions that affect the curricula each can offer. It will be impossible to recommend a single curriculum. There will have to be multi-track proposals for programs which differ in depth and breadth. Schools with limited facilities should consider whether they ought not to limit themselves to a single track, even at some cost to students who may need one of the other programs. It will be necessary in the recommendations to consider impedance matching at both ends of the undergraduate program. The Committee feels that the greatest possible flexibility should be left to individual institutions in adopting an order in which topics should be covered.

Whom are we talking about when we say "physic major"? The Committee must act within the definition of a physics major as intended by the Conference. Its first effort has been on the major program intended to prepare students for graduate school. There is a problem in describing the major program because the names that are the most convenient for the material desired are traditional names of long standing which may convey different meanings from those intended.

In what form should the curriculum be stated? One method of describing level would be to amplify the statements on p. 29 of the Report of the First Ann Arbor Conference on the work of the first graduate year. A secondary system of defining the curriculum seemed to be that attempted in the outline distributed. The form being explored consists of a preamble giving general philosophy and objectives, followed by a rather detailed list of topics with which the major should have a working knowledge. In detailing the topics, there seems to be no single best order for the subjects, and if an order cannot be specified, it is impossible to define the level of any particular course. In the descriptions given, some topics mentioned are to be considered as upper limits rather than as lower limits. Examples are the symmetrical top, mutual inductances in circuits having linear and circular geometries, and vector solutions in cylindrical and spherical polar coordinates.

Open discussion followed, and it was centered on the means of specifying the levels at which this material should be taught. Two suggestions were put forward. The level of undergraduate instruction may be determined by specifying the level of the graduate courses that students should be prepared to enter, as suggested at the First Ann Arbor Conference. The level of the undergraduate work can also be specified by the publication of an extensive list of typical problems. Correll, speaking for the Committee on testing, of the AAPT, said that such a list was in the process of preparation. A question was raised of the number of lectures which would be devoted to such a topic as quantum mechanics. Michels replied that the list of illustrative problems is probably the best guide to the desired level since the number of hours needed to develop a subject will depend, for example, on whether the subject is taught in the sophomore or the senior year.

A motion which had been made earlier by Fowler that the technique of specifying the physics major embodied in the mimeographed list submitted to the session be adopted in principle by the conference as one means of establishing the content of the program, was put to a vote and adopted.

Some discussion ensued on the committee's tentative recommendation of 44 semester hours of physics and 24 semester hours of mathematics as an optimum course for the major headed for a first class graduate school. The feeling of the conference seemed to be that the number of hours was unrealistically high and that it would be likely to produce grinds rather than well educated persons. There was considerable concern about the possible undue exclusion of the liberal arts subjects. However, the conference did not come to any specific recommendation at this stage.

Nov. 13, morning, second half. Topic: How much undergraduate laboratory (and what kind), beyond the usual introductory course, should the conference recommend, as a part of the "good preparation?" Chairman: Noah Sherman. Note-takers: Alfred Romer and Robert Little.

Walter Michels said that the subcommittee needed instructions on the role of the laboratory. The purposes of the laboratory were variously described. The laboratory carries the phenomological burden of the curriculum; it should show the way in which physical theory is not an adequate description of nature. The objectives of the laboratory are multiple; partly the acquisition of technique, partly an aquaintance with phenomena, partly the illustration of principles. It makes clear to the student that physics cannot be compartmented in the way textbook chapters suggest. It provides a personal experience of nature. It enlarges the content and meaning of concepts introduced theoretically. Demonstrations do not do what laboratory can do. They are arranged to make a special point precisely. They do not permit the student to study and discover more than this single point. It was remarked that although the gifted teacher can make laboratory work interesting with a minimum of equipment, most teachers will find it necessary to inject interest by creating experiments containing some element of the unusual.

Olsen moved that the Committee amplify the sentence concerning the advanced laboratory on page 29 of the report of the First Ann Arbor Conferences as this conference's statement of the role of the laboratory. Motion seconded and passed.

November 13, afternoon, first part. Topic: What curriculum should we prescribe for the "90% minority"—the majors who do not go on for the Ph.D.? Is it desirable and/or feasible to recommend multi-track curricula? Chairman: Sherwood Githens. Note-takers: Nelson Fuson and Roald Wangsness.

This session began with brief talks by four men who have had wide experience in hiring and using physics majors in industrial and government organizations. The four speakers were:

Dr. Robert Hollyer of the General Motors Technical Center, Dr. H. E. Mendenhall of the Bell Telephone Laboratories, Dr. John Saby of the General Electric Company and Dr. Sherwood Githens of Duke University and formerly of the U. S. Army Technical Center. The idea in scheduling these talks was that some first-hand descriptions as to what kind of work physics majors do after they join industrial or government establishments, and what their employers expect or hope to get out of them would be valuable background to have in working out a curriculum.

Dr. Hollyer was the first speaker. He discussed the situation in the physics department of the central research laboratory of the G. M. Technical Center. Out of the total of 90-95 people about half are of professional status, about equally divided between basic and applied research. Of the 34 who are physicists, one has a bachelor's degree only, 13 have master's degrees (4 of whom were hired as bachelor's), and 20 have Ph.D.'s. Generally people hired at the bachelor's level do not end up in the physics department, but elsewhere where their physics background is helpful; nor do they end up in the administration of research, which requires a Ph.D. Bachelor people are desirable as assistants. So far they have been very satisfactory, but not many have been hired, as this is relatively new. The ones that have been hired in the assistant capacity so far are mostly in engineering physics. The company as a whole hires an enormous number ofbachelor-level engineers, and trainees; many of these jobs could be done better by physics bachelors, but few apply.

The basic reason for the preference for the Ph.D. in the research lab is economic, since the salary differential is small as compared to necessary investment in laboratory facilities.

The greatest source of complaint against the undergraduate training of the physics major is the fact that he has not learned to write an understandable, well-organized report. Both the employer and the employee would willingly trade some of the undergraduate physics training for work of comparable rigor in English composition.

H. E. Mendenhall discussed the experience of the Bell Telephone Laboratories. Of the 70-100 Ph.D.'s hired each year, physicists are about a third of the total and are preferable in the B.T.L.'s program, to E.E.'s. However, the hiring of E.E.'s is increasing and is about 21% of the total; they are mostly placed in development and systems areas where it is important that they be able to apply the results of others. Ph.D. physicists have been found to be very useful in management and training programs as well as in research.

The company is concentrating on improving the skills of people already hired—by study at nearby schools, leaves to go elsewhere, and out-of-hours company courses. Some B.T.L. people aid in improving courses elsewhere, some take leaves to teach, and some retire to teach. Most of the limited number of physics A.B.'s hired are expected to go on in spare time to earn A.M. degrees. About 9% of the entire payroll is studying for a college degree in some field (35% for A.B.'s, 45% for M.A.'s and 20% for Ph.D.'s), and 25% of the payroll is taking non-credit training of some kind in the organization. Bell Labs hires many chemistry and mathematics A.B.'s but relatively few physics A.B.'s. Generally, there is no place at B.T.L. for a bachelor-level physicist unless he goes on to at least the M.S.; they definitely do not want B.S. people as technical assistants. Converted physicists are said to make better engineers than those trained as engineers. The B.T.L. has never been able to hire many women who have physics degrees. The Laboratory has some places for women, but there are few applicants.

Dr. John Saby next gave the statistics on the experience of the G.E. (the entire company) in hiring people having physics degrees. Company-wide, there are about 750 (bachelor level) physicists and 75 are hired each year. A few of these go into the research organization where the attempt is made to teach them more. However, there are about 100 genuine positions open annually for B.S.-level physicists. These jobs are virtually all experimental and most involve original work of some sort. They require a broader scientific knowledge than is possessed by engineers, and the ability to pick up new knowledge as required. For success in these jobs, a good command of fundamentals is required. They should have had a lot of lab, a useful command of mathematics, and their course work should have emphasized the problem-solving approach.

After speaking to the group Dr. Saby kindly supplied us with his written notes, setting forth in fuller detail his experiences and views in relation to the people who go into industrial organizations after getting degrees in physics. His notes contain so many points of interest to us that they are reproduced in full, as Appendix III.

Dr. Githens discussed the need of physicists in government laboratories, using the Army labs as an example where there are many now employed in civil service positions and where they are greatly needed. There are 27,000 technical personnel in 25 labs of the 7 Army Technical Services. The Army is interested in all skills, hired through Civil Service, in contrast to the Air Force which farms most of its research out on non-Civil Service research contracts.

