G. Fred Lee*
University of Texas at Dallas
Dallas, 75080
* G. Fred Lee, PhD, PE, F.ASCE is currently president of
G. Fred Lee & Associates, El Macero, CA
gfredlee@aol.com www.gfredlee.com

Graduate Education in Environmental Chemistry

In recent years there have been a series of chemical crises throughout the world caused by excessive amounts of chemicals such as DDT, mercury, and PCB's in the environment. In each case there was widespread contamination of the aquatic, terrestrial, and atmospheric environment. These chemicals tended to concentrate to such an extent in certain parts of the aquatic or terrestrial ecosystems that the concentrations exceeded previously established standards.

Accompanying these crises, there has been an increased interest in environmental chemistry as it relates to environmental quality control. Chemists have worked in the environmental quality control area since the turn of the century, but only within the last ten or so years have significant numbers of chemists entered this field specifically to work on environmental quality problems. During the 1920's and 1930's many chemistry departments had a faculty member who was concerned with aquatic chemistry. For most departments, when the individual retired, he was not replaced with someone of similar interests. Thus, until very recently, education in chemical aspects of environmental quality control was conducted almost exclusively in colleges of engineering or related programs in the applied sciences.

With the heightened interest in environmental contamination problems, some chemistry departments have developed or renewed an interest in environmental chemistry. This trend is also somewhat stimulated by the belief that substantial research funds are available in this area. Therefore, individuals who have never worked in the area and have little training are developing courses and research programs in the area. This is somewhat ironic in that just a few years ago a faculty member who emphasized work on environmental quality control would have had great difficulties in being promoted to tenure in most chemistry departments. At some schools conflicts have developed between the environmental chemistry programs operated in association with environmental engineering and chemistry departments that are becoming active in this area. This is unfortunate, as there are ample opportunities for all who have a sincere interest in working in environmental quality control.

Many departments of chemistry have recently been considering what their roles should be in the environmental quality control area. Should they develop programs specifically designed to train students for careers in this area? What should be the course offering, what kind of course work should their undergraduate and graduate students obtain? What are the research problems that could be attacked by individuals with a chemistry background, etc? This paper describes an approach which the author feels would be appropriate for departments of chemistry to consider.

Roles of Chemists in Environmental Quality Control

With few exceptions, environmental quality problems are caused by excessive amounts of specific forms of chemicals in the atmospheric, terrestrial, and aquatic environment. There are three basic ways in which chemists can utilize their training in the environmental quality control area. The first of these is by becoming an environmental chemist, i.e., one who studies the environmental behavior of chemical contaminants for the purpose of achieving control of excessive concentrations. He is concerned with the sources of these contaminants, their fate, and their significance. With respect to the latter, the primary attention is given to the concentrations of specific forms of chemical contaminants that can have an adverse affect on various ecosystems. An environmental chemist does not necessarily restrict his work to studies on pollutants in the environment. Some individuals study nonpolluted environments to determine characteristics of the system in the absence of pollutants.

The chemist can work in the environmental quality control area in two other ways. With a minimum of chemistry training, i.e., BS or MS, a chemical technician can perform analysis for contaminants in the environment. Often a person working in this area uses little of his chemistry background, but merely the tools of chemistry. There are instances where individuals with lesser chemistry training are obtaining positions as chemical technicians. Some junior colleges and other schools have initiated training programs in this area.

A chemist with limited training in environmental chemistry can also make significant contributions to environmental quality control by developing specialized skills, usually at the MS or PhD levels, enabling him to work on particular problems encountered by the environmental chemist. For example, with the recent study of excessive amounts of organics in atmospheric and aquatic systems, many pollution control agencies have hired specialists in mass spectrometry to develop techniques for isolation and identification of specific contaminants. The highly trained chemist can also study specific chemical reactions in some detail in an effort to understand the mechanism of the reaction and hopefully bring about more effective controls. An example would be the reactions involving various gas-phase and particulate atmospheric pollutants which produce smog.

