HOW TO STUDY PHYSICS

By SEVILLE CHAPMAN

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INTRODUCTION: **For the** purpose of this discussion, it is assumed **that you are enrolled in a first-year college course and that in your complete four-year course you will spend about 5000 hours in class and in study. Of this time 300 to 500 hours will be spent studying physics. Surely you stand gain much if you spend one hour— about the time required to read this** book — considering *how* **to study physics.**

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PREFACE

Although the main objective of education is to train people to think clearly about problems in life, apparently most college students do not give adequate thought to the question of finding the best methods for carrying on their chief activity-studying. It is obvious that musicians, athletes, or even good bridge players develop techniques appropriate’ to their activities; and, just as obviously, a proper procedure is necessary for effective study. The purpose of this book is to call to the attention of beginning physics. students methods for effectively studying physics.

A proper mental attitude toward the material to be studied is the primary requirement. You must earnestly want to learn. Unless you are firmly convinced that you want to do a good job in your physics work, this manual will do little good. Unfortunately, resolutions alone do not help. Learning physics takes work. This guide points out how you may work effectively but it cannot tell you of short cuts because there are none.

Every suggestion included here has been of use to somebody-a fact verified by student comment on an earlier version of this book. A few of the ideas are mutually inconsistent since not all students study most effectively in the same way. Try out the various schemes and then develop a system of study that is suited to you.

A student who read a rough draft of this material said that anyone who followed all the suggestions in it would be sure to get an-A in physics but would fail every other course from having spent all of his time on physics! Certainly it is up to you to decide what part of your time you should devote to physics. It is a fact that you can learn to use that time efficiently.

There are several full-size books on how to study, but most of them tend to be rather general.* In this guide an attempt has been made to give numerous specific examples and a summary of the main ideas has also, been included. Suggestions and criticisms of *How to Study Physics,* from ‘both teachers and students, will be welcomed by the author.

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Stanford University, California
August 1946

In this revised edition I have taken the opportunity to incorporate additional ideas and suggestions based on three years’ use of the first edition.

SEVILLE CHAPMAN

Buffalo 21, New York
September 1949

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* **Four very good short publications are: Kornhauser.** How to *Study* (University **of Chicago Press) ; Swain,** *How to* **Study (McGraw-Hill) ; C. Gilbert Wrenn and Robert P. Larsen, Studying** *Effectively* **(Stanford University Press) ; Dadourian,** *How to Stydy,* How *to Solve.* **(Addison-Wesley).**

CHAPTER 1

WHY GO TO COLLEGE?

By taxation, the government provides free and compulsory education through high school for nearly all boys and girls. A college or university education, however, is a privilege accorded comparatively few. It may be surprising to realize what the expense of a four-year course is. The cost of tuition, books, food, lodging, clothes, laundry, transportation from home, entertainment, etc., added to the university's contribution-that is, one student's share of university income from gifts, endowment, and perhaps taxes-gives a total of roughly $8000 to $10,000.[1] Allowing in addition a reasonable amount, say $6000, to represent what a high school graduate could have earned by working full time instead of going to college, the final total for the cost of a college education is impressive.

While the expense of an education is small compared to the increase in an individual's total earning capacity over a working period of forty years, it is reasonable to ask: What aspects of a college education make it a worthwhile investment? The answer certainly is not simple but every student and every university official should formulate ideas on the question. We have space here for only the briefest discussion.

Experience has shown that people whose training has developed their ability to think clearly and whose studies in several different fields, including physical or biological sciences, humanities, and social sciences, have also given them a liberal, tolerant, and understanding attitude toward life, are more able to make a significant contribution to human welfare than those without that training. If you prefer less sophisticated language, you may say that people with the qualifications just mentioned make the best citizens. Furthermore, because of the breadth of their background, such people are able to lead full and rich lives and to enjoy many kinds of things. In a materialistic sense, such people are likely to be capable and hence they deserve to hold responsible (and well-paid) positions.

The professions require not only specific technical training but also tolerance and the ability to think clearly. A college or university is an ideal place to obtain such training. In this connection, note what the research director of a large industrial company says about the qualities that make for success in industrial research: "They are, in order of importance [sic]: character, aptitude for research, attitude towards work, and knowledge. . . . Last and

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[1] Fortunately, the additional out-of-pocket expense to a student who goes to college over what he would spend otherwise is only a fraction of this figure. Food, lodging, and clothes, for instance, cost money, even-though at home they a apparently provided "free" by one's parents. It is not intended to imply that the figures given are minimum figures. At many universities the tuition paid by the student is more than matched by the amount contributed by the university.

least of these four qualifications comes knowledge but it is last only because of the higher valuation of the other three."[1]

Good character is made up of many worthy qualities, including self-discipline, reliability, honesty, tolerance, and the ability to get along with other people. It should be a prime objective of the college student to develop these characteristics. There are many opportunities to do so: for example, studying even when there is no immediate prospect of an exam; doing a clean, thorough job in the lab without, for instance, reading the scale in such a way as to favor a result in agreement with the "true" or handbook value; and learning to get along with fellow students in a pleasant, friendly, cooperative way.

As a check on his aptitude, a serious-minded student will take courses in several different departments to find out in what field he can do the best work. This is quite distinct from finding out where he can get the best grades!

According to the chief engineer of a large manufacturing organization,[2] the qualities necessary for success in engineering or scientific work in industry are *social adaptability* (ability to work cooperatively and cheerfully in a group, even under trying conditions), *expression* (ability to write and speak the English language effectively), *engineering* integrity (honesty, reliability, and responsibility in presentation of results), and *perseverance.* It is assumed that the professional man is technically competent but without the qualities mentioned his chances for personal success are small. While you are preparing yourself for professional life, then, spend considerable effort in developing these desirable characteristics. Numerous cases can be cited where an otherwise good man has failed because he could not get along with the rest of the men in his group (he may have been too cocky, he may have wasted the time of his associates, or he may have been late to work regularly, etc.). Again, he may have had good ideas but was unable to present them in a way that could help the boss to put them across at a meeting of the Board of Directors.

While technological advances bring new developments, methods of procedure often remain fundamentally the same. For this reason, a student should put special emphasis on learning how to attack problems. He must learn how to study on his own, not only to keep abreast of new developments (think how radio has developed in the last twenty years![3]) but to become an expert in his own special field. A student may get some specialized training

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[1] A. W. Hull of General Electric Company, Science, February 16, 1945.

[2] Robert J. Short of Procter and Gamble Co., Cincinnati, private discussion.

[3] In 1929, radar, television, negative feedback, and electrolytic capacitors were unknown. The commonplace superheterodyne circuit was virtually unheard of, pentodes had just been introduced in the U.S.A., and radios with built-in "battery eliminators" that operated on AC power from light sockets had just been put on the market.

in his major field in college but even there most of the work is fairly general. To be able to carry over general knowledge to a specialized field, the student must make a definite effort to learn how to apply what he learns. He must realize that more knowledge than he can ever hope amass may be bought for a few hundred dollars in the form of an encyclopedia. If a man expects to earn much, he must be more useful to his employer than the encyclopedia would be. The student must never lose sight of the principle that although the facts are important, even more important is knowing how to use them. Remember this when you study.

With these general ideas concerning a college education in mind, we may return to the subject of physics.

CHAPTER 2

WHY STUDY PHYSICS?

Physics is the basic physical science. It deals with such things as mechanics (force, energy, motion), sound, heat, light, electricity, and atomic structure. In college physics we are concerned not so much with what is so but rather with ***why*** it is so. In fact, physics has been described as the science of "why things work." It is studied mainly by three groups: (1) premedical students; (2) students of engineering, physics, and other sciences; and (3) those who study it for its cultural value.

The premedical student. Although doctors of medicine and faculties of medical schools and science departments recognize the importance of physics in medicine, the premedical student, who at that early stage of his career knows neither physics nor medicine, often does not. A 1744-page book that discusses about three hundred applications of physics to medicine [1] covers such topics as: energy as related to metabolic rate; blacking out of airplane pilots due to centripetal acceleration in pulling out of power dives; oxygen requirements at high altitudes, favorable working conditions from the standpoint of illumination, temperature, and humidity; mechanism of hearing; problems of physiological optics and vision; mechanism of nerve conduction (which is an electrolytic electronic process): capillarity; osmosis; contraction of a gold inlay as it cools after being cast but before it is put into a tooth; centrifuges; metal locators in surgery; high-frequency induction and diathermy; x-rays; physiological effects of radiations, including those from radium or from an atomic bomb; the use of radioactive tracers to follow the chemistry of metabolism; and the physical principles on which various types of medical equipment are based. All of these are strictly in the domain of physics, and there are innumerable less spectacular but nevertheless important applications of physics to medicine.

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[1] ***Medical Physics,*** edited by 0. Glasser, Yearbook Publishers, Inc., Chicago, 1944.

For several years I offered to pay fifty cents to any of my premedical students who could find ten consecutive pages in the physics text in which nothing applicable to medicine could be found! The student was to be the judge but I was permitted to think up and explain applications. Although many students accepted the challenge, we never failed to find something relevant. For a while I offered ten cents for five consecutive pages. This cost me a few dimes.

Although the applications of physics to science and engineering are rather direct, premedical students often have the impression that applications to medicine are less direct. For this reason, they are urged to be constantly on the alert to recognize the importance of physics in medicine.

