# THE UNDERGRADUATE CURRICULUM IN PHYSICS FROM THE POINT OF VIEW OF INDUSTRY

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In this paper, I shall attempt to examine the adequacy of the undergraduate curriculum to prepare the possessor of a Bachelor's degree in physics for a position in industrial research. Since the industrial laboratory is one of the main consumers of the universities' and colleges' product, graduates, it is obvious that our voice should be heard in a symposium such as this.

I hope that the suggestions that are to be offered are practical, in the sense that they can be accomplished without requiring major expenditures of money. If the suggestions are followed, I believe that graduates produced under this system should be of more immediate use and have a potentially greater future.

In doing research, one generally makes a literature survey first and proceeds to utilize the best of the most pertinent information. In constructing this paper, I preferred to start by assembling all my own ideas and prejudices which are based primarily on having read many applications for jobs, having interviewed a selected number of applicants, having hired those who were judged desirable, and in subsequent years evaluating these men's work for merit raises or promotions. My opinions have been influenced to some extent by the sharing of experiences

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with other physicists and chemists with the same general experience. After I had set down my own thoughts, I then went to the literature to judge if I had strayed too far from the opinions of others. I was prepared to take a large divergence in opinion as evidence that I was "off the beam," a moderate divergence as encouragement that perhaps I had something to contribute, and zero divergence as evidence that I had nothing new and was wasting your time. I would be wasting your time because all the remarks were in the literature. You had heard or read the ideas before and done nothing to put them into effect, and therefore I could assume that not much good would come of presenting again the same material.

So here is the plan of attack. I shall review the organization of a laboratory so that you may see where the man with a Bachelor of Science in physics fits. I shall discuss the method of hiring, the first job, the possible promotions, and certain possible fields of specialization. I shall then set up the general deficiencies of the undergraduate curriculum in terms of a comparison of the average training with a desirable training; and I shall make this discussion in terms of the training of the university or the college with respect to what a man needs for his first job and what he needs for the long run. After these remarks have been made, I shall attempt to suggest what can be done to realize some of the suggestions.

A large research laboratory will have an organization much like the following:

1. A director who has a secretarial staff, an assistant director, department heads, the plant physician, and the plant accountant reporting directly to him.
2. Department heads who have a number of section heads reporting to them.
3. Section heads who have a number of group leaders, supervisors, or foremen reporting to them.
4. The group leaders, supervisors, or foremen who have the scientists, technicians, office staff, and skilled and unskilled laborers reporting to them.

In some laboratories all the nontechnical functions are under the supervision of one man, the business manager, who reports directly to the laboratory director; and in other laboratories, the nontechnical functions are organized into several departments, each of whose department head reports directly to the laboratory director. Figure 1 gives an idea of a typical organization.

A group or project in research will consist of some four to seven men working on several closely allied problems. The supervisor of the group is responsible for a number of administrative duties. A group will contain one or two Ph. D's and the rest Bachelor's or Master's. In development work or pilot plant work, groups may be much larger with practically all of the men at the M.S., B.S., and technician levels.

The Bachelor of Science or Arts in physics will be classed as a technical trainee in his first job. At the end of his first year, he will be promoted to the rank of assistant physicist if he has demonstrated that he has adapted himself to the company's policies and if he shows evidence of being able to advance in ability. During that first year, the young physicist will have found that he has difficulty in applying what he was taught, that he has been dependent on the more mature men, that the reports he wrote have been unsatisfactory, that the laboratory has local experimental techniques that are unfamiliar, that he doesn't know enough about the literature of mathematics and physics, and that he is deficient in laboratory skill. After the first year, he will probably progress steadily, earning merit raises; and in about six years he will be promoted to the rank of physicist. After another six to eight years, he will again be ready for promotion. At this stage, if he is well above average, he will probably have assumed some administrative responsibilities and will be directing his career towards administration. If he is average or below average, the physicist with a Bachelor's may be nearing the top of his career.

Each year when the scientist is considered for a merit raise, the supervisor will have to answer a number of questions such as:

1. Has the scientist's research ability increased during the year?
2. Has he shown cost consciousness?
3. Has he gotten along well with his fellow employees and supervisor?
4. Does he show signs of developing into a leader?