The one type of chemist who fits best into the environmental area is the analytical chemist. There is a constant need for improved analytical methods in environmental studies.

Qualifications and Educational Needs of Environmental Chemists

An environmental chemist uses chemistry, physics, biology, and engineering principles to provide the knowledge needed to manage or eliminate environmental quality problems. The qualifications of an individual to work in this area are

1) A strong background in the fundamentals of chemistry, particularly quantitative analysis, organic and inorganic chemistry, and physical chemistry.
2) An introductory background in the physics, biology, and engineering aspects of the environment to be able to work effectively as a member of a team on environmental quality problems. Chemists without training in the related areas frequent-

Presented at the session on "Environmental Education for the Professional Chemist," Eastern Analytical Symposium, New York City, Nov. 14, 1973.

[Reprinted from Journal of Chemical Education, Vol. 51, Page 772, December, 1974.]

ly encounter the difficulty of being unable to communicate effectively with members of the team with different backgrounds.

3) A willingness to devote a significant part of his time to the study of the technical and, to a lesser extent, social and legal aspects of environmental quality control.

The environmental chemist generally has at least a bachelor's degree in chemistry or chemical engineering, or the equivalent training in these areas, plus graduate-level work in environmental chemistry. Training in environmental chemistry is often obtained in programs of environmental engineering. This association with environmental engineering and, specifically, civil engineering is not necessarily a disadvantage. In fact, his ties are often closer to the engineering aspects than with the chemical aspects. By definition the environmental chemist must focus on problem-solving in environmental quality control, just as the engineer, who attempts to find the engineering solutions to environmental problems. Training within engineering departments has the disadvantage at some institutions that the students must take courses designed to prepare ordinary engineering students to meet professional licensing requirements.

There are serious questions about the validity of initiating environmental science/environmental chemistry degree programs at the undergraduate level. This can be done provided the student takes the normal complement of chemistry courses prior to the environmental science or environmental quality control courses. A student who takes only environmental courses will likely find that he does not have sufficient chemistry training to be an effective member of a team working on environmental problems.

Another effective approach for training of environmental chemists involves postdoctoral appointments in environmental chemistry programs of individuals who have a PhD in chemistry, chemical engineering, or an allied area. The postdoctoral appointment needed, however, is different from the normal postdoctoral appointment in chemistry. The student primarily needs additional course work in environmental chemistry, biology, and engineering aspects of environmental quality control. Most post-doctoral appointments available today are funded via research contracts and involve such a substantial commitment to research that there is little time for course work. The cutback of EPA training grants (discussed in the preceding paper) has virtually eliminated the funding needed for these appointments.

There is a conflict between graduate training in environmental chemistry and graduate training in chemistry within departments of chemistry. The chemist in the department of chemistry is under strong pressure to focus on chemical subjects on a graduate level. Rarely is he given significant time for courses in related sciences and engineering, which he needs to become effective in the environmental area. On the other hand, programs in the chemical aspects of environmental quality control that have evolved in most engineering programs allow students to obtain degrees in some aspects of engineering or the applied sciences without taking large numbers of courses in the engineering area which are not pertinent to his career objectives. These programs allow the student to take courses in other fields such as aquatic biology, advanced chemistry, geology, etc., in order to provide the background needed.

The Future for Environmental Chemistry

All departments of chemistry have a definite responsibility to provide some environmental education for their graduates. This responsibility is derived to a significant extent from the fact that the environmental contamination by chemicals is often a direct result of the failure of chemists and chemical engineers to design manufacturing processes which would minimize the environmental impact of their products or wastes. Much greater emphasis must be placed on the design of manufacturing processes that minimize the discharge of potentially hazardous chemicals. Further, with the passage of the hazardous substances act, all new chemical products which could lead to environmental contamination will have to be prescreened for the potential environmental impact prior to large-scale manufacturing.