The engineer. Engineers and scientists ordinarily recognize the importance of basic physical principles in their work, so we need not elaborate on that matter. All professional students, however, should be impressed with the fact that their technical knowledge rapidly goes out of date, not because it is wrong but because new and better methods and techniques are developed. It has been estimated that the useful "half-life" of technical knowledge is about ten years. In other words, about half the knowledge ten years old is such common knowledge among professional men that it isn't worth much to an employer.[1] There is not enough time while you are in college for you to learn all of the facts you might conceivably need. Over a working life of perhaps forty years, you must learn a great deal more after you leave college than before. Therefore, as an undergraduate, be sure to learn how to learn by yourself.

One of the best arguments against taking a heavy program of studies is that nearly all of your learning probably must be rather superficial. Depth of understanding and intensive critical thinking are much more important in the long run than mere knowledge but these are the things you are likely to overlook if you have too full a program.

In your professional work you will find that there are two useful categories of knowledge: mastery of the subject and knowledge of its existence. The assumption is that if you know of the existence of a field of knowledge you

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[1] It is an oversimplification to imply that the half-life of all technical knowledge the same. Certainly half the technological information in engineering and applied science is out of date in less than ten years. Conversely, basic fundamental scientific knowledge may remain as true as it ever was for several decades or more, even though extensions to this knowledge may be added at intervals of perhaps ten years. While the technical knowledge a student gains in school won't support him for the rest of his life, he must not suppose that it isn't worth learning. For example, few employers will hire you to do high school algebra, but unless you have learned algebra, you cannot learn freshman physics and other subjects which are basic to many technical fields.

If you want a real shock, compare current articles in the *Review of Scientific Instruments* or the *Proceedings of the Institute of Radio Engineers* with those of ten or twenty years ago.

can master it by study. Anything less than full mastery of a subject is unlikely to justify payment of your salary.

The physicist. For the scientist specializing in physics, a few additional comments are in order. A person who knows physics may be expected to know the following:

1. The facts of physics.
2. The principles of physics.
3. Methods of attacking problems in physics (principally analytical methods).
4. Techniques for attacking problems in physics (principally laboratory techniques).
5. Procedures for applying the preceding items to new problems.

As it is evident that anyone can find all the facts of physics merely by going to the public library, a would-be physicist is hardly equipped if he knows only facts. If he knows principles, he is somewhat better off but not likely to be worth much to an employer, who can learn the principles himself by a little study. The methods and techniques are about equally important and can be acquired only by practice on typical problems. The physicist who has mastered the first four items is not really a useful man, however, unless he can use this mastery in application to new problems.

Consequently, it is clear that the real purpose of taking first-year physics is not to “get” facts and principles, although these are essential, but to train one’s thinking through practice on simple problems so that later on more difficult problems and situations can be approached effectively. For this reason discussion questions, homework problems, and practice on similar problems are very important aspects of first-year physics for the professional man.

The student who goes beyond first-year physics is likely to stay on the right track if he constantly asks himself the following questions about every new fact or theory:

1. What is the fact precisely? (Don’t be vague.)
2. Why is it so? (Very important.)
3. How does it tie in with other ideas in physics?
4. What is a typical problem concerning it?
5. Do I merely understand it, or do I know what to do with it? (Better find out by trying.)
6. What was its importance when it was discovered and how did its discovery affect the development of physics?
7. In relation to what is it important now? Why?

Having asked these questions, the student should formulate precise answers. Probably it will be more difficult than was anticipated but it is a very valuable phase of professional training.

The general student. Culture has been defined as the enlightenment and refinement of taste and mind by intellectual and aesthetic training. Anyone who is interested in the cultural aspects of physics and has read about such things as radar, jet propulsion, electronic systems for blind landing of aircraft, and the atomic bomb, cannot fail to see the influence of physics on war. Whether the men who developed these things called themselves physicists or engineers, they based their developments on principles of physics. Peacetime applications of physics [1] include such spectacular and practical things as the electron microscope (the useful magnification of which is 100 times more than that of a light microscope), the x-ray microscope, television, atomic power, better sources of illumination, better materials for housing, increased farm yields, cloud-seeding, as well as such "useless" problems of scientific research as finding out where the electricity in thunderclouds comes from.[2]

There are people interested in studying physics to learn what makes an electric motor run, or how a phonograph works, or how large an atom of oxygen is, as well as how we know these things. They are interested in finding out about the revolutionary experiments or fundamental theories of such great physicists as Newton, Faraday, and Einstein, and in studying the lives of such men. Many people want to know what the scientific method really is (when separated from tooth-paste advertisements or soap operas) and how its application and use have increased our understanding of nature.*

The person who proposes to discuss intelligently the most important problem of our age-how to avoid atomic war- should have some understanding

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[1] A very interesting authoritative book on peacetime applications of physics, written in a popular style, is: Harrison, Atoms (Morrow). An exciting book: Crowther and Whiddington, *Science* in *War* (The Philosophical Library), discusses the British scientific effort in World War II.

*This problem has been studied ever since Franklin miraculously survived his famous experiment with the kite in 1752. Little progress was made until 1937 but probably by 1951 the answer will be established. .

[3] In order that there be no misunderstanding, the essence of the scientific method is this: Through observation the facts concerning a phenomenon are ascertained, from these *a* working hypothesis is formed. and from this hypothesis deductions are made concerning probable consequences resulting from varying the conditions associated with the problem. Next, experiments are carried out to check whether the expected results actually are obtained and to see where the hypothesis needs revision or extension. The results of experiments are then classified and systematized in *a* way that leads to an understanding of both the phenomenon considered and of related subjects.

The history of science shows that scientific progress often has been made in a way not so clean-cut as is implied by the foregoing definition. In most scientific advances, however, several elements of the scientific method play a dominant role.

For an appreciation of the operation of the scientific method, one must study examples of its application. Since several chapters in a book often are required for a single instance, however, clearly we must by-pass the matter here.

of the physical science basic to the problem, in addition to an awareness of the political and social sides of the question.’ This does not imply that only scientists can discuss problems of atomic energy, but a person who discusses nuclear physics should have some notion, for instance, of what is meant by “half-life” whether he learns about it in detail in a physics course, or superficially from a dictionary.

Granting, then, that there are reasons for studying physics, we may return to our problem of how to study it effectively. In physics, perhaps more than in any other subject, it is necessary to develop an ability to analyze problems, to reason logically, and to discriminate between important and irrelevant material. Consequently, efforts to memorize physics are practically worthless. For most students physics involves many new concepts. To master the material takes work, and that takes time. Although you must decide how much time you can devote to physics, we hope you will learn enough from this discussion to develop a good system of studying. You must realize that a university cannot ***educate*** you. **You** must do that for yourself, although a college or university is the place where it is likely that you can study most efficiently.

Probably you have heard many of these ideas before-some of them apply to any course, some are specifically related to physics. Although not all the ideas will appeal to a given individual, any suggestions appearing here have been of value to some student. Try them out. They may help you.

CHAPTER 3

GENERAL STUDY SUGGESTIONS

As mentioned in the preface (which you should read), the most important requirement for effective study is the proper mental attitude and a driving desire to learn. Picture to yourself as vividly as possible the consequences of your failure to learn-flunking out, opinions of family and friends, lowered income throughout life because of incompetence. Then think of what may happen if you do particularly well-respect from family and friends, possible scholarships, offers of jobs leading to important and responsible positions.

Get interested in the subject by learning something about it, tying it in with other courses, talking it over with fellow students. Be assured that if the course is required as part of *a* curriculum of professional training, the **course** is necessary. Try to discover why.

Co to class; be alert. Make a serious effort to stay right with the lecture. Adopt a cooperative and receptive mental attitude rather than a belligerent

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[1] As a taking-off point, read Norman Cousins, ***Is Obsolete*** **(Viking Press).**

one. Perhaps you will develop more enthusiasm for the course if you sit in one of the front rows, where you will be forced to pay attention.

Find yourself a quiet place to study, with plenty of light and desk space that is free from distractions, including radios and pictures of girl friends or boy friends. (The desk is for work; put the pictures on the bureau.) Study conscientiously, keep at it; sit with your back to the door and reject interruptions. The time you save will enable you to enjoy occasional bull sessions without worrying because you aren't studying.

Budget your time. Make out a study schedule and stick to it for at least two weeks. Get adequate sleep, regular moderate exercise, and some recreation, but leave two full honest hours weekly per unit for study.

There are 168 hours a week. Of these 168 hours you will be asleep for about 60, dressing and eating for about 20. If you take Saturday afternoon off for a hike, consider Sunday morning and afternoon as time off from studying, and have two four-hour dates a week, you have about 68 hours a week for work. If you are in class and laboratory for 20 hours, you still have 48 hours for study. It seems like a tremendous amount of time, doesn't it&especially considering that you've taken off half of Saturday and most of Sunday! Just where does all the time go? A great deal of it is lost in ten- and twenty-minute idle discussions, time wasted during the twenty minutes while you wait before a class after you've needlessly spent another twenty minutes walking to the post office and back for a stamp you could have picked up just as easily on your way back from lunch, and so on. It is up to you whether you want to make good use of these numerous ten-, twenty-, or thirty-minute intervals. I'm not urging that you never take a minute off to enjoy life, but there is certainly little danger that you will use your time too efficiently.

You learn more physics by studying it for an hour a day than by studying it for ten hours on a week end, and it takes less time. Furthermore, you will get more from the middle-of-the-week classes. Don't get behind., Keep up with your work. It's much easier to learn your lessons from day to day than it is to half-learn them all at once on the day before the exam. If the prospect of an assignment is forbidding, begin on it; you may get more done than you expected.

Plan to study physics as soon after class as possible, while you still remember things that probably will be forgotten twenty-four hours later. You may find it a good idea to study physics when your mind is fresh, before you work on subjects requiring less concentration. During a study session of several consecutive hours, an occasional relaxation period of five minutes often is a help. Sometimes it is better to study one subject for an hour and then shift to another subject for an hour, rather than to study one course continuously. Sometimes it is not better. Experiment to find out which method suits you.

