

SUGGESTIONS AS TO CHANGES IN ENTRANCE REQUIREMENTS IN SCIENCE.¹

BY W. J. A. BLISS,

*Collegiate Professor of Physics,
Johns Hopkins University, Baltimore, Md.***INTRODUCTORY:**

I was reluctant to accept the invitation to address you on this subject, owing to lack of technical information as to present requirements, but consented to do so because of its bearing on the college course in General Physics, which I have been studying in connection with a report in preparation for the American Physical Society on Physics in Medical Education. This course presents a very difficult problem which is rendered more so by present defects in the preparation of the student entering college. I therefore welcome the opportunity to bring these difficulties to the notice of those who are formulating entrance requirements. Inquiry shows that present entrance requirements in science affect the first course in chemistry almost as disadvantageously as they do that in physics, and the same appears to be true of other sciences. The presentation from the standpoint of general physics and general chemistry will thus apply to all students intending to take a course in science at college, and since at least one such course is generally required for graduation, it is suitable for a general entrance requirement. It is, however, absolutely limited to the ten per cent of high school students who do go to college, and would not fit the needs of the ninety per cent who do not. The problem of rounding up a pupil's education in the four high school years to the best possible finish is totally distinct from that of preparing him for from four to eight years more of study and no specifications can be offered for a science course to serve two such diverse purposes. It would be as easy to specify a standard foundation equally suitable for a two-story dwelling and a skyscraper.

**DIFFICULTIES IN THE FIRST COLLEGE COURSE ARISING FROM
DEFECTIVE PREPARATION FOR COLLEGE.**

Talk with the instructors of the first college courses in mathematics, chemistry and physics and you will find very similar opinions with regard to the preparation and ability of their students in many respects, but each wants more school study in the other two subjects, but so far as possible a virgin field in his own! Each will tell you that the school courses introduce in-

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equalities among their students, which give rise to insurmountable practical difficulties in teaching. This is largely because the school course is commonly not treated as a problem totally distinct from the college course. The school tries to give a less thorough imitation of the college course, simply an abridgment. School text-books in physics and chemistry are mainly abridgments of college texts, frequently by the same author. In chemistry, for instance, there is an attempt to cover all of inorganic chemistry and even to close with qualitative analysis, which owing to the student's limited repertoire of reactions can only be of the cook-book type. The school text naturally omits the harder and duller parts and emphasizes those where interesting facts can be presented with minimum effort.

The ruinous effect on the college course is evident. Nothing can be omitted because the school treatment simply lacks thoroughness all through. The student recognizes some little fact and thinks "I know all about this." Instead of greeting the old friend with loving interest he takes a little nap, during which the teacher explains the great principle which was considered too abstract for the school text. The college teacher has to emphasize all the duller and drier parts of his subject, and the student is bored and disappointed. The situation is even worse when you have gross inequalities in knowledge among the students so distributed that no systematic course can be fitted to them. Yet the separation of the first course into two courses, one for students who have had physics, the other for those who have not, as at most colleges, is not very satisfactory. In the first place it presents the illogical aspect of two parallel courses, counting equally as prerequisites for other courses, but of apparently different grades, since one requires a previous study of the subject which the other does not. At Johns Hopkins we have really three distinct categories, those who have had no physics in school, those with high school courses of very varying value, and others still with a fair high school course plus a year or two of engineering applications. Shall we give three parallel courses?

Technical Terminology.

Physics presents another difficulty which is seriously affected by the school course. In no science are the technical terms so largely drawn from common speech. It abounds with words used in highly technical senses narrowly restricted to very rigidly defined meanings, so that they are capable of exact mathematical

expression, and which are in common use in wholly vague and often entirely different meanings. "Weight," "force," "power," "energy," "momentum," "heat," are only a few of the most obvious. Professor Franklin has said that the grocer and coal man call "weight" what the physicist and chemist call "mass," but it is even worse than that. If the coal man overloads his cart and the axle breaks, he will attribute it to the "weight" of the coal, whether it breaks standing still or owing to a jolt going over the car track. In the first case he uses the word in the scientific sense; in the other he does not. Physics is full of such man-traps, of which even college teachers are imperfectly aware, and which greatly increase the difficulty of the subject as a school study. The teacher must drive out the old conception and insist on the new and correct use of the term, and the student who comes to college with a year of physics under a teacher who has not done this is simply confirmed in bad habits. I heard a high school science teacher say that he did not "stress" the difference between mass and weight, because it is important only in distant and out-of-the-way places! When such fundamental misconceptions are transferred to definite mathematical formulae the trouble is vastly increased.