Dr. Githens then spoke of the needs for B.S.-level physicists in the field of education. As an example of an area in which the need was acute, he gave figures on his own state, North Carolina. There, of 350 N.C. high school teachers teaching physics, only 10 have had even a physics certificate (12 hours of college physics). The high school is a wide open field for physics A.B.'s (salary about $4000/9 months), as is teaching physics at the mushrooming number of two-year post-high school industrial educational centers (salary about $6000/year). The pay in the industrial education centers is better than that in high school, and there is more emphasis on laboratory work.

A brief period of discussion followed the four talks. Points raised (but not solved) were:

1. What happens to the 6000 or more bachelors in physics produced each year is still somewhat of a mystery. The number going into bona fide research organizations (such as B.T.L.) where they can, conceivably, practice their physics provides only a partial explanation. The answer must be that physics B.S.'s do not end up practicing physics. Evidently, then, there exists a large market for B.S.'s in physics outside of research and even outside of physics.

2. Those majors who go into the high quality technical or research organizations with a B.S. should have essentially the same basic training as those who are headed for graduate school. The reason, as pointed out by the speakers, is that the majority of, and certainly the better ones of, these B.S.'s will continue their formal study in one way or another, while employed. For example many take part-time work at nearby graduate schools.

3. The question of the capacity of the market to absorb more B.S.'s in physics was answered quickly: the demand at present far exceeds the supply.

4. Apparently there are, in round numbers, some 5000 or so B.S.'s per year in physics who do not start off applying their physics directly, but who in some way (we hope) use their physics as a basic background. Does the curriculum we are designing give proper weight to the needs of these people? They constitute the majority, but as we have often reminded ourselves, we tend to think of them as the "90% minority."

5. The conference felt that we should, at some time, get some further, and perhaps more widely representative, information as to what happens to the 6000 B.S.'s per year.

November 13, afternoon, second part. Topic: Review of the work of the writing committee. Note-takers: Nelson Fuson and Roald Wangsness.

Lyman Parratt acted as initial spokesman for the writing committee. He reported that a good deal of the attention of the committee had been directed to the question of the proper balance between physics subjects and liberal arts or elective subjects. Their present feeling was to use a 36-semester-hour program as a minimum program needed in preparation for graduate work, but with the suggestion that further hours could be added for some students in order to reduce the time needed for the Ph.D. They proposed including the amount of lab agreed on at the Denver and first Ann Arbor Conferences, and they also proposed emphasizing senior year independent study and open-end lab as being particularly good for industrial-bound students. He was not prepared to offer, at this point a solution for the important matter of separate tracks for those students bound for graduate school and for those who were planning to take jobs in physics after the B.S. degree. Rather, the committee was bringing before the conference at present a program for students headed directly for graduate school. The committee was suggesting a minimum of 36 semester hours of physics, starting with general physics, plus 10 to 12 hours of math. beyond first year calculus. Of these 36 required physics hours, 2 should be in elementary lab and 4 in advanced lab (where it is understood that 1 semester hour of lab is 3 hours/week in the lab or in the lab and library). In addition, 4 more hours of independent study (outside the 36 required hours) are highly recommended.

There was no doubt but that the efforts of the drafting subcommittee had been most valuable in stimulating the conference to face and discuss curriculum problems squarely and vigorously. The several-faceted, provocative, trial balloon drafts which the committee had so far distributed to the conference now began to draw discussion fireworks in earnest!

Dayton and others urged recommending that gifted majors should be encouraged to elect in addition 3 hours of quantum mechanics (level of Leighton), 3 hours of solid state physics (level of Kittel) and 3 hours of nuclear physics (level of Kaplan). This proposal drew immediate reaction from several, who contended that we were in danger of squeezing out the liberal arts part of the curriculum.

Clark made the following motion: this conference heartily endorses the traditional liberal arts background of physics curricula. Nothing in its recommendation is to be construed as advocating any weakening of the other liberal arts components of the physics student's undergraduate program.

This motion was passed unanimously after a spirited discussion which is summarized below.

Arons pointed out that the 36-hour program conformed to current practice in a very large number of liberal arts colleges whose students are accepted in graduate schools everywhere and whose students are not delayed in graduate school because of lack of physics hours in their undergraduate major programs. He made an eloquent statement that we should be very careful about the danger of deliberalizing the physics students' education and thus sharing the fate of the engineers. His statement was followed by general applause. Later on, he discussed the nature of liberal arts education in physics and emphasized that this is a continual process and that all aspects of physics can be used as examples and sources of material.

Arons specifically urged holding the proportion of the 120-128 hour undergrad curriculum to 36 hours of physics and 18 hours of math. He further urged that labels such as "optimum" or "to avoid having to be slowed up one year" be deleted from reference to the possibility of carrying additional hours of physics.

Other comments were made to the effect that we must not make the liberal arts colleges feel like second class institutions, and that they also require some defense against the increasing demands of the graduate schools. It was also suggested that the goal of graduate training (as well as at any level) should be to enable the person to continue to educate himself, and that learning to do this does not necessarily require a heavy concentration on physics subjects. It was generally agreed that our goal should be to upgrade content in physics courses all along the line (before, during and beyond college undergrad major) rather than to bulge the relative proportion of total college time spent in physics. Brode raised the question of including, explicitly, some recommendations concerning the fields that border physics—e.g. biophysics, astrophysics, etc. He pointed out that these are in many cases the "growing tips" of physics, and that undergraduates should be made aware of them.

The 36-hour minimum for physics in the curriculum was generally accepted, by a show of hands. Parratt raised the problem of the mushrooming length of time spent in graduate school, the present average now being almost 6 years. Discussion centered on the question as to whether a program with more physics courses than current practice now includes is really necessary to decrease the time needed to get a Ph.D. The number of years needed for a full-time graduate student to get a Ph.D. after a bachelor's degree has increased from an average of 4 years in 1950 to about 5 1/2 years in 1961. Experience at Berkeley indicates the increased time is almost completely in the post-prelim exam time of doing the thesis. Others suggested that this is so because the problems are harder and take more time and also that there is more money floating around now to enable a person to stay on longer to do the harder and longer problems.

It was pointed out that more work is required now between high school and the Ph.D. and this means more class time or intensification of some sort. This brought forth rejoinders that perhaps we should stop adding things to the courses and start taking some material out as has been done in the past. Also the question was raised as to whether graduate schools can perhaps be persuaded not to demand so much.

Ralph A. Sawyer (Vice-President for Research, and Dean of the Graduate School, University of Michigan) who was present at this session rose to comment on the matter of the lengthening time of graduate residence. He said that it was a serious problem and that he, personally, had put a good deal of effort into building fires under graduate students and departments in order to speed up the slow-movers. He commented also on the matter of the tendency for graduate schools to proliferate their formal course requirements, saying this could be traced, in part, to the increasing number of faculty members. He noted that each faculty member will have at least one subject that he believes to be absolutely essential, so in the end the number of "absolutely essential" subjects tends to be greater, the larger the faculty.

Several members urged in different ways that graduate schools not consider requiring the Ph.D. candidate to master all the knowledge of physics before getting his degree. A fresh Ph.D. should have acquired the ability and motivation to enter a career of creative work; to go under his own steam from the day he receives the Ph.D., and to become a learned and wise man in the course of the rest of his life. He should not be expected to have achieved all these things before graduation day.

November 13, evening meeting. Chairman: W. Wallace McCormick.

The group assembled for a "non-working" session, in the small lecture room of the West Physics Building, to hear of two developments of current interest in physics teaching. Mr. Jan Orsula, of the Science Teaching Center, Cambridge, Mass. gave a demonstrated talk on the new "glass solder" technique, by which students can make their own sealed-off vacuum devices. Prof. Alfred Leitner, of Michigan State University gave the group a preview of movies he was in the process of making, of phenomena at liquid helium temperature. Interesting and lively discussion followed on both topics.

November 14, morning, first part. Topic: The entire day was spent in discussing in some detail the penultimate written draft of a statement on curriculum, which was finished by the writing committee at 3 A.M. (!) and distributed to the conference at the beginning of this session. Since the reader will have available the statement as it finally was approved, the many suggestions and brief debates on wording, form, etc., which took place throughout the day will not be reproduced here. The attempt will be made to report here those parts of the discussion which dealt with policy and which will add to the background setting in which the report itself is viewed. Robert Brode was chairman for the first part and E. L. Jossem and Walter Rhein were the note-takers.

Walter Michels, chairman of the writing committee, opened the discussion. He noted that, while the committee had tried to follow the guidance of the conference as a whole, it also had had to recognize the fact that the report would be directed to a great many colleges and universities that were not represented here; that the make-up of the present conference was probably not sufficiently weighted in respect to the colleges that really needed the help; that the writing committee had been trying to keep all these factors in mind.