Now let us examine the hiring of an inexperienced owner of a Bachelor's Degree. He will fill out an application blank and submit it by mail or he will show up in person at the laboratory to fill out the questionnaire. If the laboratory is interested, an interview is conducted to assess the applicant's training, ability, and personality. A rough rule has evolved in estimating the relative training of applicants: prefer a B.S. in Engineering to a B.A., prefer a graduate of a university to a graduate of a college.

These preferences result from the fact that the B.S. in Engineering from a large university will have had about 160 or more semester-hours compared to 120 or more semester-hours for the B.A. from a college. The B.S. in Engineering will have had more physics, far more laboratory work, more mathematics, and some useful engineering. One of the important problems to be discussed then is: What can be done by the colleges to improve the position of their graduates? The obvious answer is to see that their students take about 20 credit hours or more per semester. These extra hours should preferably go into physics, mathematics, and laboratory work. If this isn't possible, the extra time could go into chemistry, geology, biology, German, and French. Particularly a greater knowledge of chemistry, the ability to read scientific German and French, and the ability to write good technical reports would improve the immediate usefulness to industry of the graduate from a college without large laboratory facilities.

However, I believe the small college can offer more in the physics and mathematics departments. In the previous paragraph, I suggested increasing the credit hours by roughly 25 percent. To put this suggestion into effect would require either a 25 percent increase in teaching load or additions to the staff with increases in student fees. Personally, I would suggest the increase in teaching load insofar as it is humanly possible. This increase in teaching load could and should be considerably alleviated by the students helping the faculty—paying the increase in fees by working for the college.

We saw previously that the physicist in industry will work in a group under an older, more experienced supervisor. We learned that his advancement will be based on his increase in ability, cost consciousness, ability to get along with people, and development of leadership. The students can acquire in college some of this general philosophy of group work if they are regularly assigned to some faculty member to help him in his work. Let us suppose that each faculty member had two seniors, two juniors, and two or three sophomores as his responsibility and that each student spent two afternoons a week or the equivalent at the laboratory repairing apparatus, taking inventory, setting up equipment for demonstration lectures or sophomore laboratory, helping in sophomore laboratory, grading problems or laboratory reports, typing, tutoring, helping the staff in their research, . . . , essentially anything that reduces the load on the faculty to compensate for the increased teaching load. A system in which the faculty tutored the seniors and graded their papers and reports, the seniors tutored the juniors and graded their papers and reports, the juniors acted in the same capacity with respect to the sophomores, and the sophomores helped in freshman mathematics or chemistry would create an atmosphere somewhat like that of the industrial laboratory: responsibility, consultation, promotion, authority, and interplay of personality.

Ordinarily a few of the students earn some money by work of this nature. However, I believe all the students should work, just for the value of learning how to work. The closer association with members of the faculty and fellow students should stimulate interest in physics. The interest in physics should be further