Another difficulty arising from school physics is that of incorrect definitions given the pupil with the idea that they are easier than the correct ones. The glaring example of this is the definition of e. m. f. as a pressure which forces through a wire what is called technically an electric current, but which the pupil much more consistently refers to as the "juice." The student is thus started with a wholly incorrect conception of potential difference. Other mistakes from which the college teacher reaps the whirlwind are such phrases as "heat in a body," "converting work into heat." It would be as lucid to speak of converting one's legs into a trolley car when one walks instead of riding!

MATHEMATICAL AND OTHER TEACHING DIFFICULTIES IN GENERAL PHYSICS.

Among the reasons that make the problem of general physics so difficult that a reconsideration of entrance requirements seems essential are those resulting from the fact that, more than any course, it is taken as a prerequisite to other studies and by students who take no second course in the subject. At Johns Hopkins 95 per cent of the class are in that category. This means that it must come early in the curriculum and that it

must be final and give the needed vocational working knowledge. It is utterly impossible to cover the entire range of even the most important applications, even in one field like medicine. What we must do is to enable the student to read physics and give him the habit of reading it for himself. We must therefore in large measure teach the general principles and leave the applications to the student, giving him simply a list of references. Moreover we must cast the principles in the mathematical form in which they will be found in books of reference and technical articles generally. That is, we must use trigonometry freely, and a modest amount of analytics. In as much as nature has at least three dimensions, we cannot stay entirely in flatland, and we have to assume that the student has a concrete idea of such things as spheres and cones and pyramids: of ellipses, parabolas and hyperbolas and of their foci and axes. These terms are simply the common equipment of scientific and professional men everywhere and we have to assume it. Not only must the student know these things but he must have attained reasonable efficiency in using them, as well as skill in the accepted school mathematics. He must also be in the habit of using the ordinary labor-saving devices, such as logarithms, and all of these things must, so to speak, be on the tips of his fingers. He must have reached the point where mathematics is to him a help and not a hindrance. The English schools I think accomplish this while ours do not. He must furthermore be in the habit of using mathematics as an aid to thought and not a substitute for it. He must visualize the concrete things that he is discussing and see in the equations only a convenient system of shorthand. He cannot possibly do this if he has been taught to cram "formulas," and solve problems by merely substituting numbers for the letters.

Finally general physics like any college course, and perhaps more than any, requires the habit of personal responsibility of the student for his own progress. We must not only rely on him to study a great deal that is set forth with reasonable clearness in the text-book, so that we may economize our time for the things that are really difficult, but he must test his knowledge by working more problems than we have time to correct. He must in a measure be his own taskmaster and look on his teacher as a guide and helper. Instead of that he expects all his work to be covered in class, and looks on the teacher as a taskmaster to be eluded when possible.

To mention only one defect which strikes directly at teaching efficiency, our investigation of the general course in physics showed that while teachers generally consider the working of many numerical problems essential, all agreed that home work cannot be accepted. Most of the college teachers recommend a provision of "Problem Periods," usually replacing about half of the laboratory time, and devoted to the childish process of working problems under the teacher's eye, because that is the only way he can get them done at all! Please don't think we blame the schools for a lack of a sense of honor, but we do blame them for the fact that a young man or woman of eighteen or nineteen still expects the professor not only to teach him but to "learn him." Even McFadden must have found he had to practice "on his own" before he was "learned" to waltz.

To summarize, the difficulties which we are trying to meet by a change in the entrance requirements are of three kinds:

1. Definite lack of certain mathematical knowledge, which is essential to the study of science in college.

2. School courses, which try to forestall the college courses in science, and which should be replaced by others of a type definitely preparatory to them.

3. Incorrect habits of study, which are largely the fault of the college entrance examinations themselves. So long as the colleges fix the passage of certain examinations, whether set by themselves, or by an Entrance Board, or a Board of Regents, or even by the schools themselves, just so long will school teachers endeavor to cram boys with formulae and tabloid facts for use in the examinations. To this extent the trouble is not with the entrance requirements, but with the mode of determining whether they have been complied with, not with the specifications but the method of testing the goods on delivery. To overcome it we must either devise an uncramable examination or accept the recommendation of the school teacher, based not on examination but on day by day knowledge of his pupils. In the latter method the college must of course support the conscientious and efficient teacher and check the easy-going one by some arrangement of quota, which may be varied from time to time in accordance with the success of that school's product in the work of the college.

