

Teaching the physics of hi-fidelity

How would you like to teach an introductory, general-studies course that is exciting, relevant, contains an enormous amount of "traditional" physics and is guaranteed to produce large quantum jumps in credit-hour generation? Sound unreal? We've been teaching such a course for several years with an enrollment of 1000 students (300 are women!) per semester, and we'd like to share some of the ideas and techniques by which this was accomplished.

Hi-fidelity equipment and recordings, which certainly rank as all-time favorites among college students, have been brought into the classroom and enabled us to present a successful introductory physics course to full enrollments. Innovators over the last few years have discovered the effectiveness of teaching subjects that are of intrinsic student interest and relevance, and hi-fi possesses both of these ingredients to an unparalleled extent. What is not so evident is that the science of hi-fidelity also represents a vehicle through which most of the basic laws of physics can be taught in a unified and coherent manner.

In planning the course our initial concern was to answer the criticisms of non-science oriented students who enroll in a general-studies physics course—they believed that physics requires too much mathematics, as a subject it was too difficult, and they wanted to know, "What can I do with physics ten years from now?" During the initial stages of the "Physics of Hi-Fi" course design, each of these criticisms was considered and specific guidelines were drawn up to obviate them. Here they are:

Most students are mathematically ill-prepared to accept a traditional physics course and, in our opinion, they shouldn't be expected to. The overwhelming majority of physics concepts can be presented easily with good classroom demonstrations and laboratory experiments that will linger in students' minds far longer than a more abstract mathematical analysis. Suppressing analytical rigor does not imply becoming less technical—the study of hi-fi is far more technical than any traditional subject we can conceive of. Remember also that, with hi-fidelity, innate interest and relevancy are such powerful factors that one is able to delve much further than usual into scientific details before losing student attention.

In answer to the complaint that physics



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was too hard, we considered that on a freshman level, general physics should, in principle, be no more difficult than other introductory courses in different disciplines. Physics can be made "easier" if only we would teach it in a more meaningful context and, in terms of sheer fascination, hi-fi is virtually unmatched in the lives of students. In our experience, when teaching the physics of hi-fi, the question of "hardness" becomes academic: In dealing with over four thousand students during the last two years we have never received a single complaint.

Finally, many students often complain that when the "traditional" course is finished, they immediately forget most of what they've learned; what's an art major going to do with $F = ma$, or an accountant with $V = IR$? Our solution to the problem was to introduce a new idea that, up to this point, physics teachers have made little use of: *physics and consumer education*.

Consumer education is of great importance to students today, and the attractiveness of physics can be greatly enhanced if a bridge is established between learning scientific principles and their ultimate relation to the quality, and hence price, of consumer products such as hi-fi equipment. Hi-fi has its roots deeply ingrained in physical laws and the study of such principles automatically leads to an understanding of hi-fi specifications—descriptions that are often so couched in

scientific jargon that the average person has no hope of ever comprehending their implications without mastering the scientific basics. The symbiotic blend of physics and consumer education opens up an exciting new twist in physics teaching that leads to substantial increases in interest and participation.

The teaching of physics via hi-fi is an extremely rewarding endeavor because, in one wave of the hand, all of the well-known objections to science courses can be removed. What remains then are the large numbers of enthusiastic students who are eager to find out how Ohm's Law can make life more pleasant and at the same time, save them a few dollars.

The ideas behind the course. A preliminary survey of hi-fi demonstrates that most of the traditional areas of physics must be thoroughly understood and integrated in order to elucidate the principles of its operation. A few examples follow here.

The summation of simple sine waves via the principle of linear superposition is represented by a record groove that contains the entire audio spectrum encoded in complex undulations. The groove is composed of two independent channels cut into the orthogonal walls—each of which corresponds to the components of the stylus-displacement vector and produces two channels of stereo from what appears to be a single groove. What a beautiful way to present scalars and vectors! Other applications to mechanics would include: Linear speed (speed of magnetic tapes, sound and radio waves), angular speed, acceleration (acceleration of the stylus in record grooves, wow and flutter in records and tapes), Newton's laws (flywheel effects of turntable platters, vertical tracking forces and stylus compliance), resonance (tone-arm resonance, speaker-cone resonance and acoustic resonance of listening rooms) and simple harmonic motion (record grooves and stylus motion, sound waves and speaker-diaphragm motion).

