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LETTERS

Understanding Chemistry

The progress reported in Ivan Amato's article "Chemistry curricula edge toward a new world" (News & Comment, 14 Aug., p. 871) is an important first step toward acknowledging the tip of a large unacknowledged iceberg. It is important to improve the introductory chemistry experience of potential science, engineering, and other majors who take the course. However, a pitifully small percentage of all college students even consider taking introductory chemistry. The iceberg is the rampant chemophobia that results from the lack of understanding by the general public and its leadership of the role chemicals play in our society. Needed are general-education college and university courses that teach *all* students about the nature of chemicals, the absurdity of "chemical-free" anything, and the understanding necessary to participate in the decision-making process regarding the risks, benefits, and trade-offs involved in the use of specific chemicals for specific purposes in our society. Perhaps in this way we can help some of the public realize it is irrational to love a product and want to ban the raw materials from which it is made.

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Use of Animal Drugs

The 21 August ScienceScope piece about off-label use of animal drugs (p. 1031) may cause the reader to believe that the Food and Drug Administration (FDA) is poised to take regulatory action against researchers if pharmaceutical products are used in an "off-label" manner in laboratory animals. Nothing could be farther from the truth.

It is true that the Federal Food, Drug, and Cosmetic Act prohibits using an animal drug in ways other than those specified on the approved labeling. The long-standing policy of FDA, however, is to exercise considerable regulatory discretion where nonfood animals are concerned. Hence there is virtually no chance that a researcher administering an anesthetic in a responsible manner to a "spiny anteater" will encounter a problem with the FDA. The same can be said for other off-label uses of pharmaceuticals in laboratory animals and, for that matter, in pet animals. We are concerned with preventing off-label use of an animal drug that has the potential for causing illegal drug residues in meat, milk, or eggs. Persons causing an illegal drug residue in food for humans should fear an FDA action, but researchers who use nonfood animal species should not.

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Hydrogen Bonding

The article "Benzene forms hydrogen bonds with water" by S. Suzuki *et al.* (14 Aug., p. 942) represents a major advance in our understanding of the interactions between water and aromatic structures. The authors show that benzene forms hydrogen bonds with water through the π electron system of benzene. Although they did not mention it, their work should also be useful for rationalizing the solubilities of aromatic compounds in water. For example, from literature tabulations (*1*) it is known that the solubility of benzene in water is 35 times greater than that of cyclohexane. The results of Suzuki *et al.* are consistent with and can be used to help understand this independent solubility information because cyclohexane, unlike benzene, does not have a π electron system and will therefore not form solubility-enhancing π system hydrogen bonds with solvent water molecules.

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REFERENCES

1. P. H. Howard, G. W. Sage, W. F. Jarvis, D. A. Gray, *Handbook of Environmental Fate and Exposure Data for Organic Chemicals*, vol. 2, *Solvents* (Lewis, Chelsea, MI, 1990).

Response: As noted by Faust, it has been recognized for some time that benzene is appreciably more soluble in water than both cyclohexane and cyclohexene(s). A large body of experimental and theoretical work exists on the solvation properties of a wide range of hydrocarbons. Readers interested in detailed analyses of the solvation properties of benzene and other hydrocarbons may wish to review recent seminal contributions (*1*). These studies, as well as several of the references in our report, identify potential energy surfaces to be used in molecular simulations of the aqueous environment. All invoke a hydrogen bond interaction of individual water molecules with the benzene π cloud. The major differences between the models concern the geometry of the potential minimum and the degree of anisotropy in the benzene-water pair potential, which can be unambiguously determined by looking at the far-infrared spectrum of the dimer. We thank Faust and other researchers for bringing these important points to our attention.

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1. See, for example, W. J. Jorgensen and D. L. Severance, *J. Am. Chem. Soc.* 112, 4768 (1990); C. J. Cramer and D. G. Truhlar, *Science* 256, 213 (1992); A. W. Garrett and T. S. Zweir, *J. Chem. Phys.* 96, 3402 (1992).

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Carbon Budget Estimates

P. E. Kauppi *et al.*, in their article "Biomass and carbon budget of European forests, 1971 to 1990" (3 Apr., p. 70), estimate "an annual accumulation of 70 to 105 million tons of carbon in European forests in the 1970s and 1980s." These numbers are consistent with the earlier estimate of about 80 million tons by one of us (R.A.H.) and colleagues (*1*). However, the assertion by Kauppi *et al.* that this (plus a 15-million-ton increase in wood products) "represents 8 to 10% of the 'missing' flux in the global carbon budget" indicates that their interpretation of the land-use term in the global budget is different from ours.

