aiding astronomers of all countries in their work. Miss Bruce, in 1890, besides her numerous other gifts to astronomy, gave the sum of $6,000 to be distributed in this way. The 15 donations are described in a circular issued in 1891. Many investigations require such large sums of money that they could not be provided for by such funds as these. On the other hand, a small sum judiciously expended sometimes leads to much larger gifts, and may furnish an observer with an instrument, an assistant, or means for publication. A small gift may thus render available, resources of vastly greater value which would otherwise lead to no useful result. For instance, the writer in 1882 received an appropriation of $500 from the Rumford fund, for an investigation in astronomical photography. Presenting the results of this work to the trustees of the Bache fund, he received an appropriation of $3,000, with which an 8-inch photographic telescope was constructed. Twenty-six thousand photographs have since been taken with this instrument which for many years has been used throughout every clear night at the Arequipa Station of the Harvard College Observatory. The early results were presented to Mrs. Henry Draper, who accordingly had a similar 8-inch telescope constructed. This instrument is used here throughout every clear night, on the northern stars, thus supplementing the work of the Bache telescope. With this instrument, also, 26,000 photographs have been obtained. The early results of the Henry Draper Memorial led to the transfer of the Boyden fund, exceeding $200,000, to the Harvard College Observatory, and also to the gift of $50,000 by Miss C. W. Bruce, with which a 24-inch telescope, now successfully at work in Arequipa, was constructed. The results attained by each gift thus helped to secure the next. Again, an appropriation of $500 from the Rumford fund, in 1899, enabled the Directors of the Yerkes, Lick, McCormick and Harvard observatories to cooperate, so that telescopes of 40, 36, 26, 15, and 12 inches aperture are now being used in the same research on the light of very faint stars. The value of the plant utilized in this research exceeds a million dollars. It is hoped that similar cooperation can be secured in continuous observations of the variable stars of long period. In many cases an award of a small sum to an observatory will assure its friends of the value of the work and thus encourage them to contribute liberally. It is believed by the writer that the real difficulty lies in the lack of knowledge of what funds are available, diffidence in presenting applications, and in some cases objection to the restrictions under which the grants may be made. Could these difficulties be remedied by a permanent committee, and if so, how should it be appointed? In no country have such sums of money been given to science as in the United States; in fact, the success so far attained and our future prospects for research depend largely upon such gifts. It is believed that in many cases wealthy men and women would gladly aid scientific investigation if they could be sure that their gifts would be judiciously and economically expended. It is, therefore, of the greatest importance to all scientific men, not only to secure aid for important researches, but to prevent, if possible, the unwise or wasteful expenditure of such money. The writer desires to learn the views of others on this matter, either through the columns of SCIENCE, or by personal correspondence.

EDWARD C. PICKERING.

CAMBRIDGE, MASS., January 25, 1901.

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*RESEARCH WORK FOR PHYSICS TEACHERS.**

THE teaching of physics is in itself a delightful thing, but to be thoroughly enjoyed

* An abstract of a paper read before the Physics Club of New York, December, 1900.

it should be plentifully seasoned with research. Science in the past has been indebted in a very great measure for its progress to the teaching class. An inquiry into the statistics of this subject, which I had occasion to make some years ago, and in which I attempted to classify the professions of all the authors up to the middle of the present century, who are sufficiently known to have found a place in the pages of Poggendorff's Dictionary, showed that nearly 90 per cent. of the scientific work of the world had been done by teachers. The remainder was divided almost equally between the members of the medical profession and the clergy. Law was found to be almost entirely unrepresented, the most notable instance of a lawyer who has left a name in science being that of Bacon. There has been of course a considerable number of amateurs in science, and the list contains some famous names, such, in physics, for examples, as Joule in England, and Holtz, Elster and Geitel in Germany; but taken numerically this class shows a very small percentage in the tables. Great as the attainments of the teacher in investigation have been when compared with those of the remainder of the community, the statistics show that in this country at least not more than ten per cent. even of college men engaged in the teaching of physics can be counted as belonging to the ranks of the producers. I have been unable to extend the inquiry to physics teachers in secondary schools, not through any difficulty in enumerating those whose names appear in scientific authorship, but through ignorance as to the total number who are engaged in teaching the subject in the United States. It is clear, however, that the ratio would be even smaller than in the case of those who are teaching in our colleges and universities.

