

cutting one triangle into a few pieces and rearranging them to form the other one. Hilbert's third problem asked whether such a proof could be devised for tetrahedra. But his real interest was in the metamathematical question of whether the use of calculus was necessary. This was the first of his problems to be solved. In 1902, Max Dehn showed that calculus was needed.

Two of Hilbert's problems have, famously, had metamathematical solutions. His first problem was to prove or disprove Cantor's continuum hypothesis, which is the statement that there is no infinite set larger than the set of positive integers but smaller than the set of real numbers. Thanks to Kurt Gödel (in 1938) and Paul Cohen (in 1963), it is now known that this statement can be neither proved nor disproved. Hilbert's tenth problem asks for a systematic method for deciding which Diophantine equations have solutions. (Diophantine equations are polynomial equations whose solutions are required to be integers.) Building on the work of many mathematicians, Yuri Matiyasevich proved in 1970 that there was no such method. Results such as these have had a profound effect on the philosophy of mathematics.

The author of any mathematical book aimed at the general reader has to decide what background knowledge to assume, and Gray, like many others, is not consistent in his demands. This can be seen from a quick inspection of his 'boxes', those receptacles much loved of popular science publishers, which contain illustrations and (necessarily inadequate) explanations of some of the technical points in the text. That said, it would be misleading to describe this book as popular science. Two indications of its serious intent are that its title does not make silly use of the words 'history' or 'biography', and that we learn next to nothing about Hilbert's personal life. (For example, I still do not know whether he ever married.) As for the intended readership, at least some exposure to university-level mathematics is essential to appreciate the book properly.

My one complaint (apart from a few minor quibbles) is that Gray's prose contains far too many clumsily constructed sentences that I had to read twice. Here is one example from a long list: apparently, Hermann Minkowski thought it "unlikely that any polynomial in several variables which was never negative was expressible as a sum of squares". Surely, several of them are, one wonders, before realizing that the word "any" is supposed to be understood, unnaturally, as "every". This sort of writing lessens the pleasure of reading the book, which nevertheless remains illuminating and highly recommended. ■

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Going one better than nature?

Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food

by Vaclav Smil
MIT Press: 2001. 339 pp. \$34.95, £23.95

John Emsley

The greatest catastrophe that the human race could face this century is not global warming but a global conversion to 'organic' farming—an estimated 2 billion people would perish. That is the underlying message of this remarkable book, which charts the discovery of nitrogen fixation—the conversion of unusable atmospheric nitrogen to useful ammonia—and its impact on the world's food supply.

If crops are rotated and the soil is fertilized with compost, animal manure and sewage, thereby returning as much fixed nitrogen as possible to the soil, it is just possible for a hectare of land to feed 10 people—provided they accept a mainly vegetarian diet. Although such farming is almost sustainable, it falls far short of the productivity of land that is fertilized with 'artificial' nitrogen; this can easily support 40 people, and on a varied diet. Of course, 'organic' farming should be encouraged in order to recycle compost and dung. But it can never compete with the bountiful supply of agrochemical nitrogen, which now meets about 40% of the world's dietary needs.

Nitrogen is abundant in the atmosphere, but in a form that is difficult to extract; only a few microbes and plants have the capacity to do this. Yet, thanks to their efforts over aeons of time, a whole planetary ecology can now be sustained. This organic nitrogen will even



Fritz Haber: discovered a way of converting nitrogen in the atmosphere into ammonia ...

support continued agriculture if properly managed, but it imposes a maximum on the density of the human population.

All this changed on 3 July 1909, when two German chemists, Fritz Haber and Carl Bosch, proved that it was possible to convert atmospheric nitrogen into ammonia on an industrial scale. Today there are Haber-Bosch chemical plants around the world, producing 150 million tonnes of ammonia a year, most of which goes into making fertilizer. The nitrogen input into farmed land from these fertilizers now exceeds the natural input. Even low-income countries can afford Haber-Bosch factories, and these should begin to turn around food production there, just as they did in high-income economies.

In the final chapter of *Enriching the Earth*, Vaclav Smil of the University of Manitoba admits that he originally intended to write a biography of Haber and Bosch, but he quickly realized that an account of the effects of their research would be far more interesting, and concentrated on this. He was right to do so.

Smil begins by looking at the fact that all living things need nitrogen in order to make amino acids, the building-blocks for the proteins on which life depends. He explains how nitrogen is fixed naturally, and how traditional farming takes this from the soil, but with only partial success at returning waste material to fertilize future crops. The first successful nitrogen fertilizers came from the Chilean guano deposits in the nineteenth century, a clearly limited supply.

The central theme of *Enriching the Earth* tells of Haber's struggle to make hydrogen gas (H_2) react directly with nitrogen gas (N_2) to form ammonia (NH_3), and of Bosch's faith that the process could be made to work commercially. Bosch then convinced the German chemical company BASF to invest in it. This was an industry born. But it was not immediately seen as the answer to the world's food



... And Carl Bosch: had faith that the process could be made to work commercially.

supply; instead, it fed into Germany's need for ammunition to fight two world wars. Ammonia from the Haber–Bosch factories was converted to nitric acid and thence to explosives. After 1945, however, the overwhelming use of such factories was to fix nitrogen for fertilizers.