PART II. SUGGESTED REQUIREMENTS.

Summary: It is evident that these conditions are to be met rather by a change in content of the courses and in the method of

instruction, than a change in subjects, and that this will be hard to accomplish under the examination system. With this warning the following distribution of time is suggested, based on a total of 4 units of science. I must, however, remind you that the courses are proposed with the intention of preparing the student for the college course in science specifically, and not as general information or cultural courses. I should divide the four units as follows:

1. Mathematics, *1 unit* if needed.
2. General science, *1 unit*.
3. A good strong course applying the principles studied in the course in general science to some one science, such as physical geography or biology, *1 unit*.
4. A *unit* divided between chemistry and physics and extending the knowledge begun in general science.

If, owing to the introduction of courses in "general mathematics" the additional preparation specified below can be given without requiring an additional unit of mathematics, I would suggest one year each of *physics* and of *chemistry*.

I will now take these up one at a time.

Mathematics: The time corresponding to the additional unit in mathematics is to be utilized in extending the working knowledge of the student in mathematics applied to science. It is not intended as an additional systematic course in any one or more subjects. I must leave to the mathematics teacher the question whether this time can best be utilized by distributing it or by collecting it in a single course in the fourth year high school, so planned as to form a review of formal mathematics, unifying its teaching, adding the specific information absolutely essential to science teaching and giving practice in rapid and facile application. It should in addition to algebra A and B and plane geometry cover: Logarithms; sine, cosine, tangent and cotangent, the signs of these functions in all quadrants, the eight or ten most useful relations between them; and abundant practice in applying all of these not only to triangles, but to such problems as lengths and directions and angles between lines, both in two and in three dimensions, direction cosines, vectors, etc. In analytics it should cover the idea of rectangular co-ordinates in two and in three dimensions; distances; lengths of lines; angles between lines; equation of the line, the circle, the ellipse, the parabola, foci, eccentricity, axes, curves as loci, intersections as solutions of simultaneous equations. The course should also include the description of the chief regular solids, such as the

circular cone and sphere, the surface and volume of a sphere and the analytical measure of plane and solid angles.

The availability of this knowledge for any freshman course in science is becoming absolutely essential, and this is the only excuse for advocating a course that cannot possibly be made systematic or entirely rigid. Perhaps the proposed courses in general mathematics will accomplish this object without the credit of the additional unit. I am told by our mathematics department that the question of general mathematics is largely one of detail and that one at least of the more recent books meets many of the objections of the more rigid and formal mathematicians.

An essential requisite is that this new unit shall be reflected in the college entrance examinations, so long as these are retained. This should be done by requiring problems to be worked involving them and not by asking for proofs of formulae, etc. Looking over the Entrance Board Comprehensive Examinations for several years, I am struck with the entirely academic character of the mathematical papers, and blame the poor showing of students in science largely on the type of teaching which they must engender. To be of real use such a course as I have suggested should limit the cramming of formulae to the most essential ones and otherwise should eschew the whole formula idea in teaching.

General Science: The course should be of a type similar to Hessler's *General Science*, which happens to be known to me. Those based on the project idea, "Science in the Home," and all the rest of it, confuse the idea of teaching with that of learning for one's self. Boys and girls ought to be taught to apply all their studies, including science, to their everyday life; this should, in fact, be their laboratory. Books of the project type could well be used as reference books for home study in connection with a more systematic and rigid course taught at school. Too much stress cannot be laid on encouraging the student to observe what goes on around him and to seek the explanation, and the course in general science should foster this in every way, perhaps by asking for periodic reports of something that the student has looked up for himself. It should develop the student's perceptions quantitatively in terms of common units. He should be encouraged to estimate dimensions, weights of bodies, to grade temperatures roughly, and to note the salient characteristics of common materials; that brass and steel are springy, copper much less so, and lead hardly at all, and all such facts. In other words, his observations should be concrete.

Students now enter Johns Hopkins who do not know steel from copper or oak from cherry.

Where mathematics is used in general science it should be of the simplest, and the formula should be avoided like poison.

3. *Second Course in Science:* The second course should afford an exercise in applying the first course along some definite single line, and physical geography is suggested not because of its own importance so much, as because it appears to apply physics, chemistry, biology and geology most simply and aptly. Moreover one might use such a book as Huxley's *Physiography*, or Geikie's *Physical Geography*, which are not cut up into pills for ready cramming, but have an additional value as literature and as the work of two masters of science.

