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Grundfagligt speciale: An advanced laboratory-research course for nonphysicists taught by physicists

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The pedagogical and research advantages of an advanced laboratory-research course for nonphysicists taught by physicists are discussed. The practical considerations which determine the structure and content of such a course are emphasized with particular attention given to those features which would be most helpful to others contemplating a similar course. A successful example of such a course developed by the authors is discussed in detail.

I. INTRODUCTION

Physics lecture courses for nonphysics students from a large number of other disciplines such as geology, biology, medicine, etc., have been discussed in detail in the literature.¹⁻⁴ Such lecture courses have been very well received and have clearly shown that the subject matter of physics can be profitably presented in a more general context than that normally found in conventional physics courses. In spite of this success, there has been very little work describing physics laboratory courses for nonphysics students in which a presentation of the experimental side of physics in a more general context has been similarly emphasized. In particular, there have been no published accounts of a laboratory course of this type at the applied research-oriented level where the advantages of such a presentation to the nonphysics student would be most obvious and direct.⁵ It is the purpose of this article to describe an interdisciplinary laboratory course of this type (*Grundfagligt Speciale*)⁶ in which the emphasis is placed on the application of the experimental methodology of physics to problems of potential research interest to the nonphysicist. Special attention is given to those practical considerations which determine the structure and content of such a course with particular emphasis on the unique pedagogical and research possibilities which can be conveniently realized. A number of other features likely to be useful to those contemplating a similar course, or interdisciplinary courses in general, are also treated in detail.

II. STRUCTURE OF THE COURSE

The structure of the course was strongly influenced by the fact that most of the experimental methods of physics likely to be of potential research interest to the nonphysicist tend to be instrumentally more difficult, requiring both a longer learning time and a thorough familiarity with the basic concepts of physics on the part of the nonphysics student. This is by no means a disadvantage, however, since the more sophisticated experimental methods frequently offer the most promising interdisciplinary research possibilities and can, in fact, be readily assimilated by a group of two or three students concentrating on a single experimental technique for an entire semester. In practice, different groups of students could concentrate either on dif-

ferent experimental techniques or on one of several different projects based on the same experimental technique. In order to more fully master a given experimental technique, it is desirable that the nonphysics students have a previous educational background corresponding to that obtained, for example, by competent senior or first-year graduate students at most American universities including both a thorough familiarity with basic physics as well as a mature appreciation of the research possibilities within their own nonphysics discipline. The latter requirement is, of course, essential in a course such as *Grundfagligt Speciale* where the students are intentionally encouraged to select experiments and interpret measurements relevant to their own field. One natural consequence of a laboratory course for nonphysics students at this level is that it provides a well-motivated opportunity for the mature nonphysics student to develop an active practical experimental familiarity with physics before being totally absorbed in nonphysics course work. The plan of the course was, in fact, developed with precisely this feature in mind as can be seen in Fig. 1 where the overall linear progression of the course from an initial learning period to a detailed concentration on a single research-oriented application is clearly shown. More specifically, the object of the initial training period was to familiarize the students with the operation and potential applications of a given experimental technique in sufficient detail that they could carry out standard measurements on their own and at the same time acquire an active practical awareness of which modifications of the experimental technique could be made for specific applications.

It is worthwhile pointing out that the course plan shown in Fig. 1 is essentially the Keller⁷ PSI self-paced system of instruction adapted to an advanced laboratory-research course. One difference, however, is the fact that the self-pacing feature, whereby the students must demonstrate mastery of a given part of the course before proceeding to the next, enters in a completely natural way as a consequence of the linear-progression structure necessary to teach a single experimental technique. Another important difference is that there is a good deal of overlap between the various course units shown in Fig. 1. In spite of the fact that such an overlapping structure has not, to our knowledge, been incorporated in a PSI course before, it is probably essential in a laboratory-research course such as *Grundfagligt Speciale* where the learning process necessarily

Fig. 3. Simple ESR spectra from unpaired electron spins in several different liquid solutions recorded using the spectrometer shown in Fig. 2. The ESR spectra in Figs. 3(a) and 3(b) were recorded without the flow system and show the contact hyperfine interaction of an electron spin located between the *N*-atoms [in Fig. 3(a) for a benzene solution] and at the site of the *NO*-radical [in Fig. 3(b) for an aqueous solution]. Figures 3(c)–3(e) were recorded using the flow system to study intermediate reaction products of several different hydroquinone and alkaline solutions. These last three spectra represent the contact hyperfine interaction of an unpaired electron spin with four [Fig. 3(c)], three [Fig. 3(d)], and two [Fig. 3(e)] equivalent hydrogen atoms on the central benzene rings. The additional subsidiary resonances in Fig. 3(d) are due to trace impurities of dichlorosemiquinone whose presence was also confirmed by thin-layer chromatography.

somewhat lesser amount of time spent in reading and laboratory preparation. Although a course load of this size is probably larger than that normally allocated to laboratory courses at many American universities, for example, it could be formally distributed over a two-semester course or reduced somewhat in its depth of detail without defeating the primary purpose of the course.