Another important factor for environmental chemistry will be the forthcoming publication of the National Academies of Science and Engineering Water Quality Criteria "blue book" which will show that the critical levels of chemicals in the aquatic environment are considerably less than previously thought. At present, most water pollution control regulations propagated by federal and state agencies are based on acute lethal toxicity to aquatic life or an impairment of drinking water quality. With the publication of the "blue book," the critical concentrations of many chemicals will be reduced 100–1000 fold based on studies that show that these chemicals can have sublethal adverse effects on aquatic life arising from chronic exposure at the lower concentrations. For many of the heavy metals, the critical concentrations are in the order of a milligram per liter for acute lethal toxicity, i.e. killing fish or fish food organisms within a few days. The "blue book" criteria will be set on chemical levels which have an adverse effect on organism reproduction, behavior, or growth. These levels generally do not kill the organisms, but effects on behavior, growth, or reproduction can be as significant to the ecosystem as acute lethal effects.

Until 1972, industrial, municipal, or agricultural activities could release chemicals to the environemnt until regulatory agencies or others were able to demonstrate that excessive concentrations were present which would significantly impair environmental use. The 1972 amendments to the Federal Water Pollution Control Act imply that anyone who wishes to discharge materials or allow the use of a product that could cause environmental contamination *must demonstrate* that such discharges cannot be technically controlled beyond a certain level and that it is not socially and economically desirable to control them beyond this level. The zero pollutant discharge goal for 1985 should not in the author's opinion be interpreted to be zero discharge. Contaminants may be released to the environment if their concentrations do not reach levels that cause adverse affects on man's ecosystem. As we approach the zero pollutant goal, greater emphasis must be placed on understanding the environmental chemistry of pollutants to ascertain whether or not a particular concentration of a specific compound does have an adverse effect. A significantly increased number of environmental chemists will be needed to provide this information.

As the limits for contaminants are reduced, greater emphasis will be placed on determining what part of the contaminant total is biologically active. Total concentrations of many contaminants such as lead, zinc, copper, etc. do not correlate well with biological activities. Excessive concentrations of elements are sometimes found without any apparent adverse effects on ecosystems. The problem is that water quality criteria are based on total elemental concentrations when, in fact, the forms used for establishing the criteria are markedly different than the forms that occur in the environment. Thus, there is little need for insistence on removal of contaminants for a particular waste if they are not in a form that would have an adverse effect on the environment.

The "blue book" recommendations for critical concentrations of many chemicals in natural waters are not absolute values that must not be exceeded. Instead, aquatic organisms from a specific ecosystem should be tested against the chemical under study to establish a relationship between the paticular discharge and adverse effects.

The approach will ultimately lead to better management of contaminants, focusing as it does on specific forms which are biologically active rather than on the total amounts. The environmental chemist will be called on to determine which specific forms are responsible for adverse effects and the transformations that may occur in the environment which would alter the concentrations of these forms. These studies would be the mainstay of environmental chemistry research in the foreseeable future.

It is unfortunate that just when there will be a great need for environmental chemists, the Office of Manpower and Budget has decided to terminate direct support of graduate education in this area. Although there may be a surplus of chemists and other scientists in general, this is not true in the area of chemical aspects of environmental quality control. As noted above, MS or PhD graduate chemists need substantial additional training to become effective in this area. Instead of phasing out the Environmental Protection Agency's training grant program in environmental chemistry as applied to environmental quality control, OMB should make funds available through EPA or other agencies to stimulate training at selected institutions.

Role of Chemistry Departments in Environmental Chemistry Education

While departments of chemistry may develop programs for training environmental chemists, it is doubtful that they would be effective at many institutions. These programs would likely compete with established programs in engineering and applied science areas. The environmental chemist must have considerable training in non-chemical areas. This essentially precludes for many institutions the development of environmental chemistry graduate degree programs within the chemistry departments without a major restructuring of the degree programs. I feel that the best role for departments of chemistry in the education of environmental chemists is a supporting role as discussed below.

First and foremost, departments of chemistry must provide a good foundation in the fundamentals of chemistry. If a choice is to be made between upgrading the chemistry education versus expanding into environmental chemistry (with possible dilution of the chemistry education of their graduates), the chemistry department must focus on upgrading the chemistry in their program.