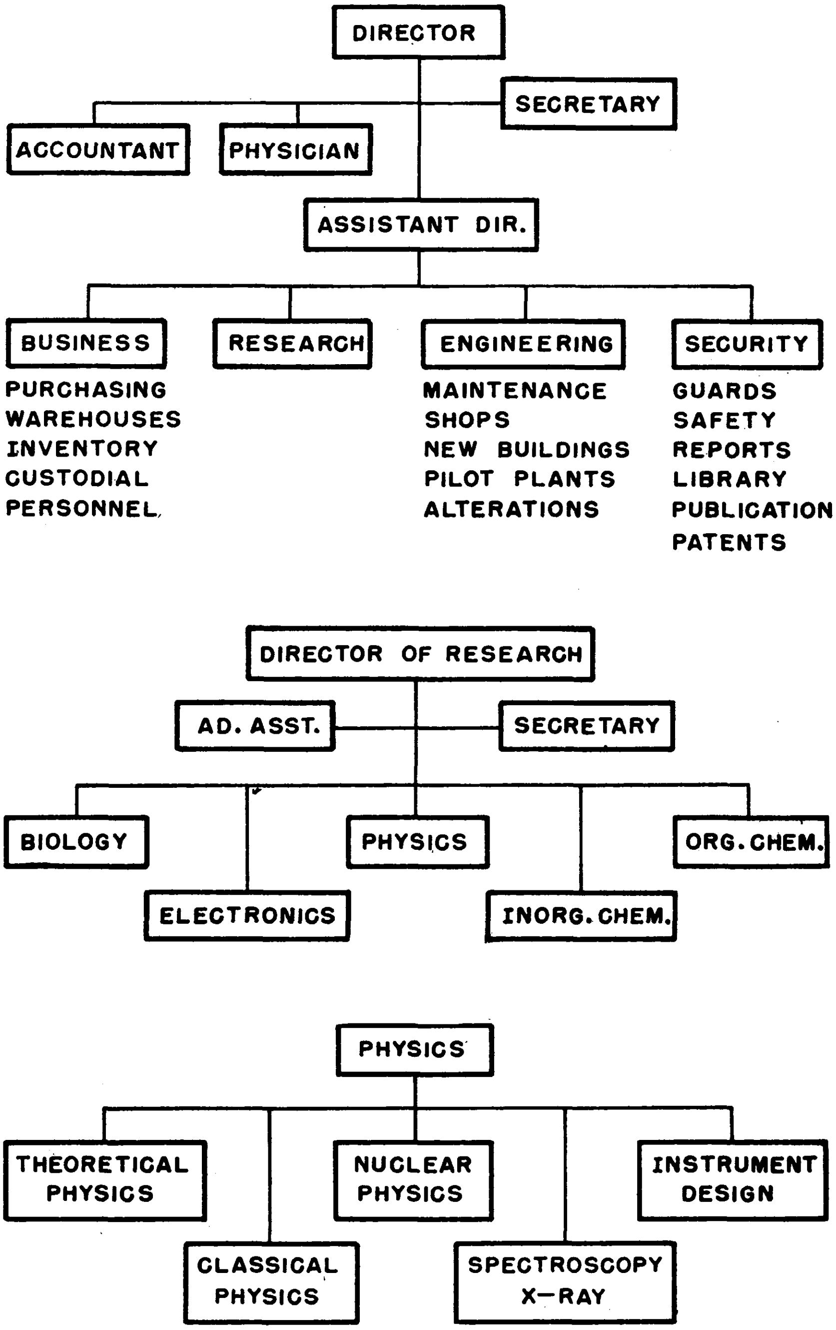


FIGURE 1. Typical organization chart of large research laboratory.

stimulated by requiring that the students spend two or three afternoons in the laboratory on their own problems. By requiring the student to spend so much of his time with the physics department in work, study, and experiment, physics and the laboratory become the focal point of his existence, a desirable psychological condition. In addition, these many hours in the laboratory should remedy the rather alarming lack of laboratory experience too often observed in the graduate from the smaller schools. As part of this process of making physics important to the student, I believe that the students should be allowed and encouraged to come back to the laboratory at night to study. The physics library should be in the same building and open for use. The students should have space available to them, a room with desks or tables and blackboards. Here again, group study and discussions would be stimulated.

The importance of laboratory training has already been indicated. There are several things I would like to suggest as potentially valuable to the student. The students should work part of the time in pairs and part time individually. The student and the faculty should be given the opportunity to judge the student's individual ability, initiative, and self-reliance and his group ability, cooperation, and leadership. The laboratory work in the junior and senior year should be sufficiently involved to require more than one session to complete. The student should be required to write a good report in conformance with some standard form. The quality of the report should be evaluated separately from the quality of the experimental work, since it is entirely likely that they will not be of equal quality. The report should contain a list of references, since the student must get in the habit of using the library. The report should contain a good discussion of the probable error of the result, distinguishing between the random errors of observation, the probable errors of the physical constants, and the systematic errors of the instruments. It would be of considerable value to require the student to look up in the manufacturer's catalogs the cost of the instruments that were used, to estimate the number of man-hours that were consumed in doing the experiment, and to estimate any additional costs involved in the experiment. This attention to cost will give the student some experience in estimating how long and how much money it takes to do things. It will also make him learn a little about what types of instruments are available commercially and from what companies. It is desirable in connection with the laboratory work that the student learn something about machine tools. The mention of machine tools reminds me of two more habits that can be cultivated while at school. These habits are: conformance to safety rules and the practice of good housekeeping.

I want to digress momentarily and then say a few more words about the laboratory. There is often discussion as to what percent of a college curriculum should be devoted to establishing a cultural background so that the graduate will be well-rounded. My prescription is that the student should take a maximum of mathematics, physics, and chemistry at the expense of the cultural courses. This opinion is based on economics and common sense. The man with the best technical training will get a job more easily and progress faster. It is easier to learn science in school and acquire culture later outside of school than it is to acquire culture in school and to learn science later outside of school. Cultural and business courses are usually more available in night schools than technical courses.