Near the end of the first half semester, a number of contacts and visits with chemical laboratories using ESR were arranged which helped to provide a more definite impression of the chemical possibilities inherent in ESR. Based on these contacts as well as on their own study of the research literature, the students were able to make a number of concrete proposals regarding those chemical applications of ESR in which they were most interested. Both the instrumental requirements of the various proposals and the advanced instrumental and technical support which the physicist teachers could offer were used as criteria in selecting a single application to be studied in the last half semester of the course. In our case, the students decided to study transient chemical reactions in the liquid phase which required an efficient flow system and an optimized superheterodyne receiver. The flow system was used to measure free electron ESR signals of various intermediate re-

action products formed during the chemical reaction process. This enabled the students to study a number of short-lived chemical reactions which were otherwise too rapid to be observed by normal chemical methods. Some of the simpler components could be built in the department workshop but the more specialized, expensive components of the flow system such as the pump and the chemical mixing cell were borrowed from other nonphysics departments. A number of different standard chemical reactions involving short-lived radicals (see Fig. 3) were investigated using ESR. This provided a check of spectrometer capabilities and practical information regarding those chemical systems which would be most feasible for a concentrated flow-system study in a research context. The final exclusively research-oriented phase of the course dealt with a quantitative experimental reexamination of previous measurements of intermediate-reaction products in hydroquinone solutions.¹³ This particular choice also made it possible to use the earlier published results as a means of checking the validity of the measurements obtained. More research-oriented measurements could, of course, be carried out depending on the particular educational background of the individual groups and the nature of the measurements themselves. The course itself was concluded by the writing of a report by the students in sufficient detail that other students and teachers would be able to repeat the work carried out without difficulty. The more specialized chemistry portions of the report were checked by an external chemistry faculty member and the final grade evaluation given in a "pass-fail" grading system.

IV. DISCUSSION

The laboratory-research course described here has been well received by both the students and the faculty members involved. This fact, in addition to the large number of favorable comments from all those less directly involved is, we feel, a clear indication that a course of this type satisfies a real need in providing both the students and the teachers with a unique form of interdisciplinary collaboration of long-term benefit to both. More important, perhaps, is that these advantages can be readily obtained within an extremely flexible course structure easily adapted to fit the special requirements of individual institutions.

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¹G. M. Julian and A. M. Stueber, *Am. J. Phys.* **42**, 556 (1974); B. S. Henderson and M. A. Henderson, *ibid.* **44**, 519 (1976).

²E. L. Chaney, W. R. Hendess, G. S. Ibbott, and M. N. Frank, *Am. J. Phys.* **42**, 465 (1974); M. G. Hare, *ibid.* **41**, 956 (1973).

³R. A. Leacock and H. I. Sharlin, *Am. J. Phys.* **45**, 146 (1977); A. P. French and E. L. Jossen, *ibid.* **44**, 1449 (1976).

⁴M. K. Garrity, *Am. J. Phys.* **45**, 1206 (1977); R. S. Newrock, *ibid.* **46**, 32 (1978).

⁵More precisely, there have been no laboratory courses in which non-physics students both learn and apply a specific experimental method of physics to problems of interest to their own nonphysics discipline in a one-semester course. As discussed in the text, a course of this type has a number of interdisciplinary advantages not to be found in courses employing a conventional course structure in which, for example, a large number of different experimental techniques are presented in one semester or in which a single experimental technique is chosen to be the subject of a master's degree program: A. H. Clark, *Am. J. Phys.* **44**, 696 (1976); V. Elings and D. Phillips, *ibid.* **41**, 570 (1973).

⁶A *Grundfagligt Speciale* (Basic Special) program in which students at the advanced undergraduate level are required to take a half-time semester laboratory course either in their own or in a different discipline has been in operation for several years at the Technical University of Denmark. This is the first time, however, that a course specifically emphasizing physics laboratory techniques has been adapted to such a program.

⁷T. C. Taveggia, *Am. J. Phys.* **44**, 1028 (1976); G. D. Putt, *ibid.* **45**, 472 (1973).

⁸The purpose of the description of ESR presented in the text is to give an illustration of some of the practical details likely to be found in the development of research laboratory courses in general. A particular application of a physics laboratory technique will, of course, involve a number of details specific to the application itself and, in the case of applications to more distantly related fields, e.g., medicine, may require a greater initial effort on the part of the physics faculty in helping to choose a research topic.

⁹L. A. Collins, M. A. Morrison, and P. L. Donoho, *Am. J. Phys.* **42**, 560 (1974); R. E. Norberg, *ibid.* **33**, 71 (1965).

¹⁰C. C. Poole, Jr., *Electron Spin Resonance: A Comprehensive Treatise on Experimental Techniques* (Interscience, London, 1967).

¹¹R. S. Alger, *Electron Paramagnetic Resonance: Techniques and Applications* (Interscience, London, 1967).

¹²J. E. Wertz and J. R. Bolton, *Electron Spin Resonances: Elementary Theory and Practical Applications* (McGraw-Hill, Düsseldorf, 1972).

¹³B. G. Segal, M. Kaplan, and G. K. Fraenkel, *J. Chem. Phys.* **43**, 4191 (1965).