The problem of the able student whose undergraduate training is such that he will have to take extra time in order to catch up, either after entering graduate school or in some kind of in-between study was again brought up. The problem is financial as well as scholastic, because fellowships are not generally offered for this in-between study. Teaching assistantships are available, but the fellow in this kind of situation is just the one who can least afford to divert part of his time at that stage to earning money through teaching. The problem is scholastic because, however capable and promising the student is, he has not had the chance to fully prove himself, with the consequence that the first-rate graduate schools are not inclined to take a chance on him. The conference felt that if better opportunities for the in-between study could be made available, and if more sources of financial assistance to tide students over this gap could be developed, then a good deal of the pressure for crowding more hours of physics into the undergraduate program would be relieved. The position of the small colleges which are limited in their offerings would thus be improved.

Several suggestions for immediate partial remedy for the above difficulty were made:

(a) Our statement of curriculum should make clear the delay which will be incurred by a preparation less than that recommended.

(b) Graduate schools should be urged to provide more opportunities, both financial and scholastic, for the kind of gap-bridging we have been talking about, for students of high intelligence but incomplete preparation.

(c) The possibility and desirability of independent study on the part of the student between graduation and entry into graduate school should be underlined.

Crane pointed out that we are in a bind all along the line because the required amount of subject matter that a student must cover between the cradle and the Ph.D., or more specifically between about the middle of high school and the Ph.D. has been going up and up. Everybody wants the student to cover more things, and it is hard to get anybody to agree to taking anything out. In redesigning or modernizing the undergraduate curriculum we should do our part in house-cleaning and in upgrading the work, but we should also expect the graduate schools to do their part. They should not keep upping their demands and expect that it can all be'taken care of by additions to the undergraduate curriculum. They should remember that when a student receives the Ph.D. he is only supposed to be prepared to enter a career of creative work and further learning; he is not expected to accomplish part of his life's work before receiving the degree. Similarly we (speaking as undergraduate teachers) should expect that some of the extra requirements (notably math, English and foreign language work) will be pushed downward into the high school bracket, displacing, of course, some less defensible high school subjects. In summary, he said, let's try to do our part (in the undergraduate bracket) but let's not think it is up to us to do all of the squeezing in of the new things that come along as "essential" subjects. By being a bit firm, and resisting having all the new additions put into the four year undergraduate bracket we can defend the smaller schools against being further snowed with requirements they cannot meet.

It was commented by several that in spite of what we think should be done by graduate schools, the pace-setting ones are probably going to continue to admit mainly students who have had the "full" preparation, and who come from colleges of recognized reputation, merely because they do not have to accept less. Therefore it was suggested that in our recommended curriculum the "good" or optimum training be interpreted as that which will enable a student to go into one of the first-rate graduate schools and progress through it without any time delay which can be laid at the door of incomplete preparation. It will at the same time be understood, however, that less than the full preparation can make possible ultimate success and the Ph.D. degree, but with probable delays which are made clear.

It was pointed out that improved communication, in itself, could do a lot toward solving the problems we have been talking about—that is, communication between graduate and undergraduate schools as to just what is desired, required, etc. Reference was made to the work on communication that was proposed earlier in the conference by Dr. Kelly of the AIP.

November 14, morning, second part. Topic: Continuation of discussion of the draft statement. Chairman: Anthony French. Note-takers: E. L. Jossem and Walter Rhein.

Robert Katz raised a question that had been before the conference earlier in other connections: How can we develop better opportunities for students to bridge the gap between a somewhat insufficient undergraduate program and a first-rate graduate school? He commented that we do perhaps have more of a mechanism than we have realized, in the master's programs of many institutions. These, he suggested, serve as "impedance matching devices" between undergraduate and Ph.D. programs.

Frank Verbrugge stated that it does not make sense to draw up an optimum curriculum without simultaneously giving attention to the problem of staffing in colleges, since obviously the program is dictated by the availability of staff in many places. He felt that a one or two-man staff is unrealistically small for the offering of a physics major. He asked if our curriculum recommendation should not include a section setting forth what we consider to be adequate staffing, or perhaps the minimum staff that could do the job.

Michels answered that he believed the staff problem to be so complex that nothing short of an accreditation apparatus would be sufficient to implement Dr. Verbrugge's suggestion. That is to say, quality of staff is so important that mere numbers and titles would mean little.

Dr. Kelly of AIP pointed out that a serious attack on the problem of staffing is just getting under way. It is the AIP-AAPT Committee on Physics Faculties in Colleges, under the chairmanship of R. B. Brode. He said the problem is a complex one, certainly too big for the present conference to make much headway on. He suggested that the conference express its concern with and great interest in, the problem, and that individuals and institutions support in any way possible the work of Dr. Brode's Committee.

Robert Brode then gave a brief sketch of the organization of his committee and of the job it had mapped out for itself. He said the committee was so new that there were no results to be reported at that moment.

Michels followed up his earlier statement that any effective action we could take on staffing would mean in effect accreditation. Just to clear the air, in one way or the other, he made the following motion: "This conference believes that an accreditation system should be set up."

The motion was tabled.

There followed a period in which points of wording and organization of the draft were debated, and duly noted by the writing committee.

William McKinley brought the question of the multi-track vs. single track curriculum up for further comment. He felt that perhaps, after all, the program that best prepares one for graduate study is the one that best prepares him for industrial work and teaching. Walter Michels commented that this might be true, and that it might be the best policy, in regard to those who are headed for industrial research, but that it simply was unrealistic in respect to prospective high school teachers. They simply will not take the same rigorous preparation in physics, on top of their education courses, that Ph.D.-bound majors are expected to take. We must somehow set up our recommendations so that the prospective teachers can be accommodated according to their needs, which are different from those of the Ph.D.-bound group.

Further work on words and phrases in the draft was next carried on and noted by the committee.

Michels and Verbrugge engaged in an interesting exchange of comments in which Michels pointed out that the enrollments in prospect would call for a doubling in the number of colleges offering the physics major in the next five years or so. Verbrugge called attention to Pake's statement that the number of colleges which are able to meet the requirements for physics major programs is probably <u>declining</u>, because of increasingly acute staffing problems and stiffening of curriculum requirements. No way of resolving these two opposing tendencies was forthcoming. The problem is not expected to go away, however!

<u>November 14, afternoon, first part</u>. Topic: Continuation of work on the draft statement on curriculum. Chairman: Arnold Arons. Note-takers: Robert Reitz and John Teasdale.

Since the afternoon represented the conferenc's "last chance" at the draft statement, most of the time was spent in a sentence by sentence and word by word consideration of the document. The many points that were raised concerning phrasing and form will not be recounted here—they were duly noted by the writing committee. A few matters of policy were, however, debated, and they will be summarized.

Some time was spent on the preamble to the recommendations, which, it was said, should describe the product we aim to produce, namely the well-prepared and promising physics major. Such a description proved difficult. Many references were made to the "Schilling sniff test" by which one physicist can recognize another by something akin to a sense of smell. It was agreed that a person might have "had" any formal list of required studies and still not pass the test just referred to. There was no attempt to give up and abandon the attempt to describe a physicist in the preamble, but the difficulty was well recognized.

Someone raised the question: to whom was the committee's report directed? This would have some influence on the form it should take. The committee responded that it would go to physics department faculties; that the students should learn of its content from the faculties.

A question of policy was raised by David Dennison. He asked if we were not specifying the material to be covered by physics majors in such detail that we would lose just the flexibility and chance for growth and imaginative study that we hoped to encourage. In line with this he put the conference to a test by moving that the list of studies (which stood at more than 15 items) be reduced to no more than six. In the discussion of the motion arguments both in support and in opposition to the list were made:

In support: (a) The detailed listing is necessary to provide upper and lower limits in depth. (b) The detailed list was made to prevent stereotyping of subject matter into conventional course-names which would mean little and would not provide for growth and development. (c) The detailed list provides needed guidance for faculties and schools, particularly the liberal arts schools. In opposition: (a) The long list makes for rigidity and conformity, which discourages growth and change. (b) The long list will encourage a "check-list" or "count-down" approach to teaching, that is, a superficial attempt to touch on every topic mentioned.

After some discussion the motion to limit the list of topics failed to pass.

It was commented that the conference had not given the matter of laboratory the same extended consideration that it had given the theory side of the curriculum, and that the writing committee had not given laboratory the prominence it deserved, in the draft statement. The committee agreed to consider this criticism and to try to modify the emphasis accordingly.

On a motion by Ronald Palmer, which was modified in discussion, the conference voted to empower the writing committee to finish the report and publish it in behalf of the conference, taking into account the suggestions that had been made by the conference, without any further debate with or circulation of drafts to, the members of the conference. The writing committee was then given a standing ovation for its fine work.

