would, I suspect, feel somewhat differently.

On some of the more basic questions of crystal chemistry, such as the success of Linus Pauling's electronegativity scale in describing charge transfer, Slater can do little more than repeat Robert S. Mulliken's formulation (1932) of the problem in terms of an atomistic scale, which is inadequate in solids and large molecules. Yet Pauling has shown that there is a tendency to charge transfer between atoms in a bonded state which is characterized more accurately and more simply by the properties of the atoms in that state than by almost all self-consistent treatments that start from the properties of separated, isolated atoms.

These remarks illustrate another aspect of Slater's work, its programmatic character. The mathematical problems associated with solving Schrödinger's equation have not all been resolved by the advent of computers—they are still with us, but in a different form. The price one pays for his (intuitively appealing) single, unified, mathematically explicit approach to quantum structure is high, but the rewards are high as well. The price involves setting aside the study of most experimental trends until after these have been identified and largely explained by semi-empirical theories. Indeed, as Slater concedes (in what he recognizes as the recent "tremendous development in the experimental side"), "It is a task for the future to apply these methods to experiment."

The rewards of Slater's program, both for the student and for science at large, are amply documented in this book. Without his efforts towards unification and systematization, very few reliable calculations would be available of the electronic structure of transition metals and their compounds. (Oddly enough, the latter are introduced in this book as the prototypical covalent crystals, while silicon appears only as an afterthought at the end of the same chapter.) Without his emphasis on the importance of translating theory into practice, our understanding of the many-body problem in real crystals (as distinguished from the free electron gas!) would be much poorer. Many physicists are unaware of the depth of his work on the multiplet structure of transition-metal atoms, which was finished only five years ago, and which may constitute the most complex many-body problem that has ever actually been solved.

For students and workers in the field of the quantum structure of matter, these books should prove to be the invaluable guides that Slater meant them to be. For science as a whole, like Landau's books, they are monumental evidence of what a man of genius can accomplish through a lifetime of patient, persistent effort.

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The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique

Thomas B. Cochran
271 pp. Johns Hopkins U. P., Baltimore, 1974. $6.95

Is the liquid-metal-cooled fast-neutron breeder reactor another uneconomic, potentially dangerous technology like the supersonic transport? Tom Cochran obviously thinks so. In this book he argues that the LMFBR may be an economic white elephant and that it and the plutonium which it produces may pose a serious threat to the human environment.

Cochran is a young physicist turned public-interest scientist. His book was written under the auspices of Resources for the Future, a Washington-based think-tank. For the past year Cochran and biophysicist Arthur Tamplin have worked with the National Resources Defense Council, a public-interest law group whose successful lawsuit under the National Environmental Policy Act forced the AEC to do a study on the environmental impact of the commercial introduction of the LMFBR.[1] The NRDC effort, along with a technical critique by a group headed by Hans Bethe,[2] has been instrumental in making a serious reassessment of the LMFBR program possible.

Cochran's thesis is two-fold; that the economic case for the rapid introduction of the breeder has not been made, and that the environmental hazards of the LMFBR may in some respects be more severe than those of the current generation of light-water reactors.

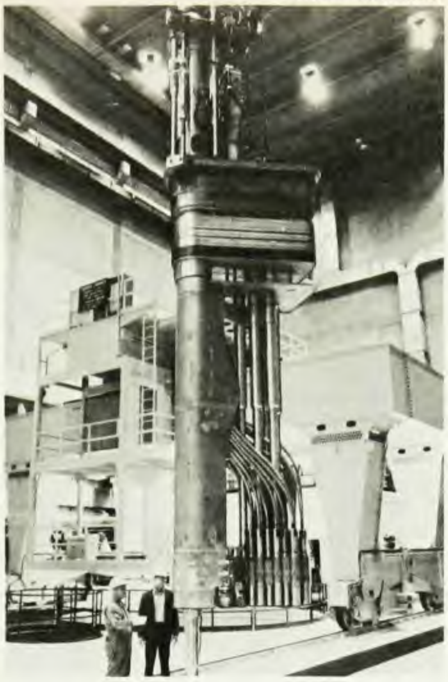
The fundamental economic rationale for the introduction of the breeder is that the current light-water and gas-cooled thermal reactors exploit only about one percent or so of the fission energy stored in uranium—primarily that in the isotope U^{235} which makes up about 0.7 percent of natural uranium. The LMFBR, on the other hand, could make available the fission energy of more than half of the U^{238} which makes up the remainder of the uranium by transmuting it into the chain-reacting plutonium isotope, Pu^{239}. Adoption of this or some other "breeder" reactor, therefore, would mean that uranium would have to be mined at only a few hundredths of the rate that would otherwise be required to support a commitment to nuclear power. Without a breeder we would be forced to turn to much lower-grade uranium ores within a few decades *if* nuclear power expands at the rate projected by the AEC and *if* our reserves of high-grade uranium ore are as limited as claimed by the AEC. Lower-grade ores mean more expensive uranium, therefore a rising cost for electricity, by perhaps ten percent by the year 2020—all else being equal.

A price increase of ten percent over fifty years does not seem very formidable when we have seen energy prices double within a year, but Cochran feels that even such a prospect is exaggerated. He criticizes the AEC's assumption that little more high-grade uranium ore will be found in the US when many likely areas remain virtually unexplored. And he questions the AEC's assumption that the consumption of electric power in the US will increase by a factor of twelve or so by the year 2020. If either of these criticisms are valid, we need not rush ahead with the breeder. We need only stockpile the U^{238} that is not burned by our current reactors for use if and when we decide to go ahead with a breeder.