When you study, really study. Much of your time may be lost in slipshod thinking, daydreaming, following blind alleys of thought, and just plain loafing. Probably you have experienced times when your process of learning was very easy and rapid. Try to figure out how this happened and then try to duplicate the occurrence. (Sometimes the prospect of an examination provides a good incentive; can you provide yourself with an artificial incentive?) While you are studying, keep personal worries off your mind. If you have a personal problem, get some good advice, think it over, then make your decision and stick to it.

You understand a lecture better if you have some notion ahead of time as to its subject matter. For this reason, spending the five or ten minutes between classes reading the main paragraph headings gives you a better return for the time spent in the lecture than if you spend the time before class reading the daily paper. (By all means, read the newspaper later.) Experiment to find out what part of your study time for a given assignment should be spent before lecture and what part after lecture, in order to give you the best return. Probably you will spend from ten to forty percent of your time studying before lecture.

Perspective is one of the chief aims of education. To see the parts in relation to the whole is much more important than to know all the details. Perspective provides a scaffolding into which the details may be fitted readily. When you study an assignment, first go over it rapidly, taking in only the high spots, to find out what it is about. Then go over it more carefully. Study to understand the material, not just to read an assignment. Go slowly. Physics can't be read like a novel or even like a history lesson. (A physics assignment is often only a half-dozen pages rather than a half-dozen chapters.) Try to think of applications of the material as you read it and of problems to which the formulas apply. Try to correlate the material with your previous knowledge and with other courses. Material in the text is not necessarily 100 percent correct. Textbook authors are human and sometimes are misinformed, just as other people are. All books have some typographical errors, although usually not very many. Be critical. Do not believe what you read unless it makes sense to you.[1]

When you finish a paragraph, think out its main idea. Say it out loud or write it down. When you finish the page, ask yourself what was on the page. It may have seemed simple when the author wrote it, but can you put it in your own words? You may have to do so in an exam.

When you finish the assignment, plan what question you would ask if you were making up an examination. Close the book and deliver yourself a three-minute formal lecture on the lesson or, if you feel silly talking to

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[1] There are over three dozen first-year physics texts on the market; clearly, some must be better than others. First printings of first editions are more likely to have typographical errors than *later* printings. Chances are, however, that *your text is* at least 99 percent accurate.

yourself, write out a fifteen-minute essay on the subject. Probably you will discover that you didn't know the material as well as you thought you did -better to find it out while studying than during an exam. The importance of frequent self-recitation cannot be overemphasized. Review the day's work in the evening, the week's work on Friday, and the whole course once a month.

Psychologists say that if you overlearn material (i.e., study it somewhat longer than is necessary just to understand it), you will remember it later with comparative ease. Furthermore, overlearning and review show you where you are weak and give you a chance to clear up the weak points.

Physics can be learned by seeing, hearing, reading, writing, and talking. Do not overlook the chance of talking things over with your friends. An excellent study procedure is for two students to study a week's material together and then give each other an oral exam on it. (Let A ask B a question. If B answers, it is a point for B; if B cannot answer but A can, then it is a point for A. The one with the most points can call the tune but perhaps the loser will want to study a little more.) Trying to explain something to a critical friend will show if you really know it. Don't delude yourself by saying, "I know it but I can't explain it," for if you do understand it, you can explain it. As a matter of fact, a good test of your understanding is furnished by the ease with which you can explain something. When you understand it well enough, you can explain it easily.

As you are outlining the course, revising your lecture notes, reading the text, or doing problems, occasionally you will come upon things you simply cannot understand. Don't say: "I can't get it at all." Rather, try to analyze your difficulty so that you can state specifically what you don't understand. Make a list of these difficult topics and ask the instructor about them at the next class. Don't hesitate to ask, either. Probably there are others who will be glad to know the answers too. Contrary to popular student impression, the instructor probably will be pleased that you ask about the course.

If you are having real difficulty with a course, spend an hour writing an essay on what you think the course is about, what its significance is, how it should be studied, why you are taking the course (or if it is a required course, why you think it is required), why you think you are having difficulty, etc. Then show your instructor the essay but ask him to count ten before he says anything. Very likely your essay will be of value to him in diagnosing your difficulty and prescribing a remedy. Writing the essay certainly will help you to profit from your instructor's diagnosis and remarks.

If the course seems to be too deep for you, try going to the main library or to the physics library, where there are some books simpler and easier to understand than your text. The instructor will be able to suggest several books of this type. But don't neglect your own book. It has an index and probably several appendices. They may help. Use your own book; don't just read it. Underline important points, put your own comments in the margin, etc. (If it costs $500 to $1000 for you to take a physics course, it is hardly worth while to worry about the resale value of a $5 text.)

Sometimes a student can learn more in an hour from a good tutor than he could in a whole evening by himself. Your instructor will know of some good tutors. Or the material may not be so difficult as you think. Don't expect too much. A thing may have a terrifying name (such as a prolate spheroid) but may actually represent something simple (a football). The sentence following an obscure one may clear up the trouble.

If your physics suffers because it takes you too long to read your history lesson, speak to your adviser, who will be able to suggest corrective procedures. Most people can greatly increase their reading speed and degree of understanding if they go about it in, the proper way.[1]

Pay special attention to definitions. Often a common word has a special technical meaning; be sure you understand it. Although in common parlance such terms as force, energy, work, and power often are used synonymously, all of them have distinct, different meanings in physics. Learn these meanings. For nontechnical words about which you are in doubt, use a dictionary. All students should own and use a good dictionary. Definitions are important not because they may be asked for in an examination but because a clear and concise formulation of the meaning of a defined quantity is essential to an understanding of it. Incidentally, do not merely mimic the words in the text but study for a grasp of the subject so that you can give the definition in your own words too.

Take an active part in recitation work. Ask questions. Try to anticipate what will come next. Such an alert mental attitude will help to make the material sink in.

In technical courses, undoubtedly you will have numerical problems to work from time to time. In addition to quantitative problems, however, discussion questions are very useful learning aids. If your text has questions of this type, be sure to go over them. If, after thinking hard, you cannot get the answers, ask your instructor for some hints. If your book does not have this type of question, you should either get a book that does or else ask enough questions in your recitation section so that you get the benefit of this kind of mental exercise.

CHAPTER 4

HOW TO MAKE NOTES

You do not go to class to get a good set of notes. It is hardly worth spending several hours a week for a whole term to get information that can be

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[1] A good discussion is to be found in C. Gilbert Wrenn and Luella Cole: ***to Read Rapidly and Well*** (Stanford University Press), 15 cents.

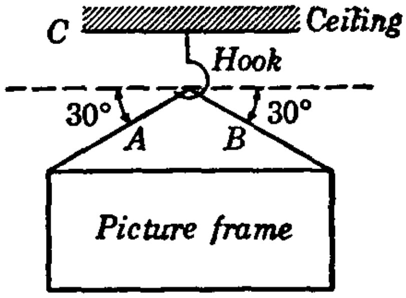
bought for a few dollars in the form of a good reference book. The prime reason for your going to class is to learn something. In taking notes, keep this thought in mind. Do not overemphasize the notes to the extent that you neither see nor hear the lecture.

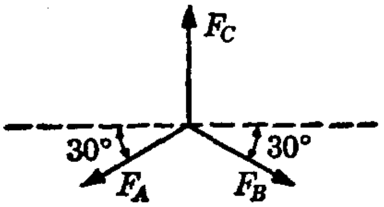
Taking good notes in a physics lecture is quite different from taking good notes in, *say,* a history class. One of the main differences is that most history lectures are largely the presentation of factual historical material, whereas most physics lectures are primarily the explanation of a comparatively small number of principles. These usually are illustrated by examples and by demonstrations. Outline form is good in history because it may be impossible to write down all the facts as rapidly as they are given to you, but if you use outline form in physics, at the end of a lecture you have only a portion of *a* page of notes, and probably they are not very illuminating. Outline form is unsuited to physics because in an outline you will not get down enough of the explanation to help you much afterwards. For explanation put down complete sentences (subject, predicate, object, etc.) but abbreviate long words. If you expect to be able to "decode" your notes later, do not omit important words whether they be verbs or prepositions. In physics it makes a lot of difference whether a force is exerted *by* one object *on* another, or vice versa. To illustrate, on the subject of the ballistic pendulum the professor explains: "The kinetic energy of the bob at the bottom of its swing is equal to its potential energy at the top of its swing. Therefore from the height to which the bob swings, one can calculate what its velocity was at the bottom of the swing, in the following way. . . ." The good note-taker writes: "KE of bob at bottom of swing = PE at top. ∴ from height bob swings can calc vel at bottom thus . . ."

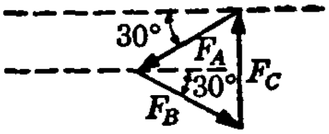
Diagrams or formulas are put on the board. Actually they are the least important things to put in your notes, since they can be found afterwards in the text, The main thing to record is the explanation that accompanies them. (You will understand the explanations better if you spend some of your time studying before class.) If a diagram is labeled on the board, be sure to put down *all* of the labels. Three arrows coming from *a* point *may* mean nothing in your notes but, if they are accompanied by several sentences of explanation and by appropriate labels on the diagram, they may show the complete story of the forces acting on some point of a complicated structure such as a cantilever bridge, or they may show something simpler, thus:

The professor says (and draws the diagrams) :

"A picture frame hangs from a hook in the ceiling C by two strings A *and* B, each making an angle of 30" with the horizontal. There are three forces acting on the hook, the upward pull F_C exerted *by* the ceiling, and the two downward forces F_A and F_B due to tensions in the strings A and B. Since the hook is at rest, it must be in equilibrium, and we may apply the force-polygon method to determine the relationships among the various forces. . . ."