4. *Physics and Chemistry Course:* The schools should decide whether the two subjects should be taught parallel, or one should follow the other. The essential idea is to give a more precise and extended knowledge of each subject than can be given in general science, but to avoid a course in any way similar to the college one, or which might possibly be looked upon as an abridgment of it or an attempt to serve the same purpose. Each subject should be taught so as to afford that general basis for the other subject which is needed so much in college. The college course in General Chemistry must deal with fluid pressure, manometers, barometers, thermometers, melting and boiling points, temperature scales, the gas law, ions, electrochemical equivalents, refractivities, and so on. General Physics must discuss molecules, atoms, combining weights, chemical equivalents, formulae of simple chemical compounds, energy relations in solution and crystallization and in chemical reactions. The school course ought to furnish this background in a pretty definite form without attempting the rigid systematization and the completeness of the college course on the one hand, or becoming merely a heterogeneous mass of miscellaneous information on the other. Amongst other things it should give the student the same general picture of the structure of matter, which is in the college teacher's mind, and which is so familiar to him that he may not realize its absence from that of the student. The entering student should picture matter to himself in terms of the general concepts of the kinetic theory, as made up of atoms, molecules, ions, electrons, in motion. He should use these terms with reasonable correctness and should have a general idea how the familiar properties of natural bodies are explained by a hypo-

thesis, which is a matter of course to the scientist but quite foreign to the minds of the uneducated.

Chemistry: Being unfortunately not at home in chemistry, mine being self taught, the only suggestion I am prepared to make is on the authority of our department of chemistry. They think that the course should be limited to the non-metals, and that if this were done there might be a substantial saving of time in the college course, which would cover this part of the subject by a comparatively brief review. Qualitative analysis they are much opposed to, as the number of reactions really at the command of the student is too small, even after the most elaborate of the present school courses. In fact, qualitative analysis at Johns Hopkins has now been changed to the end of the second year of chemistry, following after quantitative analysis. It affords a useful review of a much more complete course, and, if taught by other than cook-book methods, it is really harder than quantitative analysis.

Physics: In the field of physics I am naturally more at home. Since physics is essentially quantitative, it would be hard to give a useful course, which does not involve measuring and computing. The student should also be taught to demand proof of a scientific statement and, the laws of physics being mostly quantitative, a quantitative proof is necessary. On the other hand even our college courses carry rationalization much too far. To the physicist the great attraction of the science is the possibility of deducing its laws from a very small number of great concepts, but more judgment is necessary than is commonly shown in carrying this process into elementary teaching. The ultimate basis being experiment, it seems to be merely a question of pedagogics whether in a given course we assume two fundamental experimental laws and deduce twenty others from them, or assume ten and deduce the other ten. The vital and illuminating associations between one phenomenon and another, for instance, between Archimedes' Principle or Torricelli's Law of Efflux and the conservation of energy, should be guarded by all means and many deductions of one phenomenon from another should be made to teach such associations. But the simple proofs are the valuable ones in elementary instruction, and we should always beware of the proof which has no point except the attempt to rationalize, particularly when the attempt is incomplete. For example, the deduction of the Principle of Moments in Jean's Theoretical Mechanics from the dynamics of a particle

and the degrees of freedom of a rigid body is a splendid exercise in reasoning for an advanced student. A similar discussion is wholly out of place in an elementary book, even for college students, and the deduction is usually so incomplete that it not only does not inform but fails to convince. Why not state both the principles of equilibrium of a rigid body baldly as experimental laws, and begin right there?

In a school course in physics, one should keep very close to an experimental basis with as little theory and mathematical deduction as possible. One should emphasize the great quantitative laws, however, but be very careful not to let them become formulae. In mechanics, one should emphasize equilibrium of forces, work and energy. One should introduce conservation of energy as early as possible and use it as the connecting thread for the whole course. Properties of matter are easily treated experimentally—particularly hydrostatics and gases—and so is heat. One should deal very lightly with electrostatics and magnetism and dwell on the fundamentals of direct currents. Periodic motion and waves should be taken up descriptively, defining the technical properties frequency, wave-length, etc., and calling attention to energy changes in vibrations and the propagation of energy by waves. Dwell on the physical explanations of lenses and mirrors and generally emphasize physical rather than geometrical optics. Give a great many simple numerical problems, but avoid formulae, except possibly a few expressions of very frequent occurrence, and these only allowed after many similar examples without formal statement of the equation. One should be very particular about units, and that the student understands the arbitrary nature of the process by which a number is made to represent a concrete quantity. He must also be accustomed at the start to the fact that an equation representing a law will vary with the units, so that the law is the thing to learn, not the equation.