But why do environmentalists oppose the LMFBR? Although Cochran spends a great deal of time criticizing the economic arguments for the rapid introduction of the LMFBR, it is clear that his real concern lies not with saving the taxpayer a few billion dollars in R&D money but rather in protecting him from what he fears may turn into a technological monster. Here Cochran points primarily to two questions concerning the LMFBR and its product plutonium that have not yet been adequately answered.

The first question concerns the explosive potential of the LMFBR. Unlike current thermal-neutron reactors, the LMFBR could conceivably suffer a nuclear explosion. This would be a relatively mild explosion—a nuclear weapon must be designed very carefully to get much explosive yield—but it has yet to be demonstrated that the explosion could not be large enough to rupture the reactor containment building and eject enormous quantities of plutonium and radioactive fission products into the human environment.

The second question concerns the potential hazard from plutonium pollution, such as could result from a reactor accident or just from routine leaks out of a plutonium-fueled nuclear economy. The element Pu^{239} has a half life of 24 000 years so that it represents a virtually eternal pollutant once it has escaped from the nuclear-fuel cycle. On the other hand, its half-life is thirty



The Fast Flux Test Facility at the AEC's Hanford Project in Richland, Wash. (left) is an important part of that agency's LMFBR program. The instrument tree (right) is a model for trees that will serve as monitors for temperature and flow characteristics in the FFTF reactor vessel.

thousand times shorter than that of U^{235}, so that a particle of insoluble plutonium oxide trapped in the human lung would irradiate its neighborhood that much more intensely. Cochran and Tamplin have recently drawn public attention to the possibility that the irradiation of the lung by radioactively "hot" particles might be orders of magnitude more effective in the production of cancer than the uniform exposure of the lung to the same average dose.[3]

Both of these questions, the explosive potential of the LMFBR and the potential toxicity of plutonium-oxide particles, are important ones, and I believe that Cochran and others deserve great credit in bringing them to public attention. The result has been that much more serious consideration is being given to these problems by the technical community—both inside and outside of the AEC.

It is not clear yet how these questions will ultimately be resolved. The breeder development program might not survive the close scrutiny that it is now receiving; or perhaps a much more defensible program, even another breeder design, will emerge. In any case Cochran and other LMFBR critics appear to have made their case that we are faced with a serious decision with regard to the future direction of our nuclear technology. Equally important is their argument that we should not allow ourselves to be stampeded into backing the LMFBR by dire warnings of a uranium shortage at the end of the century. The prospect appears much less forbidding than that. We have the time to reassess the breeder design thoughtfully and to consider seriously, the alternative futures.

References

1. The AEC issued a four-volume draft *Environmental Statement on the Liquid Metal Fast Breeder Reactor Program* in March, 1974 (Wash-1535). This draft was heavily criticized in extensive written comments from both environmental groups and the Environmental Protection Agency and, in June 1974, the AEC received an indefinite extension in the court deadline for the final draft to allow it to take these criticisms into account.
2. *Report of the Cornell Workshops on the Major Issues of a National Energy Research and Development Program* (Cornell University, College of Engineering, 1973), Chapter IV.
3. Robert Gillette, "Plutonium and the 'Hot Particle Problem': Environmental Group Poses a Draconian Answer," Science **183**, 834 (1974).

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The Special Theory of Relativity

H. Muirhead
163 pp. Halsted, New York, 1973. $12.75

The right undergraduate textbook on special relativity must not only be suitable for classroom instruction, it must also be appropriate for self-study, since the subject is generally not offered as a separate course. The required standards in accuracy and lucidity present, therefore, a goal approached as yet in only a few instances.

How closely does the text under review approach that goal? The question is in order because the book is by Hugh Muirhead of the University of Liverpool, well-known author of two creditable books on elementary-particle physics, the field of his scientific activity, and one in which special relativity is pervasive; and because his preface raises expectations. But a perusal of the text's six chapters reveals, along with commendable features, some nontrivial weaknesses.

The weakest portions are contained in chapters 2 and 3 dealing respectively with basic foundations and kinematic applications of special relativity. Thus, no direct indication is given in the statement of Einstein's first postulate that the coordinate systems in question are *inertial*. But more significant than any such lapses is the author's failure to carry out fully his expressed intention "to follow the spirit of a paper by Minkowski ..." One may even wonder what he means by that spirit. On page 20 he refers to space–time (that is, Minkowski's "world") as "a fictitious (but mathematically convenient) four-dimensional space," while on page 23 the mere formal introduction of the variable *ict* is declared to "put our notions of space and time on a more equal footing."

A mild caveat cannot be avoided also regarding some aspects of the mathematical formalism. The discussion relating to ordinary vectors is in part superfluous (at least in the US) and in part strange. More importantly, space–time covariance methods are usually handled with undue restraint, as, for example, on pages 108–109 where the derivations are tortuous, and the gratuitous equation that follows is meaningless. Also, despite a section on symmetries in physics and the introduction of ϵ-symbols, pseudo-tensors are never mentioned. But these deficiencies can be corrected in the classroom.

Turning to the pedagogical features of the book, helpful and interesting problems, useful diagrams, and up-to-date references, are abundant, while misprints—though some are of a curious variety—are not excessive. A connection between Lorentz transformations and spherical triangles may interest some readers, and so may a comprehensive discussion "on spin and polarization in relativistic situations ... *from the high-energy physicist's point of view*" (italics supplied.) But the last point is also a source of weakness for a text that is to be used by as yet uncommitted undergraduates who need a broad introduction to special relativity. This could be remedied by the instructor's making some omissions, while in-