That there are very great and very real difficulties any one who has attempted to carry on research and teaching at the same time must admit. The principal excuses offered for the abandonment of any attempt at scientific performance are *lack of time*, *lack of apparatus* and *lack of the necessary qualifications for the work*. A comparison of college teachers with the teachers in the secondary schools in these respects has led me to the opinion that the differences of opportunity are much smaller than is commonly supposed. Science teachers, both in the college and in the school, are unquestionably overworked. The tax upon the nervous system of the proper teaching of science is very great, and it is more often the want of surplus energy with which to carry on investigation, than lack of actual time or of the necessary equipment that defeats us. The actual number of hours demanded of teachers is small as compared with that required by many other callings; so much so, that by the outsider the teacher is apt to be regarded as belonging to the leisure class; but measured in terms of vital energy those hours, as we all know, are quite long enough.

The plea of lack of qualification for research is one which the college man feels less free to make than does the teacher in the secondary schools; because he knows that whether he has such qualifications or not he is at least supposed to possess them; whereas it has not yet been demanded of secondary school teachers that they should be capable of actual scientific productiveness. This difference of standard I believe is a false one and most unfortunate; for it is certainly more difficult to teach successfully the beginnings of a subject than to conduct advanced work. The real explanation of the comparative unproductiveness of secondary school teachers lies, I am convinced, in the absence of *the habit of investigation*, a habit which like all others must be acquired by practise and maintained by continued practise. Research flourishes only in a certain atmosphere, and this atmosphere is to be found only where scientific work is going on. Some little corner of time can always be found even by some of the most overburdened of us, and as to equipment, it should not be forgotten that the scientific appliances at command of the school teacher of the present day are greatly superior to those of the average college man of a generation ago, and are not greatly behind those of the average college man of the present. Yet there was great scientific activity in certain localities at a time when laboratories, as we know them, had not yet come into existence. Men are still living who can remember when the first chemical laboratory in Germany was established by Liebig, and one need not to be very old to look back upon the beginnings of laboratory instruction in this country.

Qualification for research must always be acquired by individual effort. Any one who is really fit to teach science has at least the latent gift necessary to the investigator. To develop the gift he must, however, cultivate the habit of scientific reading and the habit of experimentation. The number of science journals is now so great that no one can longer pretend to read them all; but we have in the admirable summary entitled, *Science Abstracts*, and in *Wiedemann's Beiblätter*, the results of the whole world of physics presented in brief form. One of these two journals should be taken by every physics teacher, and in addition he should subscribe to and read some one of the standard journals devoted to his subject.

Given a well-developed habit of experimentation, it only remains to select some topic and to study that persistently to the point of obtaining definite results before taking up another. All subjects for investigation are not equally within the reach of the teacher in the secondary schools. We can not, for example, expect to duplicate in our laboratories the thousands of storage cells necessary to the carrying on of the researches upon which Professor Trowbridge, of Harvard University, is engaged, nor to lay out large sums for apparatus of any other kind. As a rule, the apparatus necessary to an investigation is, however, not very expensive; certain standard instruments, such as the balance, the thermometer, the spectroscope and the galvanometer, are to be found in every decently equipped school at the present day, and work of the highest interest can be done by supplementing these with special apparatus which may be either home-made or may be obtained at a small cost by employing our ordinary artisans.

The following suggestions of topics for research which may be pursued without elaborate or unusual apparatus in the spare time of any one who possesses the intense love of experimentation, characteristic of the true man of science, may serve to show that there is no lack of material within the reach of every ambitious physics teacher.