Avoid formal definitions, but be very careful in the use of terms to follow the precise usage of the science. For instance, one should never use "*power*" except for rate of work. Instill the correct significance of a term and not an analogy. For example: An electromotive force is often described as a "pressure," forcing the current through the wire. The energy relations of the circuit present no greater difficulty and lead to a correct idea of e. m. f. as the amount of energy furnished the circuit by the source of energy per unit charge passing through.

As in the case of mathematics, the college entrance examination would have to be shaped to encourage such a course. The papers now given seem vastly better than those in mathematics, but there should be more descriptive questions and fewer for which formulae can be crammed. For example, one might ask such questions as: "What three fundamental phenomena combine to produce the increasing resistance experienced in pumping up a tire? State the laws of these phenomena and the names by which these laws are known." Or "Explain fully why a distant object may be seen clearly through a convex lens if far enough from the lens or near enough to it, but becomes blurred at an intermediate distance."

Laboratory Work: The laboratory work should be largely qualitative and consist of many short and simple experiments rather than elaborate ones. The apparatus should generally be simple and all parts readily visible. But whenever measurements are made, reasonable care and precision must be insisted upon, to train the faculties and to avoid the formation of careless habits. A neat and systematic original entry, curves well plotted to intelligently selected scales, and computations neatly entered, should be insisted upon. Mental arithmetic, logarithms and the slide-rule should be the only methods of computation tolerated, and the observance of significant figures should be taught. The student should be taught to criticize his own work and that the importance of a given mistake depends on its proportion to the quantity sought.

The school should, however, not shirk its share of the duller drill work of actual training in simple, scientific technique. Not only should the student be taught such things as simple glass blowing, electrical connections, etc., which have some fun in them, but should be drilled in the precise and correct use of the commonest scientific instruments, which require no theoretical knowledge whatever. For example: Measuring time intervals to a fraction of a second with an ordinary watch; correct and incorrect use of a rule, and eye estimates of fractions of a division; testing a thermometer, reading it to a tenth of a degree, and a reasonably sound technique in its use; reading a barometer and correcting it for temperature; use of calipers, including verniers; how to focus a microscope or telescope; weighing rapidly and up to the accuracy of the balance provided. He should from the start be taught the fallibility of instruments and form the habit of

noting zero readings and making simple scale corrections. In other words: "*Start him right!*"

Summary: If four science units are accepted for entrance they should be modified so as to include:

1. A course in general science intended to familiarize the pupil with the most obvious natural phenomena, without reference to the science under which they are commonly classified, and also with the characteristic properties of common objects and materials. It should not be of the "project" type, but projects may be assigned for outside reading or as subjects for compositions.

2. A more systematic course in some one science applying the knowledge gained in general science.

3. A course, which might be styled "physical science" combining both physics and chemistry and intended simply to give that fundamental knowledge of each which is essential to the intelligent study of the other. That is, it should be preparatory to the college courses in these subjects in the same way that the general science introductory course is preparatory to course (2). It differs from the first course by being more advanced and thorough, but must on no account forestall or be an abridgment of the college courses. The laboratory work should be illustrative and simple, and such as to demand little theoretical knowledge, but it should include training in simple laboratory technique, and care should be taken that good habits are formed.

4. A course in mathematics intended specifically to prepare the students for the study of science in college.

It is intended that the last two courses shall be taken simultaneously in the last year before entrance. A high school student who does not expect to go to college might advantageously take the first two courses, and possibly that in mathematics, but a more practical type of course should by all means be substituted for that in physical science as outlined.

SODIUM WIDELY DISTRIBUTED

The element sodium is very widely distributed in the earth. It forms about 2.36 per cent of known terrestrial matter, according to the United States Geological Survey, and is the most abundant of the alkali metals. Sodium appears to occur in nature only in combination with other elements, if its alleged occurrence as the free element in blue rock salt is neglected. It is an important constituent of the feldspars and several other insoluble minerals from which sodium salts are not extracted commercially but which are nevertheless regarded as the ultimate source of the salts that are soluble in water.