Faraday's law of induction and simple harmonic motion combine to provide a complete picture of how the cartridge translates intricate groove motion into a replicated output voltage. The same law can be applied to playback heads of tape-recording systems and microphones (these allow for a variety of applications in magnetism and electromagnetism).

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concepts, can be introduced to discuss the basics of amplifier transistor circuits, which in turn are fed voltages generated by the cartridge, or tape heads. The concepts of series and parallel resistances enter naturally when considering the connection of multiple loudspeakers to the output of an amplifier. This could be followed with other topics in electricity: Power (power developed by amplifiers, power ratings of speakers and input-power levels to tuners), capacitance and inductors (speaker crossover networks, filters and equalization circuits) and electrostatics (electrostatic loudspeakers and condenser microphones). It is also clear that energy conservation becomes significant because the amplifier-speaker link involves a series of energy transformations from electrical, to magnetic and thermal, to mechanical motion of the diaphragm, and finally to the generation of sound waves.

The correlations between physics concepts and their applications to audio are quite extensive, but this partial listing can be rounded out by mentioning the other topics we've covered in our course: waves and sound (all phases of superposition, interference, wave motion, decibels and Fourier analysis), heat (stylus friction, temperature of power amplifiers, heating of speaker voice coils and cooling of power amplifiers) and electromagnetic waves (radio waves, light waves, modulation principles, polarization, reflection and refraction).

Teaching the course we found the important techniques that have worked well over the last several years have been a good balance of lab time and lecture time, an appropriate choice of texts and a careful planning of the sequence of the topics. The course is offered in a lectures-plus-lab format in a two-thirds, one-third division and the labs have been thoroughly redesigned to reflect the emphasis of an electronic age. The interdisciplinary nature of the course necessitated the selection of three texts, since no single book adequately covered the material span. P. G. Hewitt's *Conceptual Physics* (Little, Brown and Co., Boston, 1974) envelops all the physics principles while the hi-fi material is presented in the *Official Guide to High Fidelity* (Howard W. Sams, Indianapolis, 1974). A third manual, *Insights Into Modern Communications: From Hi-Fi Sound to Laser Beams* (Burgess Publishing Co., Minneapolis, 1975) was written by us to cover the laboratory experiments, behavioral objectives, consumer education and general articles explaining some of the more confusing concepts. At first glance, three texts appear to be rather awkward but, all in all, the format has worked extremely well although we are currently in the process of writing a textbook that integrates all of the above sources.

In a course of this nature the two subjects should be interwoven as closely as possible. One should avoid, for example, introducing physics concepts for the first half of the term and then following with the applications to hi-fi. An effective interweaving technique allows students to recognize immediately the applicability of physics to technology.

The course commences with an in-depth discussion of the anatomy of hi-fi systems for an overview of the nomenclature and a generalized understanding of the components. The direction then turns to a complete discussion of the properties of waves and their correlations with sound; from here, it is natural to proceed into the many types of loudspeaker systems now being produced such as infinite baffle, bass reflex, horns, acoustic suspension and acoustic labyrinth, and how each design has its origin in different physical concepts.

Three weeks are then spent on static and current electricity followed by an introduction to radio waves and modulation techniques, the latter being the familiar method by which information is carried over the airwaves. These ideas are applied by showing the operation of two electronic devices, tuners and amplifiers. Having discussed the basics it is then appropriate to analyze their technical aspects such as sensitivity, power ratings, distortion, frequency response and signal-to-noise ratios—consumer education is coupled with this analysis at the point where students have sufficient knowledge to evaluate and purchase the equipment under examination. (Following each basic science portion of the course, similar consumer-ed sections introduce students to direct applications for each of the various hi-fi components).

The course proceeds to a consideration of the energy conservation laws—a particular concern of students in this area is the heat developed by the amplifier output-power transistors and the tremendous losses incurred in loudspeaker transducers; they are surprised to learn that, in many cases, 98% of the electrical power delivered to speakers is expended in heat, with only 2% being converted into sound.

Mechanics is then inserted with an eye towards its applications to cartridges, turntables, tonearms and tape drives. Compliance, tracking and anti-skating forces are a few examples of the substantial reliance of these devices on mechanics; this leads to valuable knowledge for the student as potential consumer.