November 14, afternoon, second part. Topic: Although the main business of working over the writing committee's report had been finished, many of the conferees felt that we should give further airing to the problem of taking care of the needs of prospective physics teachers. More than half of the conferees were still present for this late session on the final afternoon. Chairman: H. R. Crane. Note-takers: Harald Jensen and Lawrence Hadley.

Julian Mack posed the question as to whether defining a program (for teachers) which is not really a major program is a part of our mission. Michels answered by saying he felt that the 26-hour program we had described in our report was a major program; that even though it would not lead to graduate school without delay, or further in-between study, it did have depth and that was the main criterion of a physics major program.

Some discussion ensued as to whether our 26-hour program agreed substantially with the NASDTEC-AAAS* Guidelines. Kelly said that actually a number of physicists were involved in the drawing up of the Guidelines, even though it came out under the label of Education. The writing committee agreed to look into the matter.

There was brief discussion of the desirability of drawing up an over-all review of the series of three (Denver and two Ann Arbor) conferences, for journal publication. It was suggested that this might best be done by a special committee, and that the Commission on College Physics might be the body to instigate such a project, since it is the body which instigated the holding of the three conferences.

The conference was adjourned, with words of appreciation to the local committee and host institution.

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* Guidelines for Preparation Programs of Teachers of Secondary School Science and Mathematics. Issued by the National Association of State Directors of Teacher Education and Certification, in cooperation with the American Association for the Advancement of Science.

PART B: THE RECOMMENDATIONS*

Guided by the deliberations of two earlier conferences on curricula for physics majors, the Second Ann Arbor Conference has recommended that two different major programs, characterized by courses at essentially the same intellectual level, be offered. One has as its primary objective the most direct preparation of students for graduate work and research; the other emphasizes the synthesis of physics with the adjoining sciences and with other components of our culture. The considerations that led the conferees to these recommendations are given. Neither curriculum is defined in terms of specific courses—the conference preferred to attempt a description of the characteristics that a student should acquire or develop during his undergraduate career. Most important to this description are statements of what he should be able to do. Statements of what he should know are included only to sharpen the primary description. Estimates of the number of semester hours required by each curriculum are given.

I. INTRODUCTION

Three conferences of physicists (about 270 individuals from about 240 institutions) have been held during the past eighteen months to discuss new trends and ideas in the teaching of college physics in the United States.[1,2] Undergraduate physics major programs, with possible agreements on educational goals and on specific recommendations to achieve these goals, were under primary consideration. This report, prepared by a designated writing committee, presents a summary of the recommendations made by the third and concluding conference.[3]

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* The recommendations were prepared by a committee appointed on the first day of the conference: Wallace A. Hilton, William Jewell College; Howard Laster, University of Maryland; John I. Lodge, Goucher College; Vernon L. Long, Lewis and Clark College; Walter C. Michels, Bryn Mawr College (chairman); Lyman G. Parratt, Cornell University, and Noah Sherman, University of Michigan. They appear in full in the May, 1963 issue of American Journal of Physics.

1. The Denver Conference, attended by 178 participants from 174 four- and five-year colleges, was reported in Am. J. Phys. 30, 153 (1962). A more extensive report is available from the Director of the Conference, Professor Byron E. Cohn, Department of physics, University of Denver, Denver, Colorado.
2. A report of the First Ann Arbor Conference, in which 55 representatives of 48 Ph.D.-granting institutions participated, is available from the Director of the Conference, Professor H. R. Crane, The Harrison M. Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan.
3. A review of all three conferences, prepared by several participants, is being prepared and will appear in an early issue of Am. J. Phys.

The third conference, held at Ann Arbor, Michigan, on 12-14 November 1962, was attended by 74 persons, almost all of whom had participated in one of the first two conferences. About half of the number represented Ph.D.-granting institutions and half represented institutions that do not offer the doctorate. Although those attending constitute only a small sample of the total number of competent persons with vital interests in the subject, the conference decided to give its recommendations general circulation, primarily in the hope that they would serve as a base and stimulant for further thoughts and discussions. It is in this spirit that this document is published.

It must be strongly emphasized that the conference was fully cognizant of the necessary high rate of change, both of physics and of physics instruction. None of the recommendations should be interpreted as an attempt to straight-jacket the programs of any department or college—rather, the conference gives wholehearted support to any and all carefully designed pedagogic experiments. Indeed, one very significant recommendation is the development of somewhat new physics courses to comprise a more or less unconventional major program.

Specific recommendations are stated in some detail in Section II of this report. In view of the needs of undergraduate students of differing interests, and in recognition of broad educational responsibilities, two different, non-collinear, physics major programs are proposed and described. Section III indicates some salient problems in the transitions of students from high school to the two different college programs and thence, for some students, on to graduate programs. It also discusses the problems involved when students transfer from one of the two college curricula to the other.

II. RECOMMENDATIONS CONCERNING MAJOR CURRICULA

Recognition of differences in the educational goals of undergraduate students was explicit throughout the discussions. In particular, five general categories of students with different needs were delineated as follows:

(1) Students who intend to go immediately into graduate work in physics.

(2) Students who intend to enter industrial or governmental service as junior physicists. The majority of such students desire and find opportunities to engage in part-time graduate work.

(3) Prospective teachers of physics in secondary schools.

(4) Students who wish to use a physics program as preparation for work in other fields. These may include pre-medical or pre-law students, or, indeed, many students interested in work in related sciences such as biology, chemistry, astronomy, or geology (although some students with related-science interests may better be included in (1)).

(5) Students who wish a general cultural education at the bachelor's degree level with an emphasis in physics.

It was the strong sense of the conference that no practical single four-year physics program, a program that is a part of a liberal arts education, can meet the reasonable needs of students in all five categories. Such a program would require that an unreasonable fraction of a student's undergraduate life be devoted to physics and would place unrealistic demands on the faculties and facilities of many colleges. Further analysis led the conference to conclude that the needs of categories (1) and (2) are very similar, both requiring specialized preparation for research (e.g., graduate work with Ph.D. prospects in a reasonable time); also, that categories (3), (4) and (5) can be grouped together. The training needs here require not only less physics specialization, but courses having a greater emphasis on the interrelation of physics with other disciplines. In this perspective, there should be two different curricular programs, one primarily devoted to preparation for research (Curriculum R) and one that emphasizes the interpretation of physics and its re-integration withother parts of our culture (Curriculum S).

In regard to Curriculum R, there is a strong pressure passed down from graduate schools to increase both the number of, and the degree of specialization in, the courses that prepare for modern graduate work. The conference expressed itself strongly that the requirements of any major program, in attempting to provide the student with the techniques and knowledge that will enable him upon graduation to understand some of the current research literature and to use advanced and specialized texts, must not be so time-consuming as to encroach unduly on the breadth of education. A physicist, no less than any other scholar, needs to be able to place his work in the general context in which that work is done. There is little doubt that, if the total time spent on physics in the undergraduate school is not to be increased, the physics courses in Curriculum R will become more specialized rather than less. The conference was emphatic in recommending that no physics major program should have a total set of requirements, i.e., physics plus all required minor courses including mathematics, chemistry, etc., that comprises more than half of the total four-year college work of the student, e.g., 60 semester hours of a total of 120. Many conferees felt strongly that if additional physics or mathematics courses are taken, they should be in addition to the number required for graduation.

It is intended that these two curricula be significantly different, and non-collinear. The difference in objectives should not be belittled simply because we, the physics part of the academic profession, do not now know how to teach suitable courses in Curriculum S. Few of us have yet developed this pedagogic ability—we have been excessively preoccupied with teaching our own specialized images, in some variant of Curriculum R. It behooves us to learn to accept and to meet broader educational responsibilities. With courses properly taught, the student will find Curriculum S and Curriculum R equally demanding in scholarship. Let there be no talk of one being a watered-down version of the other.

It is believed that only some large departments will find it practical to offer both curricula. A department that can offer only a single curriculum should decide which of the two is better for its majors and which can be done well with the available resources of the department. For example, a small department in a liberal arts college may have neither sufficient faculty time available to offer Curriculum R nor be willing to sacrifice enough of the other liberal arts courses to make that curriculum possible for its students. Such a department, with the help of the other departments of the college, may offer its able students a strong Curriculum S that will prepare them to enter graduate schools, with the understanding that they may be delayed about one year in the achievement of the doctorate. The conference urges graduate departments to keep in mind the fact that many able students, potentially excellent physicists, may not have had the opportunity or desire to specialize heavily as undergraduates.

Before entering into more detailed discussions of the two curricula, we must emphasize that both share the purpose of aiding the student in the development of competence in physics, of independence in inquiry, and of talents that enable him to become a thoughtful and productive participant in a culture increasingly molded by science.