One of the most important courses in the environmental chemistry area is physical chemistry. Physical chemistry, as taught today in many departments of chemistry, is not the type needed in many parts of environmental chemistry. The emphasis on statistical mechanics and quantum mechanics is of lesser importance to the environmental chemist than classical physical chemistry. Some institutions now offer both types of physical chemistry. For those individuals who wish to go into the environmental field, the emphasis should be on the classical physical chemistry covering the various topics such as kinetics, thermodynamics, colloidal chemistry, etc.

All graduates of chemistry departments should receive at least one good course in environmental chemistry as part of their degree programs. This should be preferably done at the junior or senior level in the undergraduate program, or at the graduate level for students who have not had such a course. Generally this should be a joint course with a variety of faculty representing various aspects of the environment and chemistry discussing their specialties. It should cover a number of topics of the air, water, and terrestrial environment: What are the known contaminants? What are the concentrations found in these various environments? How did these contaminants enter the environment? What is being done to minimize the input of these contaminants from specific sources?

The second phase of this course should deal with the environmental behavior of the contaminant from the aquatic point of view. Detailed discussions of the kinetics and thermodynamics of the various chemical reactions that occur in the environment should be presented. The recommendation that the course be given at the junior or senior level is based on the fact that the students will then have considerable training in chemistry and they can approach it at a more sophisticated level than would be possible at lower levels. Students should take physical chemistry at least concurrent with the course.

The chemistry of contaminants in natural waters can be divided into a number of reaction types such as acid-base, redox, precipitation, complexation, sorption, and biochemical reaction. The environmental chemistry courses should cover these reactions as they affect behavior of chemical contaminants in natural water systems, with emphasis on the thermodynamics and rates of reactions under environmental conditions.

The environmental chemistry course should also treat the transport of contaminants throughout the environment. Discussions of mixing processes, such as molecular and eddy diffusion, should be given as these processes largely control the concentrations of many contaminants in natural water and the atmosphere. Molecular processes rarely play important roles in overall transport mechanisms, as turbulent diffusion is often the dominant factor. Some substances are transported biologically, i.e., by organisms which have their own mobility.

One of the most important areas to be covered is the significance of the chemical contaminants to man's ecosystem. What are the critical concentrations that cause adverse effects on the environment? What is the critical concentration of zinc which inhibits fish reproduction or of copper that causes the fish breathing rate to change? How are these critical concentrations influenced by the overall characteristics of the water? Are they different between fresh and marine waters? What is the effect of hardness on these critical concentrations? What are the procedures that are used to establish critical concentrations? What is the relationship between the critical concentration found in the environment to that frequently used to establish critical concentrations under laboratory conditions? How can one ensure that the chemical environment used in bioassay tests under laboratory conditions is the same or at least similar to the chemical environment that occurs in natural waters? From the aquatic point of view, the publication of the "blue book" by the National Academies of Science and Engineering will provide a wealth of information in many of these topic areas.

The departments of chemistry should incorporate environmental chemistry topics into their basic courses in chemistry to demonstrate the application of chemical principles to the solution of problems of man's contamination of his environment.

Departments of chemistry should encourage their majors who are interested in careers in environmental quality control to take courses in biology, biochemistry, engineering, and environmental chemistry. Existing restrictions in departments of chemistry should be lifted to enable the student who wished to pursue an environmental program to take supporting courses in this area.

Students who wish to study environmental chemistry must usually choose between the atmospheric-air pollution and aquatic-water pollution areas as there is rarely time to become proficient in both areas. For those who wish to emphasize water pollution, courses in water supply and pollution control, industrial wastes, limnology, hydrobiology, pollution biology, ecology, ground-water, environmental chemistry, and marine chemistry should be considered. In the atmospheric-air pollution area, courses in meteorology, air pollution control, atmospheric chemistry, gas-phase chemistry, and biological effects of air pollutants should be taken.