I don't want to give the impression that the scientist shouldn't be prepared to enjoy life, but I believe that the student can be given some background for cultural growth directly through his science. Hobbies can be used as an outlet for a man's desire to build, to tinker, to collect, to classify, and to express himself artistically. Since hobbies are seldom unique, they provide social contacts with other enthusiasts in the same field. A few hobbies can be enjoyed by the physicist's entire family—don't let the sudden appearance of this family startle you. In their quiet ways, physicists are accustomed to accomplishing wonders. These hobbies that I am gradually getting around to mentioning involve techniques and knowledges such that part of the laboratory time could be devoted to establishing one or two of them. I have in mind such things as audio amplifiers, photography, metal or wood working, gem grinding and polishing, mirror making and astronomy, and amateur radio. I am particularly inclined to recommend audio amplifiers, as this hobby generally leads to the collection of phonograph records and a great interest in classical music, jazz, or both. The interest in music is then particularly valuable because the entire family will become interested. I don't know how far your colleges and universities would go in sponsoring another kind of study, but frankly when you get into industry the following kind of training for the industrial physicist is often very valuable—very. I refer to class-room lectures on choice and chance and on the theory of games and to laboratory work in applying the principles to craps and poker. I am sure the faculty would be amazed by the willingness of the students to attend long late evening classes in this course and by their zest in conducting experiments.

Let us talk now about the lectures and class-room work. I want first to take up two courses that the physics student usually writes off as a waste of time. If he has to take them, they will amount to about 10 percent of his total credits—8 semester-hours of physical education and 8 of military. Let us consider military study first. In these years, it appears inevitable that this study will be necessary. It appears probable that the physics graduate will go into either civilian or military work in which he uses his training in physics. So instead of the usual military training, why not give a course in which the physical principles of weapons are studied? This is only applied physics and would supply the physicist with a useful background for war research or specialized service in the armed forces. To give a few examples, the student could be shown how the principles he has learned in his regular classes have been used to develop and study radar, sonar, loran, jets, ram jets, telemetering, gyros, internal and external ballistics, snooperscopes, shaped charges, chain reactions—the list is long. Many branches of mathematics, physics, and chemistry have found practical use in military weapons.

While the suggestion of the study of physics of weapons has an unpleasant aspect, I believe that today it is a practical suggestion. I believe the student and the nation stand to gain by a study of the physics of weapons rather than the conventional military training. The other course, physical education, can also be given a rather practical slant, but this time much more pleasant. When the physicist accepts a job in industry, he will probably find a great deal of interest in sports. There will be teams and leagues engaging in bowling, golf, softball, basketball, tennis, and ping pong. Participation in one or more of these sports has a good deal of value in increasing a man's ability to get along with his fellow workers. Participation also increases the social horizons because of the chance to meet people informally. A study and practice of these games would provide the necessary exercise while in college and provide a training for continued exercise after leaving college. In coeducational schools, it might be possible to teach folk dancing as a substitute for physical education. From what I've seen, there is plenty of sweat in folk dancing, if this is a measure of value. Of course, the true value of folk dancing lies in the fact that in later years it provides exercise and promotes a community atmosphere.

Let us turn now to the discussion of the class-room work. I want to begin by restating my belief that 160 or more semester-hours is desirable. Forty or more hours of this total ought to be devoted to mathematics, 50 or more hours to physics, and 15 to 20 hours to chemistry. In mathematics, I suggest 10 semester-hours of the freshman year should be devoted to algebra, trigonometry, and plane and solid analytical geometry; 10 hours of the sophomore year devoted to differential and integral calculus including double and triple integrals; 16 hours of the junior year spent on four courses, advanced calculus and the theory of equations in the first semester and differential equations and numerical methods in mathematics (Scarborough) in the second semester; 8 hours of the senior year should be allotted to a course by some name such as "Mathematics for Engineers" or "Applied Mathematics" corresponding to texts such as Reddick and Miller or Burrington and Torrance. This program in mathematics will probably draw some disapproval because of the 8 hours of mathematics per semester in the junior year. All I can say is that it is still a compromise with my real hope and belief. I would really like to see 10 semester-hours of mathematics in the first half of the freshman year devoted to algebra, trigonometry, and analytical geometry; and 10 hours of the second semester spent on differential and integral calculus; 5 semester-hours of the sophomore year on advanced calculus and 5 semester-hours on differential equations; mathematics for engineers the junior year (Fourier series, Bessel functions, vector analysis, complex numbers, operational calculus, elliptic integrals, . . . ); theory of equations and numerical methods the senior year. While such a program is very heavy the freshman year, I believe that any student that couldn't handle it wouldn't make a good physicist anyway. This program would be hard on the mathematics department, but you physics teachers ought to regard how nice it would be to teach sophomore physics to students that had finished calculus and to teach advanced undergraduate physics courses to students that had finished advanced calculus and differential equations. Is that 20 credit hours of mathematics the freshman year any more difficult than 10 hours of physics and 10 hours of calculus in the conventional sophomore year? The two programs may be compared by referring to Curriculum I and Curriculum II at the end of the paper.