The curricular descriptions that follow are not complete, and must be used with caution and judgment. For example, from the descriptions of the four graduate courses listed below one might infer that the student's detailed knowledge of analytical theory is more important than his acquaintance with a wide range of phenomena and his knowledge of the problems and methods of experimental physics. This was not the intention of the conference. Similarly, the extended list given in Appendix A does not include as much as it should on the phenomenological and experimental side. For such shortcomings, we can only offer the excuse that some parts of our subject are easier to put into meaningful words than others. It is important to note that experimental work is given considerable emphasis in specific recommendations concerning laboratory work in both the R and S curricula.

To recapitulate, every physics major should acquire competence in approaching a new topic pheomenologically, as well as in terms of theory. He should recognize that careful quantitative descriptions of phenomena are necessary in the peculier interplay of theory and experiment that characterizes physics. Finally, he should continually increase the "insight" or "intuition" that distinguishes the physicist from the novice.

Curriculum R

Because many, or even most, of the students in Curriculum R will be preparing for immediate entrance to graduate school, the present principal objectives of the curriculum may be best defined in terms of the demands that graduate departments now make on their entering students. There was a consensus among the conferees that the well prepared student should be ready to take the following four courses in appropriate sequence, starting with at least two of them immediately upon entering graduate school:

(1) Classical Mechanics, through Hamilton's equations, canonical transformations, Hamilton-Jacobi theory, and Lagrangian and Hamiltonian formulations for fields. (Level of Goldstein or Sommerfeld.)

(2) Electrodynamics, through wave equations, vacuum electrodynamics, Lienhard-Wiechart potentials, and radiation from an accelerated charge. (Level of Panofsky and Phillips or Jackson.)

(3) Quantum Mechanics, through matrix formulations, scattering perturbation theory, and the Dirac equation. (Level of Schiff or Merzbacher.)

(4) Mathematical Physics, including topics such as field equations, variational methods, Green's functions, approximation methods, diffusion and boundary value problems. (Level of Morse and Feshbach or Landau and Lifshitz.)

Also, every beginning graduate student should be ready to enter a graduate laboratory course, where it exists, or to begin graduate level experimental research. Such experimental work cannot be characterized in as clear a fashion as are the four courses listed above. The conference felt strongly that preparation for it will prove of value to the future theorists as well as to the future experimentalist.

Appendix A gives a list of topics that is intended as a guide to the formulation of Curriculum R. If the student is not to suffer delay in his graduate work, he should have a sound and unified working knowledge of a substantial part of the topics included in the list.[4]

4. To provide a further indication of the levels of achievement implied by some of the descriptions in Appendix A, the committee was instructed to publish a set of typical problems, taken from examinations given in the past few years by graduate departments for the placement of beginning graduate students. This collection is not yet complete, but will be submitted to Am. J. Phys. in the near future.

The topics are not titled with the names of traditional courses, nor is there any indication of the order in which they are to be presented. The conference suggests that many physics departments may wish to experiment with groupings of materials and with non-conventional sequences in striving for maximal efficiency in the use of faculty and student time. As stated in Appendix A, we have tried to indicate an upper limit as well as a lower limit to the knowledge that should be required of the student.

There is no unique answer to the question of how much time must be spent by an able student in acquiring the necessary background and preparation for graduate work. Departments represented at the conference vary greatly in their requirements, but a considerable portion of the conferees believed that their departments succeed in bringing their majors to a satisfactory level if they require a minimum of 36 to 40 semester hours in physics and 18-20 semester hours in mathematics, starting with the calculus. This time allows about 12 of the 15 topics of Appendix A to be covered in adequate depth. But, on the other hand, many conferees stated that they needed more than 40 semester hours in physics to accomplish this.

A large number of the departments include in the 36-40 semester hours a minimum of six semester hours of laboratory (two in the introductory course and four in intermediate physics courses. Many require an additional four semester hours in a senior laboratory.). Some have found it advantageous to conduct an open-ended senior laboratory in which as much as half of the student's time is spent in the library, preparing for and interpreting the laboratory work. Such a laboratory can play a unique role in introducing the student to experimental research and in helping him to recognize the part that it plays in the development of physics.

Curriculum S

As was stated above, the educational objectives of Curriculum S differ in many respects from those of Curriculum R. The physics requirement in the former should be supplemented by a requirement of work in related sciences, such as chemistry, biology, astornomy, and geology and, possibly, in the history or philosophy of science. In so far as is practicable, all such courses should have the flavor of what might be called interpretation and synthsis, rather than the flavor of specialized training for modern research. The time spent on related subjects may be about two-thirds of that spent on physics and should include sufficiently advanced work in one of them to insure that the student has more than a dilettante's acquaintance. Curriculum S may offer better preparation for many students who are headed for careers in the rapidly developing borderline fields than does Curriculum R. This result can be achieved,'however, only if all courses in physics beyond the first year require the calculus.

To insure that this curriculum prepares students properly for secondary school teaching, it should be developed in accordance with the NASDTEC-AAAS GUIDELINES,[5] with which it is consistent.

It is much more difficult than for Curriculum R to describe Curriculum S by statements of next-in-line courses or by a specification of topics to be mastered or to estimate'the time requirements. This is for several more or less obvious reasons: (1) the flexibility in Curriculum S is rather great, (2) fewer institutions now approximate this curriculum, and (3) good existing texts are not as well suited to it as they are to Curriculum R.

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5. Guidelines for Preparation Programs of Teachers of Secondary School Science and Mathematics, Amer. Assoc. Adv. Sci., Washington, D. C., 1961.

A majority of the conferees recommended, however, that the requirement in physics be set at about 26 semester hours, in mathematics at about 15 semester hours (starting with calculus), and in the other sciences at 18 semester hours. The physics requirement is assumed to include at least 18 semester hours beyond a one-year introductory course and the requirement in other sciences at least 8 semester hours of bona fide junior and senior work. Physics laboratory work is no less important than in Curriculum R. It seems likely that eight or nine of the topics in Appendix A can be developed well under these circumstances, although differently from the way that they are treated in Curriculum R.

Choice of Curricula

The conference had no desire to establish rigid curricula, either in respect to content or time. Local conditions may result in the desirability of introducing variants of Curriculum R or of Curriculum S. It is strongly recommended, however, that departments that can offer only a single major sequence limit themselves to something that approximates one of the two curricula. An attempt to present both with limited manpower and faclities will probably work to the detriment of the students, as will a compromise that steers midway between R and S. If the department chooses Curriculum R, it must do so with the recognition of the strenuous demands that will be made upon its faculty to keep abreast of research, and of the fact that few students other than those dedicated to research careers will be able to complete the major work; if it chooses Curriculum S, it must be conscious that any of its majors who decide to enter graduate work in physics will need to complete, by courses or by independent study, their preparation for true graduate work, and so may suffer delays. No institution can be all things to all men—it is better to do a limited job well than to do several jobs poorly.

III. MATCHING OF PHYSICS PROGRAMS

Discussion of undergraduate curricula should include the problems concerning the interrelations among various parts of the educational system. Students enter college from diverse high school backgrounds. Many develop new interests and shift their programs while undergraduates, transferring from one college to another or from one field of study to another. And, finally, students having a broad spectrum of undergraduate backgrounds present themselves to graduate schools; this diversity will be increased by the general introduction of Curriculum S.

All three of the Curriculum Conferences were concerned with methods for improving matching among the programs taken at various levels.

High School to College

High school education is currently changing rapidly. Recent curricular studies have produced new science and mathematics courses which differ radically from the traditional offerings. Some, such as the physics course prepared by the Physical Science Study Committee, and the mathematics courses developed by the School Mathematics Study Group, are already being taught extensively. Others soon will be. What is more, additional significant changes are being proposed at the earlier levels of education and these may bring about further differentiation in the high school programs. As a result, the diversity of backgrounds among students entering undergraduate college physics programs is increasing rapidly. These students have had a wide variety in the nature as well as in the quantity and quality of high school science. In addition, the undergraduates have different educational goals, as was indicated in Section II.

Colleges face severe problems, as well as interesting opportunities, in providing appropriate introductory courses for this wide variety of students. These can be partially illustrated by discussing present practices, which form the base on which an appropriate structure must be erected to care for increasing diversity.

Many physics departments offer only a single introductory course. The several types of freshman physics majors, as well as the many other students who need or wish to take an introductory course, are all given the same basic material in the same basic pedagogic pattern. In many other schools, two or three different courses are commonly taught as follows:

α: Introductory physics requiring at least concurrent calculus and attempting to be analytical and comprehensive.

β: Introductory physics, with a prerequisite of two or (preferably) three years of college preparatory mathematics. (Calculus concepts are sometimes used, even though the calculus is not required.)