The final aspect of the course discusses the important concept of electromagnetic induction and its myriad uses, which include cartridges, magnetic heads, microphones, speakers, transformers and antennas. The last week concludes with extensive remarks on the nature of phone cartridges, tape decks, and, naturally, our friend consumer ed.

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It should be clear from this brief outline that the alternating sequence brings to the program a dynamic and versatile balance between basic and applied science. We should mention that one does not have to be an hi-fi expert to teach such a course—for anyone trained as a physicist who takes the time for a little outside reading, the transition is easy to make. The implicit reward for the effort will be the assurance that physics remains in the mainstream of student education. The explicit reward will be overwhelming enrollments!

While providing a stage for the exposition of physics principles, the physics of hi-fi possesses relevancy and excitement that students can carry with them many years after leaving the classroom. Whenever they turn on a radio, play a record or tape, or simply hum a tune, we are hopeful they will remember the experience of physics—its utility and beauty.

A more detailed version of this report as well as the lab manual are available directly from the authors. The lab manual costs \$5.00.

KENNETH W. JOHNSON
WILLARD W. WALKER
RALPH HARPER
ARTHUR ADAMS

Southern Illinois University at Carbondale

Repression in Argentina

Since the military coup of 24 March, the Argentine scientific and academic establishment, which had already been hard hit by a big purge of the universities under the regime of Isabel Peron, has been decimated to an unprecedented degree by another purge. According to information published in several issues of the Buenos Aires daily *La Opinión* of March, April and May, and from other sources, in the first two months after the coup more than 2000 lost their jobs at the universities and no fewer than 700 at different research institutes, among them the National Science and Technology Research Council, the Physics and Technology Institute at San Miguel, the Atomic Energy Committee, the National Institute of Industrial Technology, the National Institute of Agricultural and Cattle Breeding Technology and other places. According to an estimate by members of the Asociación Física Argentina, one fourth of the members of this organization have lost their jobs. Also grade-school and high-school teachers have been fired, as have several hundreds of physicians, psychologists and social workers at hospitals and mental-health institutions.

These dismissals have been carried out under two laws passed by the Junta, the so-called "security" law and the *ley de prescindibilidad* (not needed personnel

law). The second law allows any public employee to be fired, with the proviso that he or she cannot be given any job in the public sector for the next five years. The leading positions at the universities, like those of rectors, deans of schools and even directors of courses of study (such as psychology and so on) have been taken over by military officers. They have also taken over the leading positions at all research institutes mentioned.

New repressive regulations have been passed at the universities that cover everything from dressing habits to "immoral" and "potentially subversive" actions carried out by teachers and students even outside their institutions. Some university libraries have been depurated of "subversive" literature and the books of Marx and Freud (called "ideological criminals" by an Air Force officer who is now Secretary General of the Universidad Nacional de Cordoba) publicly burned. Several intellectuals have disappeared and may have been killed by the repressive forces, others have been arrested, some have been tortured and some have had their houses plundered. Among those arrested since March or April and not accused of any specific crime nor being tried are the physicists Antonio Misetich and Máximo Victoria and the sociologist Emilio de Ipola. The constitutional right according to which people arrested under an *état de siege* but not being tried could choose to leave the country has been suspended by the Junta.

We are seriously worried by this situation, which can only cause further damage to the development of scientific and cultural activities in Argentina. We call on our colleagues to demand that our imprisoned fellow scientists be freed and that those dismissed should be given back their jobs, as a first step towards the reestablishment of a climate favorable to the development of science and culture.

FELICIANO SÁNCHEZ SINENCIO
EDGARDO CALVA-TÉLLEZ
CARLOS FERNÁNDEZ TOMÁS
*Centro de Investigación Y de Estudios
Avanzados
del Instituto Politécnico Nacional
Mexico City, Mexico*

Nuclear waste disposal

In his letter to the editor (January, page 9), Bernard Cohen presents what he calls a numerical estimate of the health hazards of buried nuclear waste. His conclusion is that the upper limit is 1.1 cancer deaths from the waste produced in generating 400 gigawatt-years of electrical energy, and he illustrates this in his figures 1 and 2. If one reads the text carefully, however, one finds the following condition that must be met in order to expect such a low number: The waste would have to be incorporated into the



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