The temperature at which pure water reaches its maximum density has been carefully determined, and it is known that the introduction of a gas such as ammonia, which is largely absorbed by water, or of a salt in solution like sodium chloride, or of alcohol or sulphuric acid, not only lowers the freezing point and changes the density of the liquid, but that the point of maximum density falls, as the amount of added substance is increased, more rapidly than the freezing point itself; until finally the phenomenon of maximum density disappears altogether. Any one who possesses a good thermometer reading to low temperatures or who has sufficient skill and experience to make and calibrate a thermo-junction can readily extend this investigation to solutions and mixtures not yet studied. The only instruments required for such investigation, aside from the usual laboratory utensils, are a good thermometer and a

Fahrenheit hydrometer, or a hydrometer of the variable immersion type with the diameter of the neck reduced to the least practicable size. The work is of sufficient delicacy to tax the manipulative skill of the observer, and the investigation is on this account worth the doing simply as practise work, while the results of a careful study of the subject would be welcomed by any of our standard journals of physics. By a similar method, studies may be made of the density and coefficient of expansion of liquids having low freezing points, such as alcohol, ether and carbon disulphide. Something has been done in this line, but the subject is far from being exhausted. By the use of liquid carbon dioxide and ether one can readily reach the temperature −80° C., and it is probable that the time is near when liquid air will be available for the extension of such work to much lower temperatures. Data upon subjects such as these are useful even though no startlingly new phenomena be brought to light, and the observer has before him the possibility of discovering new and important relations which may have a bearing upon our theories of the nature of matter. The verification through this extended range of temperatures, viz., from −80°, and ultimately from −200°, upwards, the law already theoretically established by Van der Waals * for the relation of the expansion of liquids to their critical temperatures; or, failing in that, the experimental demonstration of the necessity of a modification of the theory, would be in itself ample incentive for the investigation.

The subject of specific heats at low temperatures is still awaiting the attention of our experimental physicists. H. F. Weber † a quarter of a century ago studied boron and silicon, in this respect, down to −40° C. and carbon to −50° C., with most interesting results, after which comparatively little was done until 1898, when Behn * obtained values for several metals down to −200°. The specific heat of a great variety of solids and liquids still remains to be determined through the greater range of temperatures now within our reach, and the calorimetric observations are no more difficult nor elaborate at low than at high temperatures. Any one who can set up and calibrate a Bunsen ice calorimeter is in position to make the measurements. A cylinder of carbon dioxide and a can of ether will give refrigeration to −80° C. and perhaps by the time the work for this range of temperatures is completed it may be possible to order a gallon of liquid air by telephone at a reasonable cost and thus readily extend the research to −200° C. Temperature measurements are best made in such work by finding the change of resistance in a coil of fine copper wire.

What I have attempted to point out, in a fragmentary way in the case of two or three particular problems is true of the whole domain of physics. No research is ever complete. However exhaustive it may at first sight appear, it will, when critically considered, be found to afford merely a starting point from which to push further out into the infinite region of the unknown which lies beyond the boundaries of our present knowledge. Every theoretical discussion is based upon assumptions which must be tested experimentally, and such tests usually lead to new and more accurate knowledge of the properties of matter and ultimately to modifications of the theory. Thus Poisson, long since, pointed out that the numerical value of the ratio for the relative contraction of the diameter of a stretched rod to the elongation would be one-fourth for all substances for which the assumption

* Van der Waals, 'Continuität des gasförmingen und flüssigen Zustándes.' Leipzig, 1881.

† H. F. Weber, *Poggendorff's Annalen*, 154, pp. 367 (1875).

* Behn, *Wiedemann's Annalen*, 66, pp. 237 (1898).

made in his theory of elasticity holds true. Measurements, however, showed widely varying values for Poisson's ratio and led to important modifications of the theory. All this may be thought to belong to the ancient history of the science, but to-day, after nearly half a century, exact data are known for only a few substances. I do not mention this as one of the determinations especially adapted to the secondary school laboratory. The quantity to be observed is, of course, exceedingly small. Still the method by which I am accustomed to illustrate the phenomenon to my classes; that of stretching a glass tube filled with mercury and noting the fall of the liquid in the very fine capillary neck gives a good result with glass, and would probably be adaptable without serious difficulties to such other materials as can be obtained in the form of tubes. With the interferometer, direct measurements of the change of diameter ought to be readily made but this instrument is at present not a part of our school equipments.

