

of science and education in Russia, we believe that Russian physics will survive regardless of Western help, as it survived after the Bolshevik revolution. It should also be noticed that physicists were greatly overproduced in the Soviet Union. A substantial migration of physicists to other occupations, which Sagdeev calls "internal emigration," would now be natural and, probably, inevitable.

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six alumni who are not on the list, and I do not know personally anybody on the list. It would be reasonable to guess that only 10% of those alumni residing outside the FSU are on the list. That would give us a 6% drain rate for the younger (less than 35 years old) generation of Soviet physicists. This number looks impressive if one takes into account traditional Soviet xenophobia and the fact that travel abroad by individuals in the FSU is still subject to a number of restrictions. For obvious reasons, the older generation of physicists is less "mobile," and their drain rate is less.

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FSU's Brain Drain: How Fast a Flow?

The plight of science in the former Soviet Union came again into focus in the May 1992 issue of *PHYSICS TODAY* through the articles by Roald Z. Sagdeev (page 22) and Evgenii L. Feinberg (page 30). A brain drain of physicists is often presented as an important manifestation of a decay process. Exact numbers on the brain drain from the FSU are not available, so an attempt to give a semiquantitative estimate of the problem is of some interest. I have made such an estimate based on a list of alumni of the Moscow Physico-Technical Institute residing outside the FSU and accessible via e-mail. This list was originally compiled and is maintained by Alexander Kaplan of the Johns Hopkins University. (FizTech alumni are encouraged to contact Kaplan and join the list by sending an e-mail message to sasha@super.ece.jhu.edu.)

FizTech is probably the best of the institutions that trained Soviet physicists. Each year about 700–800 students are graduated from eight FizTech departments with a degree equivalent to an MSc in physics. FizTech graduates were considered to be the *crème de la crème* among young Soviet physicists, and they are (or at least were) widely sought by the Academy of Sciences and by military and industrial research establishments.

In the updated list, covering the US, Canada, Israel and Western Europe, there are about 90 FizTech alumni, of whom 54 graduated in 1980 or later. This constitutes about 0.6% of those who graduated during those years. A large uncertainty is obviously involved in estimating the probability that a FizTech alumnus who works outside the FSU is on the list. For example, I know personally

What Gas Lies Behind GreenH₂Ouse Effect?

Alison Campbell (February 1992, page 123) is mistaken when she states, "Were it not for atmospheric CO₂, the mean temperature at the Earth's surface would be substantially below zero." CO₂ is a minor greenhouse gas, so its disappearance from the atmosphere would, in fact, have a minor impact on the average global temperature.

Information given in the Search and Discovery department (February 1990, page 17) allows a crude estimate of what the cooling would be. The news item says, "A doubling of CO₂ would increase the atmospheric trapping of long-wavelength radiation by about 4 W/m², compared to the trapping of about 150 W/m² in today's atmosphere." Evidently CO₂ contributes only 3% to the greenhouse effect. Furthermore, if a doubling of atmospheric CO₂ would increase the greenhouse effect by 3%, then conversely its disappearance would decrease the greenhouse effect by 3%.

The step from here to the corresponding decrease in global warming is uncertain because of our far-from-complete understanding of global climate. *Theoretical* models of global climate typically include a positive feedback loop due to water vapor, which magnifies the effects of changes in the CO₂ level. It is unclear (to this writer, at least), however, whether the models also include the *negative* feedback due to the direct linkage between water vapor, average global cloud cover and the Earth's albedo. To make an order-of-magnitude estimate, let us smash through this positive-versus-negative-feedback roadblock with the not unreasonable approximation that the amount of global warming is directly

proportional to the amount of greenhouse effect. Global warming, which is the difference between the 15 °C average global temperature and the bracing –18 °C temperature that would prevail if the Earth's atmosphere were perfectly transparent at infrared wavelengths, stands at 33 °C. With the aid of our low-tech direct-proportionality argument we see that if by some magic all CO₂ were removed from the atmosphere, the 3% decrease in the greenhouse effect would lead to a 1 °C decrease in global warming.

One may use the much publicized models of global climate to check this crude estimate. These models typically predict¹ that if the concentration of CO₂ were to double, global warming would increase by somewhere between 1.5 and 4.5 °C, so conversely the complete removal of CO₂ from the atmosphere would *decrease* global warming by the same amount. Evidently, although the global climate models cannot tell us what the precise temperature decrease would be, they confirm that it would be of order 1 °C. In other words the disappearance of CO₂ from the atmosphere would fall far short of plunging the average global temperature below freezing.

Campbell's mistake stems from her implicit assumption that CO₂ is the major greenhouse gas. So if CO₂ is not the major greenhouse gas, what is? Plain old all-natural water vapor!

Her CO₂ illusion puts her, however, in good company. In an impromptu survey I asked ten of my fellow astronomers, "What is the major greenhouse gas?" Six said, "CO₂." One said: "CO₂. Er, er, but isn't water vapor in there?" Two said, "Water vapor." And one said, "Don't know." (The department chairman was one of the CO₂'s.) Evidently a surprisingly large number of astronomers also think that CO₂ is the major greenhouse gas—this in spite of the fact that astronomers need to know how the Earth's atmosphere stamps its spectral imprint on the radiation from heavenly bodies. In other scientific disciplines that do not deal with the Earth's atmosphere on a professional basis, the illusion that CO₂ is the major greenhouse gas is probably even more prevalent. Among the general public it must be almost universal.

This means that most people must also be under the impression that the rate of increase of the CO₂ concentration in the atmosphere causes an equal rate of increase in the greenhouse effect. In fact, as shown by the numbers quoted above, the greenhouse effect's rate of increase is dilut-