YOU copy the diagrams and write:

"Picture hangs from hook. Forces acting ***on hook*** are upward pull $\mathbf{F}_C$ exerted by ceiling and downward pulls $\mathbf{F}_A$ and $\mathbf{F}_B$ exerted by strings. At rest ∴ equilibrium ∴ polygon method. . . ."

Probably the professor will show how F,, F,, and $\mathbf{F}_C$ are related and then go on to discuss the forces acting on the ceiling or the forces acting on the picture frame, ***none*** of which has been mentioned yet.

One of the most deflating experiences a professor can have is to examine the notes taken by students in his classes. In the example above, the professor probably puts nothing on the board except the diagrams (writing many sentences on a blackboard makes a dull lecture) and some students' notes consist of nothing but the diagrams. The important ideas, however, are in the application of the principles to the specific problem represented by the diagrams. In other words, the explanation that accompanies the diagram is the most important part of the discussion and the student-if he takes any notes at all-should put the explanation in his notes. If the instructor goes ***too*** fast, ask ***him a*** question to slow him down; for example, "Would you state that conclusion again, please?"

For most students, two to four pages of notes is a reasonable amount for one physics lecture. Do not ignore the demonstrations. Draw a diagram of the experimental setup and tell what principles are illustrated. If you don't know what the demonstration is supposed to demonstrate, ask the instructor.

If the lecturer follows a text rather closely, study the book before class, take it to class, keep it open, and make notes in the margin or on a separate sheet of paper.

Some students find it better to take no notes at all during lecture (or to take very sketchy ones) and to spend the full time concentrating on what is being said without being distracted by frantically trying to write everything down. Immediately after lecture, they write out a complete set of notes (with detailed explanations), using the text (and their sketchy notes, if any) to aid them in remembering what was discussed.

Sometimes students pair off, one of them concentrating on getting good notes (making a carbon copy) and the other concentrating on digesting the explanation. After class they discuss the lesson together. While this procedure has something to recommend it (especially in advanced courses), it puts too much emphasis on the importance of notes.

Psychologists say that the physical operation of writing a set of notes contributes something to the learning process, in addition to the fact that the material being written almost of necessity has to have made some mental impression. Therefore you must have at least one set of notes in your own handwriting. This set ought to serve the double purpose of being a learning aid physically, as well as helping in review. Consequently, whether or not you take notes in lecture, when the lecture is over your note work has only begun. While the material is still fresh in your mind (preferably within a few hours after lecture), go over your notes and smooth them out. Add to the explanations. Compare the lecture with the text and fill in the parts you missed. If the material still seems obscure, consult another text in the library. Pick out the important statements in the notes and the important formulas; then underline them with red pencil to facilitate your review for exams. It is likely that in a whole term's work there will be fewer than twenty important formulas you must know. But remember it is the method of applying them that really counts.

CHAPTER 5

HOW TO WORK PROBLEMS

One of the very effective methods of studying physics is to work problems. Qualitative knowledge (e.g., if a force is applied to a steel cable, it will stretch a little) is but slightly useful; you really haven't learned much until you know quantitatively that if a force of 1000 pounds is applied to a steel cable one-eighth of an inch in diameter and 100 feet long, it will stretch 3.26 inches. You may have in mind merely a general idea of some point and hence delude yourself into thinking you understand it. Only when you can do a quantitative problem without hesitation, however, and work directly to the correct solution, is it certain that you understand the subject. Because problems illustrate basic ideas, it is probable that you will have a set of half a dozen problems weekly. This is the absolute minimum number of problems you can do and still get by. Working two or three times this number will help greatly. If your text does not have enough problems, get another text or one of the many books of physics problems.[1, 2] If you start your weekly problem set early, you may have opportunity to ask questions in class about parts you do not understand.

In working problems, it is very important to do the work in an orderly fashion:

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[1] A useful book is: Schaum, Outline of with several hundred problems solved in detail with explanations, Schaum Publishing Company, $1.25.

[2] A very good booklet on mathematics problems is: Dadourian, *How to Study, How to Solve*, Addison-Wesley, *50* cents.

1. Read the problem carefully twice.
2. Reduce the problem to its essentials.
3. Draw and label a suitable diagram.
4. List the given quantities and the required quantities.
5. Put down some relevant principles (usually in mathematical form).
6. Analyze the problem, think about it, correlate the various factors, grind out some useful ideas.’
7. Solve algebraically as much of the problem as possible (very important, especially in complex problems) .
8. Complete the numerical solution. (Do not do lengthy arithmetic “longhand”; use a slide rule.)
9. Check the problem.
10. Check the units.
11. Look critically at the answer. Does it seem like a reasonable answer? Develop your technical judgment by making a decision.’
12. Look up the answer in the answer book.
13. If your answer is correct, review the problem; otherwise correct the problem and then review it. In either case, be sure to review it.

Perhaps not every step is needed in every problem, but most of the steps are useful in the majority of the problems you will have to work. An illustrative example is given at the end of this chapter.,

There is a definite (although not complete) correlation between orderly work and orderly thinking. Do your problems as neatly as you can the first time, preferably in ink. Being neat has a tendency to stimulate clear thinking. The same idea applies to lecture notes.

After reaching the answer to a problem, you should go over the problem, work it backward (i.e., with the answer as a known quantity and one of the given quantities as the unknown), make modifications in the problem, and do it again. For instance, the problem may be: “A stone falls from rest from a tower 144 feet high; neglecting air friction, calculate the time for the stone to reach the bottom.” The answer is 3 seconds. Working the problem backward involves solving this problem: “Calculate the height to which a baseball goes if it takes three seconds to drop to the ground from the

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[1] Some students find it useful to close their eyes and meditate on the problem, undistracted by even their own notes.

[2] For instance, the problem may be: A man of given weight runs up a flight of stairs in a certain time; what horsepower does he develop in lifting his weight against the force of gravity? If your answer comes out 30 horsepower, it is obvious that you have made a mistake, for no man can develop 30 horsepower even for a short time. Probably you determined the number of foot pounds of work done by the man per minute and then divided by 550 foot pounds per per horsepower, thereby getting a wholly unreasonable answer, sixty times too large. Learn to estimate answers approximately; it helps in checking the reasonableness of your work.

highest point in its flight.” A variation of the problem is: “A first-aid kit dropped to a stranded mountaineer from a helicopter 144 feet above the ground is falling with what speed just before it strikes the earth?”

Under no circumstances can you regard your problem study as being sufficient if you merely get the right answer and then stop. The instructors and the readers [1] already know the right answer anyway. Doing the problem is worth while only insofar as it gives you training in thinking. You get a poor return for the time spent if you stop when you have explored only a single route to the answer. In typical cases, by spending twenty or thirty percent more time, you can study a few variations of the problem and for this slight extra time can learn two or three times as ‘much. If your time is very short, instead of doing all the problems and then stopping, do three out of four, but review the three. During the review, light may dawn so that you can do the fourth problem in not much extra time. If you doubt that this extra study pays big dividends, just try it. I know it takes extra time in the short run, but there is no question about its paying off in the long run.

After two or three students have worked a set of problems independently, it is entirely in order, and quite worth while, for them to have a review session with each other concerning the problems.

If you really understand the principles involved in problems, you will find that there are perhaps only half a dozen fundamental ideas presented in a whole week’s stint. Each principle may have a dozen variations. It is much wiser to go after the main idea than to try to memorize all the variations without correlating them to the main principle. For this reason, when you start working a problem don’t merely hunt in the text for some formula that may seem to have the right kinds of symbols in it. Your procedure should be to analyze the problem to see what physical principles are involved and then to work on that basis. The formulas are merely shorthand representations for the principles. Analyzing from principles rather than hunting for formulas may take a bit longer (especially the first time you try it) but you will learn more.

For example, the general problem of calculating potential energy, work, kinetic energy, etc., and of correlating these quantities with the distances the bodies move and with their velocities, etc., has so many variations that no student can hope to memorize them all. Yet dozens of variations of this general problem can be handled with the aid of a few physical principles which can be expressed mathematically in one or two square inches of notes. For this case these simple relations are: $PE = mgh$, $KE = mv^2/2 + I\omega^2/2$, work $= Fs\cos\theta$, and a statement of the principle of conservation of energy.

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[1] A reader is one of those underpaid essential persons (usually a senior or graduate student) who reads and grades a portion of the hundreds of papers turned in every week by the students in a large class.

Be sure you know what the symbols stand for, because formulas without definitions mean nothing. (The student who hasn't reached this point in his physics *course* may wonder what the symbols mean, but he will find out in due time.) For a whole week's work you may need to memorize no more than the set of formulas just mentioned but the rest of the weeks work is to learn to apply them properly. Actually you may easily apply the right formula in the wrong way if you do not understand the fundamentals. Rely on your memory only for the few essential formulas and for the rest learn to reason from the fundamental principles.

As an example of proper procedure in working problems, consider the following question: If in the take-off of an airplane, a 192-pound man is uniformly accelerated for 16 seconds over a distance of 1280 feet, what force is exerted on him (by the seat)?

Step 1. Read the problem carefully.

Step 2. Reduce the problem to: A 192-pound object is accelerated from rest for 16 seconds over a distance of 1280 feet by what force?

Step 3. Since all the motion is in a straight line, a diagram is unnecessary.