Smil recounts how the industry developed, and how much of the world's population is now supported by it. He discusses how this chemical bounty is disbursed. Relatively little is used by US agriculture, but a great deal by Chinese farmers. Smil considers what will happen when developing economies also want their protein to be in the easily digested and tasty kind that comes from meat, even though this is the least efficient way of producing food. But can our planet support another 5 billion people on a Western diet, and won't more food simply encourage more humans to have yet more children? Smil's answer is found in his chapter "Nitrogen and civilization". The future looks surprisingly reassuring. The annual increase in global population will continue to decline even though food production is rising, and the total might well peak at less than 9 billion by the year 2050, declining thereafter.

This is a wonderful book, highly readable and replete with referenced data. It is soundly based on the chemistry that underpins our food supply, or at least the protein part of it, and is an ideal corrective to the misleading ideas we are constantly being fed by the organic food movement. Humans have a stark choice to make: do we farm four hectares of land 'organically' to feed 40 souls, or do we farm one hectare 'artificially', thereby leaving the other three to natural woodland and wildlife? There is a place for 'organic' farming, but only insofar as it permits us to recycle nitrogen that would otherwise go to waste. ■

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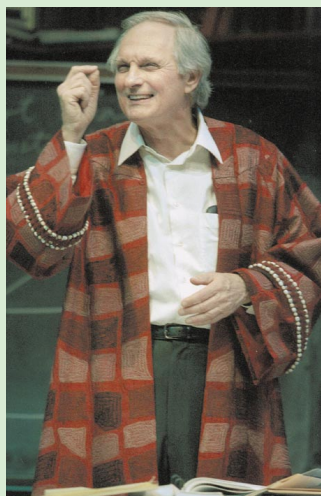
Science in culture

Enter Feynman, as clown

QED, a play by Peter Parnell, directed by Gordon Davidson. Horace Freeland Judson

The public Richard Feynman: O-rings, safe-cracking, bongo drums, naked women, atheism, the joyful questioning of authority, whether in physics or bureaucracies. The one thing everybody knows about him is that, when testifying before a panel of the US Senate investigating the Challenger disaster, he dropped a piece of O-ring, a rubberoid gasket, into a glass of ice water and demonstrated that such rings get brittle when cold — thus illustrating the cause of the fuel leak and explosion. Many have also read that, arriving at Los Alamos National Laboratory in 1943, a brilliant kid, PhD at 24, he could crack any of the offices' safes containing the secrets of the bomb research, thereby demonstrating that security was lax. And he played bongo drums, and was an obdurate, thoughtful atheist, and frequented topless bars in Los Angeles, and took art lessons so that he could draw nude models. Some also know that he was an inspired teacher at Caltech. The persona grew from interviews, public appearances and several books about him in which he connived. He played himself as trickster, an eccentric genius.

Enter Alan Alda as Feynman, rushing in to the bongo beat. Except for some voices on his answering-machine, and a brief appearance of a young woman student in Act II, this is a one-man show, and Alda plays Feynman broadly, as clown. The play is set in Feynman's office during an afternoon and evening in 1988, while he was dying, as we learn, of a crushing abdominal carcinoma. The office is cluttered, bongo up



front, desk piled, behind it a blackboard scrawled with mystifying mathematical jottings. Alda drums, jumps about the stage, drums, talks to the audience, to the telephone — his surgeon, his oncologist, this colleague or that — drums, piles up the Feynman anecdotes.

Alda is an actor celebrated for a variety of theatre and film work, but above all for 11 years in the TV series *M*A*S*H*. His New York accent is perfect, he even looks acceptably like the man, his comic timing is

professional — but there are occasions in theatre when 'professional' is a substitute for depth, a term of reproach. What was behind the persona? Almost any photograph of Feynman shows his alert intelligence, twinkling with speculation, waiting to pounce. In the bruising intellectual world of high-energy physics, where everyone who makes it is an alpha male, Feynman's wit and assertiveness sprang from the originality and speed of his understanding. He applied this to the public world as well. Scientists know that he invented a graphic method, astonishingly original — Feynman diagrams — for anatomizing interactions of subatomic particles so that their behaviour could be calculated. This led to his work developing quantum electrodynamics, QED, the theory of almost everything, which won him a Nobel prize.

Actor, playwright, director — in this piece of theatre they have conspired to keep us from Feynman's intelligence. We get 40 seconds of a Feynman diagram scrawled on that blackboard as a gee-whiz illustration, when these were tools for discovery. Instead of Feynman's speed of comprehension we get frenetic, fussy movement. Elements of potential pathos — in Act I reminiscing about his first wife, dead of tuberculosis in 1945, in Act II facing the imminence of his own death — are drained of emotion by the constant straining for laughs.

What's left? An anthology of anecdotes and aphorisms. "Nature is a woman." "We must think in probabilities." "All science is a constant attempt to describe nature" — standing alone, a silly statement. "If you ask Nature the right question, she will give you the right answer." And at the end an embarrassing brief homily to that young student, to the effect that if she works really, really hard and can find the courage not to know certainty, she too can be a physicist. ■

Horace Freeland Judson is at the Center for History of Recent Science, George Washington University, Washington DC 20052, USA. *QED* is playing at the Mark Taper Forum, Los Angeles, until 13 May 2001.