Let us look at a minimum physics curriculum now. General physics with three or four hours of laboratory would be taken in the sophomore year. The student would take 4 hours of heat and thermodynamics in the first half of the junior year and 4 hours of light and optics the second half. In the senior year he would take 5 hours of mechanics and 5 hours of electricity and magnetism the first semester; and in the second semester he would take 5 hours of modern physics and 5 hours of atomic physics. As I mentioned earlier, the student would spend 4 or 5 afternoons in the laboratory on his own work and helping the faculty.

General chemistry and laboratory would be taught the freshmen year and one semester of physical chemistry with laboratory would be taught the junior year. These basic courses in the sciences should be extended in the junior and senior year by allowing the physics students that get suitable grades to take an elective of three hours each semester.

The rest of the curriculum would be devoted essentially to cultural subjects; but even here I would give many of them a technical flavor. The freshman year would be completed by the following semester hours: two in engineering drawing with most of the emphasis on sketching, six on English grammar and the technical report, three on economics, and three on business administration and research administration. The sophomore year would be completed by a 4-hour survey course of the various branches of modern chemistry and of the chemical industry, 3 hours of geology, 3 hours of mineralogy, and 4 hours of abnormal psychology or sociology to teach the student something about the human mind and human nature. The junior year would include 3 credit-hours of astronomy; and the senior year would include 4 semester-hours of the history of mathematics and physics.

I prefer to make no suggestions about electives, as I believe that they are best handled by allowing a group of students to ask a faculty member to teach a mutually acceptable course.

The physics staff ought to furnish the student a number of noncredit services: a journal club or seminars, instruction as to the standard journals and books in physics and mathematics, and several talks on orientation. Orientation should acquaint the seniors with the names, locations, and purposes of industrial laboratories, government laboratories, and research foundations. The seniors should be informed qualitatively with respect to wage scales, pension plans, group insurance, health insurance, and working rules and conditions. The student should be given hints on how to conduct himself during an interview. He should be taught how to write a letter of application for a job and should be instructed to enclose a transcript of his record. The chairman of the department should keep a file on each student compiled from the opinions of the department members with respect to the student's classroom and laboratory ability, research attitude, initiative, cooperativeness, leadership, and other personal characteristics. An accurate letter of appraisal of a student's college record by his teachers is very important in obtaining the first job.

There are a few specialized jobs in the laboratory for which a student might modify the suggested course. Students interested in becoming administrative assistants to research directors might sacrifice some of the suggested courses in order to take accounting, business, and management courses. Students interested in becoming a technical editor would want to study more English and probably ought to attempt to learn more chemistry and some biology. Students interested in library work would of course want some library science, a reading knowledge of German and French, and some knowledge of biology. Students interested in instrument design should take much more training in engineering drawing and some courses in mechanical engineering such as kinematics of machinery and machine design.

In teaching the physics and mathematics courses, I believe the students get the most value from final examinations consisting of reasonably difficult problems to be done during the last two weeks to a month, using any text or journal for reference. This nicely approximates writing a report to meet a dead-line in an industrial laboratory.

If this proposed curriculum is as successful as I hope in imbuing the student with an interest in physics and with the research attitude, I am afraid the student will decide to go to graduate school. I have one consolation, the faculty that successfully administers a program calling for such close association between faculty and students will find that the teachers are playing the roles of group leaders in industrial laboratories. Those faculty members that find this system agreeable can step right into the industrial laboratory. So perhaps if industry loses the well-trained students to graduate school, industry may console itself by hiring the well-trained faculty.