Step 4. Given: weight of man $W = 192$ pounds
time $t = 16$ seconds
distance $s = 1280$ feet
Required: force $F = ?$ pounds

Step 5. Relevant principles for uniformly accelerated motion starting from rest and for problems involving force and motion:

$$v = at \qquad \text{equation (1)}$$

$$5 = \bar{v}t \qquad \text{equation (2)}$$

$$s = \tfrac{1}{2}at^2 \qquad \text{equation (3)}$$

$$v^2 = 2as \qquad \text{equation (4)}$$

$$F = ma \qquad \text{equation (5)}$$

$$W = mg \qquad \text{equation (6)}$$

Perhaps in your course, equations (5) and (6) will be combined to give

$$F = \frac{W}{g}a. \qquad \text{equation (7)}$$

In these equations, $v =$ final velocity, a = acceleration, $\bar{v} =$ average velocity, $m =$ mass, and g = the acceleration of gravity or 32 ft/sec^2.

Step 6. To solve for the force from either equation (5) or (7), we must find the acceleration. The acceleration appears in equations (1), (3), and (4). Which one shall we choose? Since we do not know the final velocity v in equations (1) and (4), we must obtain the acceleration a from equation (3) in which we know both the distance s and the time t.

Step 7. From equation (3) we have

$$a = \frac{2s}{t^2}. \qquad \text{equation (8)}$$

Now when the expression for a in equation (8) is substituted into equation (7) we get

$$F = \frac{W}{g}\frac{2s}{t^2}. \qquad \text{equation (9)}$$

Step 8. Putting in the numbers, we have

$$F = \frac{192\ \text{pounds}}{32\,\frac{\text{ft}}{\text{sec}^2}}\,\frac{2\ \text{X}\ 1280\ \text{ft}}{16^2\ \text{set9}} = \frac{\overset{6}{\cancel{192}}\ \text{pounds}}{\cancel{32}\,\frac{\cancel{\text{ft}}}{\cancel{\text{sec}^2}}}\,\frac{2\ \text{X}\ \overset{5}{\cancel{1280}}\ \cancel{\text{ft}}}{\cancel{16^2}\ \cancel{\text{sec}^2}}$$

$$\boxed{F = 60\ \text{pounds}} \quad \text{(answer).}$$

Step 9. Check the problem.

Step 10. Check the units. The units may be canceled as if they were fractional quantities, as shown. Every unit cancels except “pounds,” which is a perfectly proper unit for force.

Step 11. Considering the way one sinks back in his seat on the take-off of a modem airliner, or even in an automobile starting in low gear, 60 pounds appears to be a reasonable accelerating force for a 192-pound man.

Step 12. The answer book gives 60 pounds for the answer.

Step 13. This is the all-important step-review the ***problem.***

Working the problem backward involves solving: What time is required for a 60-pound force to accelerate a 192-pound object uniformly over a distance of 1280 feet? Or: What distance is required for a 60-pound force to accelerate a 192-pound object for 16 seconds? (You had better work out both problems just to make sure you are following along.) Variations of the problem include finding the average acceleration (for instance, from equation (8) — the answer is 10 ft/sec^2) , and the final take-off velocity (the answer is 160 ft/sec or about 109 miles/hour). Then you can work backward from the last two variations. If you keep this up, of course, it will take time, but as a studying system, this actually works. Some amount of time can be saved by omitting the numerical part of the review.

Another part of the review is to ask what would have happened if the 32 ft/sec^2 had been omitted from the calculation. This is equivalent to taking the mass, rather than the weight of the man, as 192 pounds. Either procedure is permissible if you don’t make a mistake and in either case, of course, he is a 192-pound man. Had you omitted the 32 ft/sec^2 you would have obtained 1920 lb-ft/sec^2 for the force. Certainly 1920 lb-ft/sec^2 is not the same as 1920 pounds, which would be quite wrong (not because the book says so but, rather, because nature doesn’t work that way). It happens that some people call pound feet/second2 by the name “poundals,” and it happens that a force of 1920 poundals is equal to a force of 60 pounds.

Students who are required to get the answer for the force in customary units, i.e., pounds, must include the 32 ft/sec^2 in the calculation. In your physics course you will be instructed when to multiply by 32 ft/sec^2 and when to divide by it, and *why;* but even if you can't remember which to do, you can still get the correct answer if you write down all the units, and cancel them as shown in the illustrative example.

CHAPTER 6

MATHEMATICS IN PHYSICS

Many students imagine that they are having trouble with physics when actually the difficulty may be with their mathematical background which perhaps is too rusty to be useful. Suppose you are given $T = 1.92$, $l = 3.0$, where $T = 2\pi\sqrt{\frac{l}{g}}$, and you are asked to solve for g. If this causes you the slightest worry or concern, then you need to brush up on your math. (In this illustration we are overlooking the units.) It is astonishing how few students actually can do arithmetic properly, i.e., accurately with moderate speed. You should be able to multiply 8,642 x 9,753 and get. 84,285,426 without making a mistake; and you should be able to do it within two minutes. You are not good at arithmetic unless you can do it in one minute. (Some modern electronic calculating machines can do it in less than a thousandth of a second!) For most students, three to six honest hours of mathematical review represents an adequate brush-up; some students may need a dozen or more hours of practice, especially in arithmetic, high school algebra, geometry, and perhaps trigonometry. It is a delusion to blame physics for being difficult when you don't know your math. Obtain a good inexpensive book of review exercises in elementary math.[1] If you find any of the exercises difficult, then you need to review that topic. It is well to go over the math the first week, rather than to 'put it off until the physics begins to become involved.

Many students, plagued by derivations, wonder why they must be studied. The chief reason is that many formulas are of limited validity because in the derivation some simplifying assumption is made that limits the generality. Thus if acceleration is assumed to be constant, one may use the formula that the distance a body moves from rest is given by (1/2) (acceleration) (time) ^{2}. When the acceleration is not constant, however, this formula does not give the correct answer. For instance, in the case of simple periodic motion, where the acceleration is proportional to the displacement from the midpoint, another approach is needed. Frequently it is just as necessary to know the range of usefulness of a formula as it is to know the formula itself.

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[1] For instance, Lapp, Knight, and Rietz, *Review of Pre-College Mathematics* (Scott, Foresman and Company), $1.00.

Another reason for studying derivations is that they often illustrate fundamental principles. Ten years ago students studying the diffraction pattern produced by an illuminated slit did not know that the same method of procedure would enable them to calculate the directional characteristics of an underwater sound signaling apparatus. Some of the students who had studied the principles, however, were able during the war to make useful contributions to the problem of locating enemy submarines. Students who had merely tried to memorize formulas could see no connection between the two kinds of phenomena, both of which involve wave motion (light waves and sound waves). Similar considerations apply to the directional characteristics of radar.

Another reason for studying derivations is that if you can derive a formula, you are not lost if you forget it during an exam, nor are you likely to use it in the wrong way.

Still another reason for studying a derivation springs from the fact that most of the technological information you have when you leave college gradually will become obsolete. If all you have learned in college is the end result, you, too, will become obsolete. If, however, you understand the intermediate steps, then as extensions are developed you will be able to fit them in with what you know.

A good way to discover why you don't understand a derivation is to go back to the very beginning and go through it again carefully. One step missed somewhere can throw you completely off, and a review of the steps helps you to remember them as well as to understand them better.

Do not expect that every mathematical relationship is an important formula. In the same way that many words are needed to build up to a concluding key sentence in a paragraph, often many mathematical equations are necessary to deduce some new principle from the initial assumptions. A whole page of math may be forbidding in its entirety but if you take it step by step, it may turn out to be fairly simple.

Probably you will need to memorize one or two dozen key formulas during your course. A convenient way to do this is to put the symbols of a given formula on one side of a 3 x 5 inch card, and on the other side to put the complete formula, the meaning of the symbols, the application of the formula to a typical problem, and suitable units. If on looking at the first side of the card you can't give the information on the other side, you place the card back in your pile of formula cards near the top. If you know the material well, you place the card on the bottom. Whenever you have a few minutes you run through a part of or all of your pile of cards. (The same method, with smaller cards, works well in learning a vocabulary in a foreign language.)

Just because you have used a formula correctly in part of a problem is no reason why the same formula may not be properly used again in another part of the same problem. For instance, Ohm's law, potential difference = current x resistance, may be applied successively to several parts of a problem on electrical networks.

If you do not want to waste a lot of time doing arithmetic, learn to use a slide rule. Get a simple, inexpensive one at first (for about one dollar). After you have used it for a while, you can tell which of the more complicated slide rules with fancy scales will be useful to you.

There are some parts of physics that are almost impossible to explain without using calculus. Usually most of these parts are omitted from all but the most substantial first-year courses. If they are not left out of your course and you have not had calculus, you need not necessarily be in despair. It may be quite possible to understand the physical ideas, even if you can't do the mathematical manipulation. Probably you can understand the principle involved in finding the side of a cubical box having a volume of 120 cubic inches, although unless you are a very rare student you cannot take cube roots directly to find that the cube root of 120 is 4.932. (The answer seems reasonable, though, because you know the cube root of 125 is 5.)

Mathematics is one of the most important tools of the engineer-scientist. The more math you know and can use, the better off you are. Do not, however, use mathematics to sidestep the effort of clear thinking or writing; do not use mathematics to the extent that simple ideas are obscured by it. Do not get bogged down in the mathematics of a discussion. At all costs keep in mind the physical ideas.