Another field of work which is easily opened to physics teachers in our secondary schools is that of the study of flame temperatures. The temperatures of the Bunsen burner, the ordinary luminous gas flame, the candle flame and the acetylene flame are already pretty well established, although many important details which are capable of being worked out by a patient observer are still lacking. When it comes to the question of other flames than these, we have only the wildest estimates based upon measurements made by methods, the inadequacy of which has been abundantly demonstrated. The flames of alcohol, of ether and of carbon disulphide burning in air would afford subjects for an interesting and profitable study during one's leisure hours. The apparatus needed for such a research consists of a fairly sensitive galvanometer, a resistance box and a standard cell, together with about one meter each of platinum and platinum-rhodium wire. The obstacles to even approximately accurate high temperature work have until recently been almost insuperable on account of the difficulty of calibrating the thermo-element used; but I have shown in a recent paper* how the very elaborate and laborious methods of calibration hitherto employed by those engaged in such work may be avoided without loss of accuracy and how by the ingenious method first employed by Waggener† in the study of the Bunsen burner, and subsequently by myself for the measurement of the acetylene flame, the heat losses in the thermo-junction which had vitiated the results of earlier observers may be eliminated.

We physics teachers have amused ourselves at one time or another, like many other people, with photography, and a few of us, doubtless, deserve to be classed as experts in the fascinating art. Herein lies a double opportunity for research; in the further development of the science which underlies photographic processes and in the application of the photographic method to the numerous problems in physics to which it is especially adapted. Consider, for example, in illustration of the former, the fruitful field of inquiry suggested by Professor Nipher's‡ recent memoir upon the action of light and of the X-rays on previously exposed plates, and of the latter the countless investigations of recent years in which the photographic plate has been utilized for recording and studying the phenomena of our science.

By means of a camera containing a revolving drum, upon which a piece of the flexible film used in the making of ani-

* Nichols, *Physical Review*, Vol. X., p. 324.

† Waggener, *Wiedemann's Annalen*, Vol. LVIII., p. 579.

‡ Nipher, *Transactions of the St. Louis Academy of Sciences* (1900).

mated pictures may be mounted, a great variety of interesting work may be performed. Professor Merritt* and I have shown in a recent paper that very beautiful photographs of the manometric flame are obtainable with the aid of such an instrument, and Professor Hallock has made use of a similar method in an extended analysis of the human voice. Any one who has the patience to systematically study and interpret records of this sort, might add greatly to our knowledge of the physics of articulate speech. With the same instrument the motions of vibrating strings and rods and the decadence of overtones with the time may be studied. The instrument is, indeed, applicable to a very great variety of short-time phenomena, such, for example as the duration of exposure obtained by various flash powders, a subject of which at present our knowledge is very incomplete.

Still another interesting line of work within the reach of physics teachers in our secondary schools consists of the photography of the infra-red spectrum. Becquerel showed many years ago that the fluorescence of calcium sulphide and other substances could be checked and almost annihilated by the long waves of the spectrum, and Fomm, a student of von Lommel, in 1890 succeeded in photographing the infra-red spectrum of the sun by placing a fluorescent screen in the spectral image and subsequently making a contact print by laying the screen face to face with an ordinary sensitive dry plate. In this way he was able to identify and determine the wave lengths of numerous dark lines in the spectrum. The absorption spectra of chlorophyll, of water, of the salts of didymium, samarium, erbium and of other substances which possess well-marked bands in the visible spectrum, have been mapped in this way by Becquerel, but his work should be repeated since his estimation of wave-lengths is known to be entirely at fault. The number of substances as yet untested is very great and the accurate investigation of them might lead to results of high importance. The method of direct photography by means of plates sensitized for the infra-red is probably to be preferred for such work, to the troublesome use of the fluorescent screen.