## Curriculum I

*Mathematics essentially concurrent with physics*

### FRESHMAN

| | Credit Hours | | Credit Hours |
|---|---|---|---|
| General Chemistry | 6 | General Chemistry | 6 |
| Algebra and Trigonometry | 5 | Analytical Geometry | 5 |
| Technical Composition | 3 | Technical Composition | 3 |
| Economics | 3 | Business and Research Admin. | 3 |
| Engineering Drawing | 1 | Sketching | 1 |
| Physical Education | 1 | Physical Education | 1 |
| Military | 1 | Military | 1 |

Two afternoons in chemistry laboratory and one in drawing

### SOPHOMORE

| | | | |
|---|---|---|---|
| Calculus | 5 | Calculus | 5 |
| General physics | 6 | General Physics | 6 |
| Geology | 3 | Mineralogy | 3 |
| Abnormal Psychology | 2 | Abnormal Psychology | 2 |
| Survey of Modern Chemistry | 2 | Survey of Industrial Chemistry | 2 |
| Physical Education | 1 | Physical Education | 1 |
| Military | 1 | Military | 1 |

Two afternoons in general-physics laboratory, other afternoons spent in helping faculty and in study laboratory.

### Curriculum I—*Continued*

#### JUNIOR

| | Credit Hours | | Credit Hours |
|---|---|---|---|
| Theory of Equations | 4 | Differential Equations | 4 |
| Advanced Calculus | 4 | Numerical Methods | 4 |
| Thermodynamics | 4 | Light | 4 |
| Astronomy | 3 | Physical Chemistry and Lab. | 4 |
| Elective | 3 | Elective | 3 |
| Physics Laboratory | 3 | Physics Laboratory | 2 |
| Physical Education | 1 | Physical Education | 1 |
| Military | 1 | Military | 1 |

Afternoons spent in laboratory on own work or helping faculty.

#### SENIOR

| | | | |
|---|---|---|---|
| Mathematics for Engineers | 4 | Mathematics for Engineers | 4 |
| Physical Mechanics | 5 | Modern Physics | 5 |
| Electricity and Magnetism | 5 | Nuclear Physics | 5 |
| History of Physics and Math. | 2 | History of Physics and Math. | 2 |
| Elective | 3 | Elective | 3 |
| Physics Laboratory | 2 | Physics Laboratory | 2 |
| Physical Education | 1 | Physical Education | 1 |
| Military | 1 | Military | 1 |

Afternoons spent in laboratory on own work and helping faculty.

### Curriculum II

*Mathematics essentially one year ahead of physics*

#### FRESHMAN

| | Credit Hours | | Credit Hours |
|---|---|---|---|
| Algebra, Trigonometry, and Analytical Geometry | 10 | Calculus | 10 |
| General Chemistry | 6 | General Chemistry | 6 |
| Abnormal Psychology | 2 | Abnormal Psychology | 2 |
| Physical Education | 1 | Physical Education | 1 |
| Military | 1 | Military | 1 |

#### SOPHOMORE

| | | | |
|---|---|---|---|
| Advanced Calculus | 5 | Differential Equations | 5 |
| General Physics | 6 | General Physics | 6 |
| Engineering Drawing | 1 | Sketching | 1 |
| Geology | 3 | Mineralogy | 3 |
| Technical Composition | 3 | Technical Composition | 3 |
| Physical Education | 1 | Physical Education | 1 |
| Military | 1 | Military | 1 |

#### JUNIOR

| | | | |
|---|---|---|---|
| Mathematics for Engineers | 5 | Mathematics for Engineers | 5 |
| Thermodynamics | 5 | Kinetic Theory | 4 |
| Astronomy | 3 | Physical Chemistry and Lab. | 4 |
| Geometrical Optics | 2 | Physical Optics | 3 |
| Physics Laboratory | 3 | Physics Laboratory | 2 |
| Physical Education | 1 | Physical Education | 1 |
| Military | 1 | Military | 1 |
| Elective | 3 | Elective | 3 |

#### SENIOR

| | | | |
|---|---|---|---|
| Theory of Equations | 4 | Numerical Methods | 4 |
| Physical Mechanics | 5 | Modern Physics | 5 |
| Electricity and Magnetism | 5 | Nuclear Physics | 5 |
| History of Physics and Math. | 2 | History of Physics and Math. | 2 |
| Physics Laboratory | 2 | Physics Laboratory | 2 |
| Physical Education | 1 | Physical Education | 1 |
| Military | 1 | Military | 1 |
| Elective | 3 | Elective | 3 |