CHAPTER 7

THE LABORATORY

The laboratory work in physics can be an exciting part of the course or it can be drudgery, depending upon your attitude toward it. If you regard it merely as an impediment to your getting through the course, probably you will not enjoy it and, furthermore, you will derive very little benefit from it. On the other hand, if you approach laboratory work with the thought that it is an opportunity to learn and with a desire to make the most out of it, then it is almost certain you will find the time you spend on it both profitable and interesting.[1]

An experiment is a controlled quantitative investigation-controlled in the sense that the various quantities entering into the experiment are under the control [2] of the experimenter and quantitative in the sense that numerical

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[1] Some parts of the introductory 'paragraphs to this chapter are from Seville Chapman, Laboratory *Manual* Engineering Physics, The National Press, Millbrae, California; by permission.

[2] In the torsion pendulum experiment, for instance, the diameter of the torsion wire, its length, the moment of inertia of the plate or disc, the amplitude of vibration, etc., are under the control of the experimenter, who may vary them at will.

data are obtained. There is nothing mysterious about an experiment; the investigator ordinarily proceeds according to the scientific method (see footnote, p. 6).

There are several ways in which you may expect to benefit from the laboratory work. It helps you to understand and remember the physics you have studied; it gives you practice in the application of physical laws and logic to real cases, and in that way aids you to think clearly; and it gives you some skill in the use of scientific instruments and techniques.

A whole year's course adds up to less than two full weeks of'actual laboratory time (the Ph.D. candidate ordinarily spends about two years of full-time laboratory work on a single problem) so that you cannot expect to get any very thorough mastery of specialized laboratory techniques; however, you can learn much about less specialized techniques. You can try to get the most reliable data possible from first-year equipment that is often oversimplified and therefore not capable of high precision. In this way you will become familiar with averaging and estimating procedures as well. as with experimental techniques for improving the accuracy of measurements in difficult situations where ideal measuring equipment has not yet been developed. Should you think of objecting to making several runs with the free-fall apparatus to improve the accuracy of your average value for the acceleration of gravity, remember that it may have taken many months to determine accurately a single figure for some quantity that appears in a handbook.

It is true that you are not likely to be the discoverer of anything new in physics during your first-year course, for most (but not all) of the material in first-year physics has been known for decades. It is also true that you have not known the material for decades and you may, therefore, be able to experience the thrill in the laboratory of *discovering* for *yourself* some of the principles of physics. Most of the principles of physics were discovered by men using equipment no better than yours; most of it, in fact, was not as good. At times, unfortunately, you will know beforehand what the results of your experiment are supposed to be, since mature investigators have done the experiment many times over. Even so, you can imagine yourself rediscovering the principles of physics while you are in the laboratory. With the equipment in front of you, you have the chance to try out your own ideas, to reason about the results, and to draw conclusions from them. In brief, you should regard the laboratory as a place for *intellectual exploration.*

Before you come to the laboratory, study the laboratory manual so that you will know what you are going to do and so that you can plan in advance how to use your time efficiently. As you do the experiment, make an effort to correlate the behavior of the apparatus with the principles discussed in lecture. To get an idea of the reliability of your measurements, after you have determined what you think is the best reading, gradually put the apparatus out of balance (or whatever is appropriate) to see how great an unbalance you can secure before the effect becomes noticeable. Make some record in your data of this observation. Pay special attention to the derivations and the equations used; eventually, when you substitute values into the equations, you will know why you use them.

Keep your mind open and alert to the possibilities of the experiment; try out things not specifically asked for in the instructions. True, your first original ideas may not seem particularly brilliant to you if the instructor points out their obvious fallacies but you must begin thinking for yourself sometime (rather than merely learning from a book) and the laboratory is a good place to start. The equipment is handy and the results of trying your own ideas are apparent immediately.

Constantly ask yourself such questions as: Why do we do it this way? What would happen if we did it another way? What does this measurement show or prove? The purpose of the laboratory manual is to direct your thinking along those channels most likely to be fruitful. Let us hope the manual is clear enough so that you need not waste time puzzling over simple matters. The manual, however, cannot possibly deal with all the points that can be uncovered by a wide-awake student. A few examples may be cited.

In the mechanics experiment on vectors using the force table the theory is straightforward and were it not for friction in the pulleys, the weight of the strings, and the weight of the ring, “perfect” results could be anticipated. Discrepancies of a few percent are obtained ordinarily. The student who “takes” physics will pass off the discrepancy vaguely as being due to some unspecified kind of friction, hurry through the experiment, and leave the laboratory as soon as he can. The student who wants to make use of the opportunities to learn from the laboratory will devise procedures to diminish the errors or, if that is not possible, to correct for them. For instance, he may weigh the ring and the strings to estimate a limit for the error they introduce.

In the electricity experiment on divided circuits, the student can measure the current in some resistor both with and without the voltmeter being connected across it, thereby providing an estimate of the inaccuracy in the current reading introduced by the voltmeter (which takes some current). Likewise, he may measure the voltage with and without the ammeter in the circuit.

In the optics experiment on diverging lenses, the student may wish to apply the concave-mirror procedure to determine by reflection the radii of curvature of the lens, from which he can calculate the focal length if a value of the index of refraction of the glass is assumed. This focal length may be compared with the experimental value to serve as a check on the accuracy of the assumed index of refraction. Such measurements may not be suggested in the laboratory manual but alert students have thought of them and unquestionably did profit by making them.

A student must realize that the laboratory work has applications outside the laboratory. The centrifugal force experiment may suggest to the student that he calculate the force due to an unbalanced tire on an automobile traveling at high speed (e.g., assume two ounces unbalanced weight at the rim) . The magnetometer experiment may suggest ideas in connection with the magnetic prospecting for minerals. The experiment on diffraction may help to explain why better directivity is obtained from the higher frequency radars. The experiment on optical instruments may suggest an approach to the projection of television pictures. There are, of course, innumerable other examples.

Writing laboratory reports is a significant part of your professional training. Speaking and writing are the most important tools of the engineer-scientist. Learn to handle them well. It takes work to transfer thoughts from your mind to somebody else's. Your report should convey information to the reader rather than puzzle him. Anyone who has ever suspected that the author of a vague, verbose, confusing technical book seems to be "trying to prevent overcrowding at the top by making it difficult for the uninformed," should recognize the importance of lucid expression. Your report should be well-organized, accurate, clear, concise, and easy to read. Since you will have to write reports anyway, while you're doing them try to improve your command of the English language. Do not try to impress the reader with your own learning but write as if you were trying to explain the matter to an intelligent personal friend. Ability to express oneself clearly is extremely important for the professional man, even if a few people may tell you otherwise. Careful habits in handling things and in making accurate quantitative statements should encourage the professional man to an equal nicety in the use of words and to an observance of rules regarding their arrangement.

A few horrible examples will illustrate some of the differences between bad and good English.

In answer to the question: "In the rifle-bullet ballistic-pendulum experiment, what principle determines the height to which the block will swing after it is struck by the bullet?" one student wrote: "The principal [sic] is that in the transfer of energy from one body to another, the total amount of the original body goes into the other body and the force which it has (the old body) will be related to the moment of enertia [sic] of the new body and the torque applied by the force of the old body. Therefore the block uses the distance which the force of the bullet can make the block go with the blocks [sic] inertia and mass as it is." A better answer is: "The potential energy of the block (weight x height) at the top of the swing is equal to the kinetic energy of the block at the bottom of the, swing just after impact." [1]

An engineering report which read, "The optimum method of accomplishment of the purpose of the investigation . . ." was changed by an editor to "The best way of doing the experiment. . . ."

In one of the professional journals, a "scholar" wrote "Available evidence tends to indicate that it is not unreasonable to suppose that. . . ." What he meant was, "Probably. . . ."

Study these examples, laugh, and then take your work in English seriously, Be precise and concise; brevity is a virtue.

CHAPTER 8

STUDYING FOR EXAMINATIONS

If you have done your work carefully from day to day, reviewing for exams can actually be a pleasant experience. In any case, begin your systematic review for the final exam two weeks before exam week. For the midterm exams, complete all your original learning at least two days before the exam. This gives your subconscious mind a chance to digest the material and also it is insurance against visitors or an illness the day before the exam. Plan your work so that the day before the exam you will need to do no more than review the previously learned and understood material. In that case a couple of hours' work the day before the exam will be all that is necessary. Since physics is a subject where clear thinking is especially important, remember the importance of a good night's sleep.

There is no particular objection to cramming except that most of it is a waste of time. Cramming a set of formulas into your head an hour before the exam may raise your score, and in that sense may be justified, or it may merely confuse you. Certainly you will not be able to learn any significant amount of new material by cramming. Do not make the blunder of trying to memorize the tough spots, for unless you understand the basic ideas, your half-memorized effort will do you no good either on the exam or later. Probably the exam will concern the part of your half-learned material that you didn't understand. If you do not have time to study all the material, then discard what you think is least important and forget about it. Learn the rest of the subject well. You may or may not be able to bluff your way through an essay question in economics but definitely you cannot do it in a physics problem. Either you can reason how to do the problem or you can't. Hence, if time is too short for you to learn all the course, learn part of it cold not just "sort of."

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[1] Students studying the ballistic pendulum experiment must be careful to distinguish between that part of the experiment in which momentum is conserved (the impact) and that part in which energy is conserved (the swing). Energy and momentum, although related, are entirely different quantities,

You may infer possible types of questions from previously given exams or quizzes or from the kinds of problems in the problem sets. Referring to your own exams will help for the final exam.

During your study, try to anticipate exam questions and plan what your answers should be. If you have a sufficiently good grasp of the material to be able to make up possible questions and then solve them without your notes, you are practically assured of an A. It puts you on the "other side" of learning when you try to make up questions. This is a very effective kind of study, for in order to devise good questions you must have studied for the fundamental ideas.