γ: Introductory physics for non-science majors, a terminal course. (Since this course is not part of a physics major program, it is not discussed further in this report.)

Course α is normally intended as the first course for most physics majors. Often it is also the introductory course for students of engineering and perhaps for students majoring in chemistry or biology.[6] It may be a two-year sequence course, but in liberal arts colleges it is more likely to be a one-year course. Course β is normally intended for most pre-medical and biology students, as well as for physics majors who enter with deficient high school backgrounds. In a department that does not offer a γ or an α course, β usually serves in its stead.

In the context of this report, course α is clearly the appropriate one for students in Curriculum R. It should normally be taken by students who have had one year of good high school physics and who are taking a concurrent course in calculus. (Its character may well alter significantly over the next few years as a result of several curricular studies now under way, as well as in response to more sophisticated high school courses.)

Course β now is usually a somewhat less analytical and rigorous version of Course α. If it is merely a weak copy of α, it has limited value in Curriculum S. However, it can be developed into an appropriate first course in such a curriculum and, at the same time, become of greater value to the non-major students normally enrolled.

Since many students may choose early to transfer from one physics major curriculum to the other, there are distinct advantages in making Courses α and β the same length—normally one year. However, other issues may well outweigh this consideration in determining the lengths of the courses.

An increasing number of students is entering college with advanced standing. Any freshman who has had more than one year of good high school physics should realize that advanced placement in physics should be coupled with advanced placement in mathematics, even if summer study is needed for the mathematics preparation. There is little point in achieving advanced

6. Physics courses specifically designed for students of engineering, chemistry, biology, geology, etc., were recognized as possibly needing a different treatment (e.g., to "fit" with courses in other departments to minimize unnecessary overlap) but were not specifically discussed at these conferences.

placement in physics only, since the next physics courses in either Curriculum R or S will generally require calculus as a prerequisite.

College Program to College Program

Many students enter undergraduate physics major programs after the freshman year from engineering, chemistry, mathematics, and some from less closely related disciplines. A rapidly increasing number of students enters after two year at junior or community colleges.

Many such students may find it necessary to spend additional time in college, but in schools offering Curriculum S this loss of time may be minimized or even obviated. It is generally possible, although difficult, to devise an R Curriculum starting in the second year of college, but it is relatively easy to do so in the S Curriculum. In any case it is practically imperative that calculus be started no later than the second year.

Some departments may offer both Curriculum R and Curriculum S. In such schools there will undoubtedly be students wishing to transfer from one curriculum to the other. Also similar transfers may arise as students change schools. For well-motivated students such shifts should not prove to be too difficult before the start of the third year of college. However, if each curriculum is properly structured, some special make-up work will probably be necessary if the students are to graduate on schedule.

College to Graduate School

We have implied several times above that there are or should be different types of emphasis in the first year of graduate work. The Ph.D. seems to be well established as a research degree, and the R Curriculum is specifically designed to speed the student on his way in this program, hopefully to halt or even reverse the trend for an increasing number of years of graduate study in the attainment of this degree.

During the past decade or two, a number of institutions that do not offer the doctorate have introduced master's programs that are sound and demanding and that serve as excellent bridges between the undergraduate work of Curriculum S and the type of graduate study outlined in our discussion of Curriculum R in Section II. Such programs may be of increasing significance and, in combination with Curriculum S, may prove to furnish one of the best paths to the Ph.D. degree.

Finally, the conference would emphasize to the strong Ph.D.-granting graduate schools, the pace-setters in the rapidly expanding subject of physics, (1) that many potentially excellent physicists will certainly have undergraduate physics preparation of a quantity and quality, when judged only in terms of training for Ph.D. research, considerably inferior to that of Curriculum R; (2) that Curriculum S, or anything like it, will have a hard time establishing its legitimacy if the strong schools do not give it their blessing; and (3) this blessing should consist of two parts—first, the establishment of a Curriculum S within many of the strong schools and, second, the wholehearted acceptance of graduates from Curriculum S into their own graduate programs.

APPENDIX A

FURTHER DESCRIPTION OF CURRICULUM R

The conference felt that it would not be doing a service by recommending any fixed course of study or, even, any minimal set of courses that should be taken by students in Curriculum R. It preferred, instead, to specify the characteristics that a graduating student should have at the time that he starts further work in physics. Readiness for the graduate work outlined above in Recommendations Concerning Major Curricula was considered as an essential element in the description of Curriculum R. The list of subjects and techniques that is given below represents an amplification of that part of the description, in the sense that the conference believed that a student who has mastered the rudiments of a substantial part of the list should be ready for the graduate work indicated.

This list is not intended to imply in any way either the particular courses that the student should have taken or the manner or order in which he should have acquired the indicated skills and knowledge. Some of the items may well be covered sufficiently in a general introductory course or even outside of the student's academic program; others may not be encountered before his senior year.

The suggestions of level of schievement are intended to imply an upper limit of requirements, as well as a lower limit. Thus the exclusion of the asymmetrical top from #1, of confocal coordinates from #2 and #3, of Fresnel diffraction from #7, etc., is deliberate. It is better to leave some of the student's appetite to be appeased at a later date than it is to induce mental indigestion by gorging.[7]

* * * *

(1) Particle dynamics in inertial and accelerated reference frames. Newton's law of gravitation, gravitional potential, orbits in central force fields. Elementary rigid body dynamics, including introduction to precession. The notions of generalized mechanics, including the application of Lagrangian methods to conservative systems.

(2) Vector analysis, including gradient, divergence, curl, Laplacian, together with their physical significance. Line and surface integrals, Gauss and Stokes theorems. Vectors Cartesian, cylindrical, and spherical polar coordinates. Some knowledge of existence of other orthogonal systems and of physical applications of matrices and tensors.

(3) Electrostatics, including the Coulomb and Gauss laws, the Poisson and Laplace equations, energy in the field. Solutions of Laplace equation (e.g., by method of images, inversion) and separation of variables in cylindrical and spherical coordinate systems.

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7. See footnote 4.

(4) Electric circuits involving steady currents, slowly varying currents, conservation of charge and energy in circuits. Ampere and Faraday laws, use of vector potential and some applications. Energy considerations in the magnetic field. Displacement current and Maxwell equations. Lorentz forces and particle ballistics in static fields.

(5) Basic instruments for the measurement of mechanical, electromagnetic, optical, and thermal quantities. Sources of uncertainties, their effects on calculated quantities. Limits of sensitivities, basic concepts of noise. Interpretation of data by graphical methods, including ways in which departure from a given theory may be analyzed.

(6) Simple harmonic, damped, and forced oscillations. Resonance. Extension to two and three dimensions in simple cases. Coupled oscillations in one dimension, including characteristic modes and dependence on initial conditions. Applications of Fourier series.

(7) Kinematics and dynamics of one dimensional and plane waves, including momentum and energy considerations, wave and group velocities, standing waves, modes in two dimensions. Interference, coherence and incoherence. Fraunhofer diffraction. Polarization. Acquaintance with the following phenomena and the elementary theory of them: interaction of waves with matter, including radiation, optical dispersion, absorption, Rayleigh scattering. Electromagnetic waves, their propagation, transmission of momentum and energy, interaction with classical oscillators.

(8) Phenomenological knowledge of mechanical, optical, thermal, electrical, and magnetic properties of common substances, and of fluorescence, phosphorescence, photoconductivity, work function. Basic concepts of the free electron model and of the band approximation. Structural properties of simple crystals.

(9) Zeroth, first, and second laws of thermodynamics. Entropy, enthalpy, free energy, and application of these functions to equilibrium. Kinetic theory of ideal gas, Maxwell-Boltzman distribution, specific heat of gases, simple transport phenomena. Basis and derivation of Bose-Einstein and Fermi-Dirac statistics.

(10) Atomic and molecular spectra, x-rays, Rutherford scattering and the nuclear model, Bohr-Sommerfeld atom, stationary states, Franck-Hertz experiments, existence of electron spin, Stern-Gerlach experiment, Pauli exclusion principal, vector model, Zeeman effect. Descriptive knowledge of: stable nuclei, isotopes, natural and induced radioactivity, nuclear reactions, nuclidic masses, binding energy, scattering experiments, nuclear cross-sections, spins, evergy levels, basic ideas of nuclear models. Experimental evidence for elementary particles.

(11) Failure of Galilean relativity and Newtonian mechanics at high speeds and their inconsistency with Maxwell equations, Michelson-Morley experiment. Einstein assumptions, their consequences concerning the behavior of clocks and measuring rods, velocity addition, mass, momentum, and energy. Lorentz transformations and invariance. The equivalence principle and its simpler consequences.