The net flux of carbon resulting from changes in land use (the land-use term) is not considered to be the gross flux of carbon from deforestation. On the contrary, the land-use term includes not only the release of carbon to the atmosphere from deforestation but the accumulation of carbon from reforestation, afforestation, and regrowth of forests after logging or abandonment of farmland. The term also includes the longer term decay of plant material left on site at harvest, the oxidation of harvested products, and the oxidation and subsequent recovery of soil carbon after logging. Thus, the assumption criticized by Kauppi *et al.* "that nontropical forests are in [near] equilibrium with the atmosphere" is not an assumption at all but a result of analyses accounting for all of the carbon originally contained in the forest.

In the budget of Kauppi *et al.*, the "buildup of wood in unexploited forests makes only a minor contribution to the observed trends of increase in standing stock and growth." Thus, virtually all the storage is the result of regrowing forest and should be included in the land-use term of the global budget. However, their budget does not account for the decay of plant material left on site after harvest or for the oxidation and recovery of soil carbon. These two factors will substantially reduce their estimates of net carbon storage.

Kauppi *et al.* cite an annual rate of "138 million cubic meters of sawed wood and wood-based panels" used in Europe, 58 of which replace old wood products (no net storage) and 80 (or 15 million tons of carbon) of which is new storage. The plant material left (both above- and belowground) from harvest can be three to four times as large as the actual harvest (*1*, appendix 1). Using a more conservative factor of two and using their volume-to-carbon conversion factor of 1/5, we estimate the decay contribution to the land-use term to be about 55 million tons of carbon (138 × 2 × 1/5). This would reduce the storage rate of Kauppi *et al.* to between 15 and 50 million tons per year. (Houghton *et al.* estimate 28 million tons per year) (*1*). To this is added the 15-million-ton increase in wood products for a net storage of 30 to 65 million tons of carbon per year.

Can this 30 to 65 million tons of carbon per year be tallied against the "missing" carbon in the global budget? As we have pointed out, this flux is more properly attributed to the land-use term. To contribute to the "missing" flux, the 30- to 65-million-ton flux would have to be greater than the land-use flux already accounted for in the global budget. Houghton *et al.* (*1*) estimate a net sink in Europe of 28 million tons of carbon per year. The difference between the Kauppi *et al.* and the Houghton *et al.* estimates of this sink is between 2 and 37 million tons of carbon per year. This difference can reasonably be tallied against the "missing" sink, but it accounts for no more than 0.2 to 3% of the missing flux. As pointed out by Daniel B. Botkin *et al.* (Letters, 10 July, p. 146), the errors in estimating terrestrial carbon fluxes are large. The additional flux in the budget of Kauppi *et al.* is well within these errors.

A more important indicator of increased carbon storage in terrestrial ecosystems, which might help explain the "missing" flux of carbon, would be an increase in the rate of forest growth. Kauppi *et al.* state that the annual increment of stemwood volume "increased by about 30% between the early 1970s and the late 1980s." However, they also cite a greater than twofold increase in the rate of use of forest products since 1949. Therefore, the increase in growth may simply reflect a younger average forest age. If so, there may be no net effect on carbon storage because of the decay associated with previous harvests. That is, this increase in growth rate is also accounted for in the land-use term of the global budget.

To account for the "missing" carbon in the global budget, the rate of forest regrowth would have to be faster now than it was for the forests used to estimate regrowth in the original global budget. Kauppi *et al.* cite a German study (*2*) in which "present stands were observed to grow faster than the stands of earlier rotations on the same plots," resulting presumably from favorable climate and increased nitrogen deposition. This is indeed compelling evidence of increased storage in terrestrial ecosystems which might help explain the "missing" sink of carbon in the global budget, but Kauppi *et al.* do not distinguish between the original estimate of carbon accumulation in regrowing forest and any enhanced accumulation estimate. It is that difference that can be attributed to the "missing" flux.

We join with Kauppi *et al.* and Botkin *et al.* in urging that the carbon budget of the terrestrial biosphere be given high research priority. The evidence for a terrestrial sink is growing. Until we understand this sink and its dynamics, predictions of the future ramifications of increased carbon dioxide are difficult to justify.

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1. R. A. Houghton, *et al.*, *Tellus* 39B, 122 (1987).
2. G. Kenk and H. Fischer, *Environ. Pollut.* 54, 199 (1991).

Response: Houghton *et al.* estimated that European forests accumulated 28×10^{12} grams of carbon in the year 1980 which acted as a weak sink in the global carbon budget (*1*). The suggested reason was the abandonment of croplands. We estimated a higher rate of annual buildup, 70 to 105 $\times 10^{12}$ grams of carbon, and attributed it mainly to an increase in the biomass of existing middle-aged and mature stands (*2*). Either one or both of these estimates must be revised.

Soil carbon in our analysis was assumed