CHAPTER 9

TAKING EXAMINATIONS

If you have studied carefully and really know well what you have studied, then you are not likely to get rattled on an exam. Treat it like a game; be concerned about it ahead of time but do not worry about it. You'll worry less if you consciously act not worried. The morning of the exam get up early enough so that you can take an extra long shower (as though you hadn't a care in the world) ; after breakfast walk slowly to the exam (as though you were sure it would be simple) ; and if you arrive early, read the funny paper. When the door is opened, get the exam and walk calmly to your seat. Read the directions carefully (you may be offered a choice of questions, in which case there would be no point in doing them all). Some students recommend reading the entire exam first so that your subconscious mind may start to work on all the problems or so that you may start with the ones you know best. Others prefer to start at once with the first question. (Even if you do not do the questions in order, it is wise to put them in the proper sequence in your bluebook, since often the first three questions will be read by one reader, the second three by another, etc.) In any case, attack each question with an air of confidence (not cockiness) . Do your best; keep the rest of the exam and everything else out of your conscious mind and concentrate on the problem on which you are working.

Read the questions carefully; you don't get credit for getting the right answer to a wrongly read problem or for a part you didn't do because you overlooked it in the rush. Take it easy and don't start using your pencil until you have thought out just how to begin. A common practice of physics professors is to gauge the time to allot to a problem by giving the students five times as long as it takes another professor to get the right answer. This means that it is mechanically possible for a student to make a perfect score by spending forty minutes thinking what to write and only ten minutes writing during a fifty-minute exam.

Don’t rush; haste is likely to induce slipshod thinking. Work at a convenient pace but without wasting time.

Don’t try to read a complicated or unnatural meaning into a simple question. If it is really vague, then ask the instructor what was intended (be diplomatic). In essay questions or derivations, write legibly. The readers give credit only for what they can read and they do not spend much time trying to decipher chicken tracks or the faint marks made with very hard pencils. Do not cramp your thinking by cramping your writing. Use plenty of space (paper is cheap) and write clearly, preferably in ink if you are used to writing with a pen.

Think about the questions; don’t worry about how you are doing. As one student says, “Heaven and Earth won’t come down if you miss a problem.” Don’t spend too long on any one question. Don’t hurry to do a lot of arithmetic until you are sure it is necessary (frequently things will cancel out if you give them a chance). Don’t work on scratch paper (you are certain not to get points for it). Do everything in an orderly fashion in your bluebook. Don’t take time to erase anything but rather cross it out neatly if it is wrong. Perhaps it is right after all, and you will get partial credit if you leave it in. (Decide which to do.) You are likely to get more partial credit for an incomplete answer if the arrangement of the material you do have is neat and orderly. Underline or box your final answers and remember to put down the units.

Ten minutes before the examination is over, take about one minute to check your work to make sure you have made no major blunder (such as leaving out an easy question) and to plan how you can use the remaining few minutes to the best advantage.

After the exam papers have been returned to you, be sure to clear up the points you missed; there is no need to lose credit on the final exam for the same mistakes. Furthermore, if you clear up weak points, it improves the solidarity of your foundation so that later material is learned more easily.

(The following section is intended for graduate students, freshmen and sophomores should postpone reading it for a few years.)

Oral examinations: In studying for an oral exam for an advanced degree, the student should realize that if he fails it is more likely to be because he was a trifle hazy on the application of Newton’s Laws of Motion (first-year physics) to some unusual problem rather than because he did not know a lot about the general theory of relativity. Consequently, advanced students should be careful to see that their comprehension of fundamental ideas is impervious to “attack.” While memorized knowledge is desirable, the important thing for candidates is the ability to think on their feet, or to apply what they do know to questions for which they do not know the answers.

The purpose of an oral examination is to explore and locate the borders of a student’s knowledge and ability. Consequently, the student may expect that a significant fraction of the questions asked will be beyond him. To make a good impression, he ought to try to answer the questions, being careful to state what he feels sure of and what he is hazy about. The professor asking the question probably will give a few hints to aid the student in his reasoning (as distinct from telling him the facts) but the student should be prepared to think on his feet. Do not, however, assume that the hints are necessarily bona fide. Sometimes they are cleverly stated to see if a student who has answered part of a question correctly merely stumbled on the right answer or whether he really understands the subject. Even if his mind is a complete blank, the student should make some sort of response; occasionally the professor will interpret it as a sign of life and offer a useful hint. Oral examinations are much worse in anticipation than in reality. Be concerned about them ahead of time but don't worry. Probably you will pass anyway. Even if you don't, your career isn't necessarily finished. One of the foremost scientists in the country failed one of his Ph.D. orals the first time he took it. Now he is the director of an organization of hundreds of scientists. He is a good man and always was but the first time he hadn't studied the right things. Next time he did brilliantly.

Most questions are leading questions, followed by related questions which take the student rapidly through a given field, touching here and there only. Every now and then your professor will explore some small section of a field very thoroughly to probe the depth of your knowledge. It is a rare examination in which you will be asked as much as five percent of the material for which you are liable.

Probably more than half the questions asked you will be related to course material (undergraduate and graduate) you have studied. They may be not unlike final examination questions (usually with the numerical work omitted) and if in your preparation you have kept in mind the list of seven questions given in Chapter 2, you should have no serious trouble. Of course, you may be asked about your research. On this subject it is conceivable that you will know more than some of the members of the committee, so you ought to be prepared to give a well-organized, lucid, and accurate discussion of any phase of it-especially the background of the problem, why it is worth doing, and what you have found out. Probably you will be asked some questions of a type not suited to written examinations; such questions are intended to show whether you can think on your feet. Since these may be of an unfamiliar type, it seems appropriate to give a few examples (all of them are well-known and are duly recorded in the several "black books" surreptitiously circulating among graduate students on most campuses, with the unadmitted connivance of the faculty who continually hope the students may be able to answer some questions for a change) :

In Situation A, a cylindrical peg stands vertically in the center of a frictionless horizontal table. A string is fastened from the peg to a small frictionless block (considered to be a mass point). The block is given a tangential velocity so that it spirals in toward the peg as the string winds up. In Situation B, with the same table and block, the peg is removed, leaving a hole in the table. A frictionless eyelet is placed in the center of the hole. The string goes through the eye and after the block is given the same initial tangential velocity, it is made to spiral in as somebody pulls on the string. In which case is the velocity of the block greater as it approaches the center? Why? What is conserved in each case? (This is a rather difficult question in first-year physics but should be fairly simple for a graduate student. It is used to get you off to a good start.)

A horizontal conveyor belt has a constant velocity of 4 ft/sec. Every second 8 lb of sand fall on the belt with negligible vertical velocity and zero horizontal velocity. The sand is accelerated and carried along by the belt. What power is required to drive the belt? (You will discover quite quickly that if you work by kinetic energy considerations you obtain 2 ft-lb/sec for the answer but if you work by momentum considerations you get 4 ft-lb/sec. One answer is right. Explain the paradox. This question is more subtle than the first one and if you've never heard it before, probably you'll not get the answer without some prodding.)

What is a volt? What is an ampere? What is an ohm? (Needless to say Ohm's law can be used to define only one of these three quantities. Strangely enough many students who can solve Laplace's equation in three dimensions can't answer this question without prompting, although any freshman should be able to do so. Incidentally, the so-called international units based on the Weston cell, the silver voltammeter, and the column of mercury became obsolete in 1948, so you had better be prepared to define the absolute units.)

Why is mercury 198 of importance in defining the standard of length? (This question may lead to a discussion of spectroscopy, nuclear reactions, discharge in gases, interferometry, or legal standards, etc.)

List half a dozen sources of electrical noise (thermal noise, shot noise, etc.) and discuss any one the professor selects. (This question may lead to a discussion of communication theory, cybernetics, practical electronics, probability, or thermodynamics.)

To what extent are x-rays reflected, refracted, diffracted, polarized, scattered, and absorbed? Why does the product of the permeability and permittivity of free space equal the reciprocal of the square of the velocity of light? Why can't there be electrons in the nucleus? Why is wet sand darker than dry sand? Why does a cathode follower have a low output impedance? Why is a finite angular displacement not a vector? What is a Maxwellian distribution? What is entropy? What is a decibel, a parsec, a millibar, a nucleon? What is resolving power? Define c, h, e, m, and Avogadro's number and tell how they are measured or determined. Why do winds circulate counterclockwise around low pressure areas in the northern hemisphere? Derive $PV = RT$, or the Rutherford scattering law, or Lagrange's equations. How big is a one-inch pipe, or a 6/32 screw? What is the price of brass? List ten scientific instruments ending in "scope" (there are fifty at least) and tell what they are for. How does a synchrotron work? Given some properties of a "black box" tell what is inside it.[1] Integrate $(1/x^2)\,dx$ from -1 to $+2$ (be sure not to get $-3/2$ for the answer). List several types of electric motors and tell how and why they run. Identify the following and tell what they have in common: Becquerel, Braun, W. H. and W. L. Bragg, Barkla, Bohr, Bridgman, and Blackett. And so on and on.

CHAPTER 10

SCIENCE AND SOCIETY

Most physics books do not discuss questions of the type mentioned in this chapter. Since these problems are so important, however, in the way the affect your life as a human being, it seems worth while to bring them up for' your consideration while you still have a chance to select those colleg courses which will best prepare you to meet them.

Ever since the atomic bomb was dropped on Hiroshima, people have realized that engineers and scientists in their professional activities ca markedly influence the course of human events. This general understanding of the importance of science and engineering has been quite recent. In fact, until World War II the public was content to ignore the scientists an engineers, about whose professional activities they knew little and care

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[1] A DC generator (of large power capability) is connected in series with an ordinary ammeter reading 5 amperes, a 10-ohm heating element, and a two-terminal black box. Ordinary DC voltmeters connected across the heating element, the box, and the generator, read 50 volts, 50 volts, and 100 volts respectively. A calorimetric measurement of the heating element shows that it *is* dissipating 500 watts. The box stays cool. Explain. (The box may contain resistors, capacitors, inductors, transformers, batteries, generators. motors, and switches.)

less.[1] In 1945, however, when it became common knowledge that the development of airborne radar was a primary factor in winning the Battle of Britain against the submarine [2] and that the use of two atomic bombs against Japan brought an end to the war, popular respect for scientists and engineers jumped tremendously.