(12) Evidence for atomicity of matter and of electricity. Breakdown of the predictions of statistical mechanics and electromagnetism. Introduction of the quantum hypothesis, application to photoelectric effect, specific heats of gases and monatomic solids, Compton effect. Wave-particle duality and the Davisson-Germer experiment. Heisenberg

uncertainty principal. Schroedinger equation, application to particle in a box, rectangular barrier penetration, rotator, harmonic oscillator, hydrogenatom. Symmetry principles.

(13) Thermionic emission. Vacuum and solid state diodes and triodes in the linear approximation. Simple amplifiers and oscillators, including frequency response, gain and stability considerations. Basic oscilloscopes, devices for detecting and measuring radiations and particles. Fundamental considerations involved in pulse analysis and counting.

(14) Analysis of dynamical physical systems by the construction of appropriate differential equations. Solutions of ordinary differential equations. Solutions of partial differential equations as involved in 1, 3, 4, 7, 9, 12 above, involving at least solutions expressed in Legendre polynomials.

(15) Methods of measurement and accuracy of determination of several of the fundamental constants. Familiarity with approximate magnitudes of basic constants and quantities, methods of their measurement, and significance of these magnitudes.

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APPENDIX II

The following are some proposals relating to the problem of the communication of information about graduate schools. These proposals were presented to the Second Ann Arbor Conference for purposes of discussion, by Dr. William Kelly of the American Institute of Physics, in answer to a direct request which was made to the AIP by the First Ann Arbor Conference. The proposals were presented as tentative, with the idea that if certain of them should meet with strong acceptance by the representatives at the Conference, the AIP might then proceed to seek support for their implementation.

Subsequent to the Second Ann Arbor Conference, a proposal, which followed along the lines suggested by the Conference, was prepared by the AIP and submitted to the National Science Foundation. The NSF was not able to support the request as submitted. We are informed by Dr. Kelly that the AIP is continuing in its efforts to find ways of implementing, at least partially, the recommendations it has received from the two Ann Arbor Conferences.

The Ann Arbor Conference on Curricula for Undergraduate Majors in Physics, held on May 14-16, 1962, at the University of Michigan under the auspices of the Commission on College Physics, discussed the increasing seriousness of the problem of matching prospective graduate students to graduate departments of physics. The Conference recommended to the American Institute of Physics that it explore this problem and seek solutions.

Background to the proposal

In recent years, the number of bachelor's degrees awarded annually in physics in the United States has been approximately 5000. Some 680 institutions award such degrees. Currently there are about 9400 graduate students of physics at various stages of their graduate studies. About 109 institutions offer graduate work leading to the Ph.D. in physics. In 1960-61, 614 doctor's degrees were awarded, an increase of 86 over the number awarded in the previous year. In addition, 1322 master's degrees were awarded.

Direct information about the number of students dropping out of graduate study in physics each year and about the causes of drop-out is being sought, but is not yet available. However, if we consider the attainment of the doctoral degree as one of the important goals of higher education in physics, the data given above indicate that significant drop-out occurs at the undergraduate-graduate transition, during the graduate years, and by termination at the master's degree. To be sure, not all drop-out is undesirable, since some of these individuals move into fields related to physics or in other ways make use of their education in physics. However, one of the largest graduate departments in physics has estimated that only about one-half of the students who enter their institution with serious intent to obtain the doctorate actually receive it. Since these students presumably passed stringent entrance requirements and were strongly motivated toward graduate study in physics one must assume that the drop-out indicates an educational problem with serious effects upon the Nation's supply of Ph.D. physicists.

The causes of drop-out are probably the same as those that contribute most to lengthening the time required to attain the doctor's degree in physics, including inadequate undergraduate preparation, insufficient financial support, and insufficient ability to cope with the intellectual and psychological demands of graduate study in physics. In addition, since students and institutions differ in significant ways as to what they expect of each other, there are often mismatches resulting from the poor choice of graduate institution, and these too contribute to delays in receiving advanced degrees and to failure to obtain degrees. It is to this last problem—one of information—that the present proposal is directed.

Kinds of information needed

The Ann Arbor Conference suggested certain kinds of information about graduate physics departments that prospective graduate students and their advisors would like to have in order to match a student reasonably well to a graduate institution. Other kinds of needed information have been proposed in correspondence directed to the American Institute of Physics. Still other kinds have been discussed by the AIP Advisory Committee on Manpower.

Combining these, we find that the significant questions that one would like to have answered before advising a student to apply to a particular institution fall into three groups: (1) those involving information that can be readily obtained and published (For example, what are the research specialties of the department?); (2) those involving information that some institutions might object to having published, but that most would provide (What is the Graduate Record Examination profile of entering students?); and (3) those that deal with important characteristics of physics departments, but that cannot be answered in print without having misunderstandings arise (What percentage of the graduate faculty consider that their principal activity is research as opposed to supervision of thesis work and formal teaching?). Some of the questions that one might ask within each group are listed in Appendix A.

Proposal

We propose to use different methods of gathering and disseminating information about graduate study according to the group of questions involved.

1. A handbook for advisors of prospective graduate students. The American Institute of Physics publishes biennially the reports Graduate Physics Research Specialties in American Educational Institutions and Graduate Assistantships and Fellowships in Physics and Academic Institutions. (Copies are attached.) We propose to combine the kinds of information in these publications and extend them by seeking answers to questions like those in Group 1 of Appendix A. The information would be published in a handbook for advisors of prospective graduate students—a booklet containing between 200 and 250 pages, 8 1/2 inches x 11 inches in size, reproduced by the photo-offset process. Each participating graduate department of physics that awards the Ph.D.—109 in all in 1961-62—would have about two pages available for its statement. We would attempt to adopt a uniform format for these presentations so that information would be as nearly comparable as possible from one institution to another and so that the information could be readily located. Following the recommendations of the Ann Arbor Conference, we would allow each graduate department the option as to whether it wishes to be included in the book. Certain minimal information would be included for each of these departments, and they would be allowed to add optional information. Some of the departments might be willing to provide answers to questions in Group 2 of Appendix A. If so, this information would be included. If the handbook proves useful, we would hope that we would be able to obtain support to revise it biennially. What we are proposing here is to compile and publish the first edition of such a booklet and to evaluate its usefulness.

2. A national office for advisory services in graduate student placement. To compile the handbook for prospective graduate students in physics, to arrange and evaluate the regional conferences referred to below, and to maintain liaison among graduate departments of physics a and the physics departments of smaller institutions, we propose to establish at the American Institute of Physics a national office for advisory services in graduate student placement. The director of the office would be a physicist with an interest in these problems and sufficient stature to be able to enlist the active participation of physicists in both graduate and undergraduate departments. In addition to supervising the preparation of the handbook and the arrangements for conferences, he would have the responsibility of visiting some of the leading centers of graduate study in physics to inform himself about their situations in regard to the admission of graduate students. He would also visit selected undergraduate institutions to inquire into the problems their students face in being admitted to graduate institutions in whichthey can carry on effective work. One of the problems that he might well explore and seek solutions to is that of establishing uniform recommendation procedures so that the recommendations for prospective graduate students are more nearly comparable from college to college and from year to year. Another is the problem of providing feedback to the colleges about the graduate-school performance of their students.

3. Regional conferences. We believe that the measures proposed under points 1 and 2 above will not solve completely the problem of convey adequate information about graduate physics departments to advisors of undergraduates—particularly the answers to questions such as those in group 3 and many of the questions in group 2. It is difficult indeed to cope with those questions in printed statements, yet the answers often go to the heart of the problem of matching students and graduate departments. Further experience of the director of the project may indicate tactful and effective ways of handling these questions in print, but at the moment opportunities for informal discussion—similar to those that occur at national meetings and conferences—would seem to ovver the only hope for dealing with the more sensitive questions.

   We therefore propose to arrange a series of regional conferences between representatives of large graduate departments of physics and representatives of smaller institutions whose graduates seek admission to graduate study. Three regional conferences—one in the East, one in the Midwest, and one in the West—would be held in each of the two years of the proposed program. Each two-day conference would be attended by about 60 physicists from smaller institutions in that region and about 10 physicists from larger graduate departments. The representatives of the graduate departments would be selected on a national basis, but with some emphasis on the region in which the meeting was held. Formal activities at the conferences—such as panel discussions and talks on trends in undergraduate and graduate education—would be used to stimulate discussion and introduce the participants. Informal discussion within small discussion groups would be stressed so that the physicists could have ample opportunity to exchange opinions and information on an off-the-record basis. For example, the representatives of the graduate institutions might rotate from one group to another so that all of the representatives of undergraduate colleges could meet them informally. There would also be opportunities for informal discussion between group meetings and during meals.