Finally, not to extend this list of feasible experiments further, permit me to remind my fellow teachers of physics that we have in the spectro-photometer, an instrument by means of which one may investigate visible radiation, reflecting power and the transmission of light, by all sorts of substances. It is a great convenience in such work to have at hand the very perfect modern instruments designed by Lummer and Brodhun or by Brace. I am aware that none of our school laboratories are likely to contain such apparatus; but it is only necessary to purchase a Vierordt slit and to adapt the same to any good ordinary spectroscope in order to be in position to do good spectro-photometric work.

I have attempted in this paper to mention only a few of the numerous topics of research available for physics teachers. It is one of the characteristics of our science, that every contribution to our knowledge brings with it a group of further problems to be solved. One can not read intelligently any memoir describing experimental work without perceiving the possibility of extending the investigation further. The one essential requisite to the carrying out of the suggestions thus received is that burning desire to try things for one's self which characterizes the investigator. Such a desire is the fruit of that habit of experimentation to which I have already referred, a habit which I deem it the first duty of every one, who has the ambition to lay claim to the title of man of science, to foster and

* Nichols and Merritt, *Physical Review*, Vol. VII., p. 93.

cultivate. Given this desire for research, which is the inevitable result of the habit of experimentation in every one whose mind is fit for scientific pursuits, and all other difficulties, those of time, opportunity and equipment can be overcome. Certain lines of investigation which one would gladly follow must indeed be abandoned for lack of means with which to pursue them; but he who keeps alive his knowledge of scientific progress by the systematic reading of the literature of first sources need never lack topics of research.

The proper stimulus for scientific work is the love of experimentation for its own sake rather than any desire or expectation of fame; the delight of witnessing the wonderful performances of matter under conditions conceived and imposed by ourselves, rather than the hope of achieving some momentous result. At the same time we should not forget that the very simplest phenomenon of nature is worthy of our closest, even of our reverent attention and that some experiment as seemingly unimportant as the shooting of quartz fibers, may, like that now famous operation of a fellow teacher (Boys), be ultimately of inestimable value to science.

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ON ECLIPSE PHOTOGRAPHY.

SOME months ago the writer suggested that the dangers of over-exposure in photographing eclipses might be avoided by a long exposure covering the entire totality of the eclipse, and a development of the plate as a positive in the light. Since that time the interval of exposure in the camera has been considerably reduced by increasing the illumination of the plate while in the developing bath. Plates can with proper exposure be developed in direct sunlight, with a reflected beam of sunlight also thrown down upon the plate. But while such pictures leave nothing to be desired for clearness and sharpness of detail, they do not show any details which can not be brought out in a negative. Moreover, the exposure required to produce a good positive is still rather too long to make this method in its present condition seem of much advantage in eclipse work.

But it has also been found that the developer best suited to producing fine positives will develop beautiful negatives in the dark-room, on plates that have been over-exposed as much as two thousand times. Such plates thus exposed may be developed either as negatives in a perfectly dark room, or as equally good positives in a light room, and with the same developer. Where the normal camera time is a tenth of a second, the exposure may be as great as three minutes and a half, and still secure a sharp crisp negative. With greater exposures it is better to develop the plate as a positive in the light room.

The developer recommended, as the best so far tried, is hydrochinone made up according to Cramer's formula, with the bromide left out. The sodium carbonate solution may be made up at half the strength given in the formula if the developing is to go on slowly. To half an ounce of the mixture of solutions one and two, add an ounce and a half of water and four or five drops of saturated hypo solution.

When the plate has been normally exposed and it is treated with this developer containing two drops of hypo, in a covered tray in the dark room, nothing will develop for 30 or 40 minutes. But in course of an hour and a half the picture will be fully developed. The details will show sharply through the film. The tray should be uncovered as little as possible. The plate is sensitive even to red light. Until the last stages of development are reached, the exposures for examination of the plate