According to the president of a very large company employing thousands of engineers and scientists, in these days "the engineer-scientist must solemnly consider his duties and obligations to society." [3] Scientists and engineers, who make such extensive contributions to our modern mechanistic civilization, bear an obligation to accept the responsibility of helping to solve the problems of society which those contributions bring about; for instance, problems of labor and management, housing, taxation, education, conservation and development of natural resources, transportation, atomic energy development, national security, and so on. Because of the increasing importance of technological considerations in the problems of society, the public looks to the technical men for leadership and guidance. Today everyone, especially the professional man, is obligated to understand social problems and, even though it involves him in controversy and takes his time, to act on them; that is, to take an active part in the discussion of community problems. Let the engineer realize that the business man, the working man, the farmer, the lawyer, the politician, the military man, and the housewife do not all speak his own language [4] but let him seek a common ground on which to unite for a course of community betterment.

The day never existed when atomic scientists properly could say "We made the bomb, now you decide what to do with it." A few did say that, to their discredit; a few others claimed to know all the answers and tried to regiment the public to their line of thinking: and the rest, to their credit, realized that the proper approach to problems of atomic energy was to foster open public discussion of the questions.

In fact as well as in democratic tradition, all of us together are smarter than any of us individually. In view of his superior technical background and the respect accorded him in virtue of his profession, the engineer-scientist is better able than other *laymen* to take part in the discussion of public

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[1] World War I added to the prestige of American chemists to such an exte that in the popular mind any scientist was a "chemist."

[2] Had the schnorkel submarine (virtually invisible to radar) been ready for in 1942 rather than after the Normandy invasion in 1944, probably Britain would have been starved into defeat. In two world wars it has been fortunate that o allies have been able to hold off the enemy until we could get ready and that t enemy did not make more effective use of his scientific and technical abilities.

[3] C. E. Wilson, *General Electric Review,* March 1949.

[4] Certain facts about the nature of scientific research, obvious to nearly all scie tists, have made relatively little impression on some Congressmen because the fac were presented in a way that did not take into account the very different ba grounds of scientists and Congressmen.

questions. In order to accept his moral responsibility of leadership in such matters, he must have the necessary breadth of background.

It is easy to see how these considerations should influence your choice of undergraduate studies. It is clear that the technical man must be technically competent but since most of your training in technical subject-matter will be obsolete before you use it, you would make a mistake if you specialized in technical subjects to the exclusion of everything else. Probably three-quarters of your courses must be technical (mathematics, physical and biological sciences, engineering, report-writing, technical foreign languages, etc.) but you should give special attention to the fourth quarter, the cultural courses. Not only will this help to make you a better citizen by broadening your social outlook but it will make you a better human being by giving you an understanding of human nature. No man becomes cultured merely by being exposed to cultural courses for a few years in college; sometimes, however, those years help to open his eyes so that he can begin to understand the world we live in. When you choose your nontechnical courses in such subjects as literature, music, social studies, philosophy, and so on, probably you will do better if you select the professors rather than the courses. Do not neglect your nontechnical courses; if you want to be a human being rather than a technical automaton without a soul, you ought to be educated and not just trained.

Unfortunately, special courses are not given for the development of character. Some people with undeveloped senses of social responsibility believe that, in the short run at least, propaganda and persuasive advertising pay off better than quality of product. Others feel that the world owes them a living, not realizing that salaries and wages are commensurate with productivity. In -the long run, the prosperity of any individual is related to the general level of public welfare. You should be glad that in your profession you can earn a living by contributing to the general good, since scientific, engineering, and medical developments benefit everyone.

At the time of writing, we are faced with growing unemployment and increasing international tension. Even if these particular problems are resolved by the time you read this book, there will be other serious questions facing the world. Do not be naïve to the extent of supposing that in a few months you can solve matters that have puzzled the world's experts for decades but, while you are in college, discuss problems such as the following and try to find answers to them.

Why could the most favored country in the world, the U.S.A., have one-third of its working people unemployed (in 1933)? How should we act to prevent such catastrophes in the future? In peacetime (in 1949) why should we spend $15,000,000,000 a year for war, while we spend only one-tenth of one percent as much for peace by support of the United Nations?

When wars cost hundreds of billions of dollars and bring personal tragedy to tens of millions of people, is it not worth your while to give considerable effort and attention to the prevention of war? If you don't, who will? This problem is complicated, for if war comes, we must be prepared in a military sense, yet history shows that military preparedness alone is not a guarantee of peace. In these days one man can kill 100,000 people in a few microseconds with an atomic bomb (there are other equally frightful procedures) . Science can be of great benefit to humanity or can destroy it. If you have enough moral strength of character, you, whose professions will be in pure and applied science, can help to direct scientific and engineering developments into channels that benefit mankind. But if you, yourself, are to play your own small part and make your voice heard, you must have the breadth of background and understanding that will command attention from others and hold that attention. Keep these thoughts in mind while you are planning your curricular and extracurricular activities.

SUMMARY

1. Proper procedure in studying is necessary for effective study.
2. The proper mental attitude-an earnest desire to learn-is the most important requirement for effective study.
3. Develop a system of study that is suited to you.
4. Since a college education represents a big investment in time and money, it is worth while to examine the reasons for going to college.
5. The aims of education are to train people to think clearly, to give them a liberal, tolerant, and understanding attitude toward life.
6. *Qualities that make for success are character, aptitude, attitude toward work, knowledge, ability to get along with others, ability to use the English language effectively, integrity, and perseverance.
7. Put special emphasis on learning how to attack problems and on how to apply what you know.
8. Physics, the basic physical science, is fundamental in medicine, science, engineering, and many present-day social problems.
9. It is better to study four subjects thoroughly than six superficially.
10. Since technical knowledge soon becomes obsolete, be sure to learn how to learn by yourself.
11. Ask yourself questions about the material while you study it.
12. For most students, physics involves new concepts, about which logical reasoning is necessary. Hence, efforts to memorize physics are worthless.
13. Adopt a receptive and cooperative attitude toward your instructors.
14. Study in a place free from distractions.
15. Get adequate sleep, exercise, and recreation, but leave enough time for study.
16. Study regularly, preferably soon after class.

17. In addition to getting details, be sure to get an overall view of the subject.
18. Study to understand the material.
19. Don't believe everything you read; see if it makes sense to you.
20. Review material frequently, both in self-recitation and in discussion with fellow students.
21. Overlearn.
22. Seek help from the library, or from a tutor if necessary.
23. If you are a slow reader, see your adviser, who can suggest corrective procedures.
24. Pay close attention to definitions.
25. Be alert; take an active part in recitation classes.
26. Go to class not just to take notes but to learn.
27. In taking notes be sure to include explanations.
28. Soon after class, smooth out and fill in your notes.
29. Have an orderly, well-organized procedure for working problems.
30. Do more problems for practice than the assignment calls for.
31. Review your problems by working them forward and backward and by doing variations.
82. Memorize, for convenience only, a few of the most important fundamental formulas and for the other material learn to reason from the fundamental ideas.
33. Don't be rusty in high school math. Practice up if necessary.
34. Study a derivation to learn the origin of and the range of usefulness of the formula, so that you can fit into the picture technological extensions that develop after you leave college.
35. Keep in mind the physical ideas.
36. The laboratory is a place for intellectual exploration, where you can rediscover many of the principles of physics.
37. Study the experiment before you come to the laboratory.
38. Try to correlate the behavior of laboratory equipment with what you learn in lecture.
39. Try out your ideas in the laboratory: keep your mind open and alert.
40. Write your laboratory reports in a well-organized, accurate, clear, concise style.
41. Prepare for exams by reviewing material previously learned and digested.
42. Anything worth learning is worth learning! Half-learned material is of little use.
43. Attempt to make up suitable exam questions and then answer them. This is an excellent method of study, for it focuses your attention on the fundamental ideas.
44. Take it easy during exams.
45. Think first; don't begin to write until your ideas are clearly in mind.

46. After exams are returned, always review to see where you were weak, and then clear up the deficiency.
47. Keep in mind your obligations to society as a professional engineer-scientist.
48. Be educated, not just trained.
49. Learn to talk in terms other people can understand.
50. Carefully choose your nontechnical courses so as to obtain a broad background.
51. Science can benefit humanity or destroy it; assume your share of responsibility in determining which way science is used.
52. Check through this book every month or two to be sure you are using the suggestions that can help you.

CONCLUSION

A university is not a place where education is forced upon you but rather a place where the faculty have tried to make your learning process as efficient as possible. It is their obligation to provide you with a good return for the effort you exert, but you yourself must make that effort and keep your mind open and alert.

Now you may say, "Yes, I agree with your ideas on how to study," and then you may proceed to forget all about them. In that case, neither of us is better off than if you had never read this book. A good plan is to put this guide where you mav review it occasionally. You will be interested to see how your own ideas change as you get further along. Ten years from now you will wish you had done things differently while you were in college. Probably most of the thoughts in here on what you should do in college would. have come to you sooner or later anyway but it is my hope that from studying this manual you will get these thoughts soon enough for them to be helpful to you.

How many ideas in the Summary on the previous page can you give right now? Perhaps reading it [illegible] eread it,
se

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