   The plan for regional conferences is admittedly very experimental. Evaluation of their effectiveness would be based on what the participants had to say about them afterward. Modifications in procedures would occur as the series of conferences proceeded. The least result that one could expect would be that representatives of about 360 of the more productive undergraduate institutions would be better informed about the practices of graduate departments of physics, and representatives of about 60 graduate departments would have had an opportunity to examine the problems of the undergraduate-graduate transition. One might anticipate, however, that the conferences might lead to greatly improved advisory services to both graduate and undergraduate students. The conferences of the second year would also be able to profit from the availability of the handbook for advisors of prospective graduate students and to suggest improvements in the handbook.

APPENDIX A

Information about graduate physics departments

1. Information that can be readily supplied by physics departments, compiled in a booklet, and published:

   a. What undergraduate preparation is expected of candidates for admission?

   b. What are the general requirements for advanced degrees?

   c. What are some typical graduate programs: (1) courses (2) thesis research?

   d. What forms of financial support for graduate students are provided by the institution and what are the corresponding requirements for service in teaching or in non-thesis research?

   e. What graduate examinations are given and when: qualifying (appraisal), general (comprehensive), oral?

   f. What are the foreign language requirements and when are these to be met?

   g. What are the research specialties of the department? (Perhaps list recent papers.)

   h. Who are the members of the staff who supervise thesis research, give graduate courses, serve as graduate advisors, or in other ways come into contact with graduate students?

   i. What facilities are available for experimental research?

   j. How many graduate students are enrolled and how many advanced degrees are given each year?

   k. What kind of an environment does the institution provide for graduate students: i.e., what can be said about opportunities for student-student interactions, colloquia, journal clubs, student housing, etc.?

2. Information that some institutions might object to having published, but that most would provide:

   a. What is the Graduate Record Examination profile of entering graduate students?

   b. What has been the average time to obtain a doctor's degree during the last five years? What is the range of times?

   c. What can be said about student-staff relations within the department as a part of the student's environment?

d. What opportunities are there for the graduate student who wants to be a teacher to engage in teaching under faculty supervision?

e. What are the personal characteristics of students who can be expected to find the environment stimulating and the assistance of the faculty adequate for productive work?

f. What is the publication policy of the department where graduate students are involved? Are they encouraged to be authors or coauthors of papers deriving from research that they have engaged in?

g. What emphasis, if any, does the department place on these qualities in an applicant for for graduate admission: creative ability, experimental talent or aptitude, self-direction or initiative, ability for independent study, physical insight or intuition?

h. How large are the classes in typical first-year graduate courses?

i. How is thesis research initiated? Does the student have the responsibility for finding a sponsor and a topic? Which fields are so much in demand that research facilities are strained?

j. To what extent is "team research" prevalent in the department?

k. What percentage of Ph.D. candidates do an appreciable part of their thesis problem under the guise of project employment before being admitted to the Ph.D. program?

3. Information that, if available, could not be published:

a. Where does the department's strength lie as a physics research center?

b. What are the characteristics of the graduate staff as supervisors of graduate students?

c. What percentage of the graduate faculty consider that their principal activity is research as opposed to supervision of thesis work and formal teaching?

d. What percentage of graduate courses are taught with serios didactic effort as contrasted with perfunctory exposition?

e. What is the percentage of graduate admissions among applicants from the smaller colleges as compared with graduates of larger and possibly more prestigious institutions? Is the department reluctant to admit the former?

APPENDIX III

NOTES ON B.S. PHYSICISTS IN THE GENERAL ELECTRIC COMPANY
(Supplied by Dr. J. S. Saby)

The following approximate figures are quoted to put into perspective B.S. physicist employment at General Electric:

250,000	total employment by G. E.
15,000	technical graduates B.S. (or higher degrees) at G.E.—6% of total employment
750	B.S. physicists employed at G.E.—One in 20 technical people (total includes a small number of M.S. physicists)
75	approximate annual number of employment opportunities for inexperienced B.S. physicists.

I. Where do they go?

A. A few B.S. physicists occupy research positions in laboratories at General Electric. For these, further study is essential on the job or at the university (encouraged by Company tuition refund benefits). This group includes largely those of high scholastic ability and achievement whose formal education was interrupted at B.S. by circumstances. For these, the B.S. is not really terminal; many will return to graduate school. Their optimum undergraduate physics curriculum would be very similar to pregraduate curriculum.

B. Most B.S. physicists in the company are employed in product department laboratories, engineering organizations, and other technical organizations. Nearly all are doing applied "physics", but not at the Ph.D. research level. The work is nearly always experimental rather than theoretical and requires the ability to make physical measurements and to develop new methods of physical measurement. Most are hired to fill positions for which management has requested B.S. physicists in preference to B.S. engineers. A number of such openings were cited as examples which demonstrate that there is in industry a genuine demand for individuals holding a terminal B.S. degree in physics, not merely as substitutes for engineers. Employment opportunities for M.S. physicists are very similar and this small group will not be considered separately.

Many B.S. physicists occupy positions of responsibility at G.E. and the opportunities for promotion appear similar to the opportunities for B.S. chemists and engineers.

II. Do these observations imply anything about the optimum curriculum for the terminal B.S. in physics?

A. Ability to make use of fundamental scientific relationships is important for any physicist. Since most graduate students in physics can be financially self-supporting today, and in view of the economic and professional advantages of acquiring the Ph.D., it should be presumed that the typical terminal B.S. physics major in most cases does not have the necessary mental equipment to succeed in graduate school.

As curricula for terminal B.S. physics majors, it is natural simply to consider truncated selections of the same list of courses offered for the pregraduate school majors. Perhaps this process is a good way to build an optimum curriculum for the terminal B.S. physicist but it isn't obviously the best way. It may even be wrong. This question deserves conscious attention since it turns out to involve most of the students in most schools.

B. General basic skills are likely to be much more useful than specific skills, e.g., enough experience with electrical circuits, optics, or mechanics to originate or modify an unfamiliar measuring instrument rather than, for example, a smattering of experience operating an electron microscope of spectrophotometer. It does not appear necessary that the terminal B.S. physicist should have a "sound working knowledge" of: quantum theory, relativity, or Lagrangrian methods, etc. It would be desirable for him to know of the existence of topics too advanced for his mastery as an undergraduate so he will recognize the need for help or further study when need arises. Perhaps survey courses have a place here.

C. Practical mathematical skills are essential, with emphasis on widely used analytical methods, rather than the more abstract branches of mathematics. It is easier to pick up these skills in college than later on by self study or from the advanced courses which are offered from time to time by the company.

D. In undergraduate physics courses, the terminal bachelor physicist may derive more benefit from emphasis on problem solving, whereas training in abstract theoretical synthesis is more vital to the pregraduate school physicist. This may appear as differences in emphasis or teaching technique rather than as differences in formal curriculum outlines. This may also be a factor in the choice of a textbook.

E. Flexibility is valuable. If the terminal B.S. physicist due to intellectual limitations takes fewer physics courses than his pregraduate school classmate, he should be encouraged to take courses which may help broaden his perspective and increase his maturity—he will be on his own as soon as he graduates. The ability to think independently will contribute heavily to his success. Of course this trait is inborn to a great extent but it can be encouraged by individual curriculum choices and by the attitude of advisors.

III. In conclusion.

Employers hire people, not curricula. The terminal bachelor physicist in most cases will have more limited ability than the pregraduate school candidate. His interests and capabilities are apt to be concrete rather than abstract and there are many jobs where this can be an advantage for him. In view of the demand for his services, the terminal B.S. physicist should not be regarded simply as a "reject" in the academic process of manufacturing Ph.D. research physicists—granted, that the future development of physics as a body of knowledge will depend squarely on the Ph.D. physicists of tomorrow.

It seems very likely that some of the most important distinctions between terminal B.S. and pregraduate school physics curricula may be in appropriate differences in presentation and point of view lying deeper than the official outline of the course, which, however, we hope will include:

(1) Fundamentals in usable form including good mathematical skills.

(2) Good general experimental skills—if the terminal B.S. physicist does not need as much theory as the pregraduate school physicists, perhaps he will have time for even more experimental training.

(3) Awareness of the existence of a number of advanced topics sufficient to recognize his need for more information later on as new problems arise.

Finally, as brought out in discussion by Professor Marsh White, we are producing annually in U.S.A. about 10 times as many bachelors degree physicists as Ph.D. physicists. It follows that a large majority of our undergraduate physics majors will terminate their formal education at the bachelor level. I feel their optimum training deserves careful study. In institutions where the size of the student body permits, some bifurcation of curricula may be desirable to provide optimum training for terminal bachelors. This may also have the salutary effect of minimizing dilution of more advanced courses by students of less than superior ability.