molecule crystallography forms a subset of the larger class of general Fourier phase problems that arise in many areas of applied science. Direct methods cannot be applied to these more general problems, but substantial advances have been made recently in general Fourier phase retrieval. Although direct methods represent the most successful attack to date on phase problems, these different techniques are also becoming useful.

The general Fourier phase problem is concerned with determining an "image" from measurements of the magnitude of its Fourier transform.[1] This situation arises in many applications of remote sensing where the intensity, but not the phase, of the scattered radiation is measured. Examples occur in x-ray crystallography, electron microscopy, optical and radioastronomy, acoustic tomography, time series analysis, radio engineering and communications, to name but a few. The image may be, for example, an electron density, potential, brightness or density distribution. The fundamental question is, does the intensity alone uniquely define the image or, equivalently, the phase? It has been known since the 1960s that in general the solution is not unique in the one-dimensional case.[2] However, recent results show that in two or more dimensions, the Fourier phase problem has a unique solution under very general conditions.[3] These are simply that the image occupies a finite region of space and that the intensity is measured (effectively) continuously throughout Fourier space. This was quite unexpected, as loss of the phase amounts to discarding half of the data. General purpose algorithms for Fourier phase retrieval have been developed.[4]

The phase problem in small-molecule x-ray crystallography represents a special case because of the atomicity of the image: It consists of separated sharp peaks. However, as a result of the sampling theorem, there is an eightfold reduction (in three dimensions) in the number of data (the intensities of the Bragg reflections) compared with that in the continuous intensity.[1] The implications of this in crystallography were recognized quite early.[5] Although uniqueness has not been formally proven, the overwhelming success of direct methods suggests that uniqueness is usually manifest. Presumably, then, atomicity is sufficient to make up for the reduction in the number of data. In one dimension, however, the solution is not unique.[6] The situation in two dimensions is not clear, although taking all the above together suggests uniqueness in this case. Positivity of the electron density further constrains the solution, but it appears not to be necessary.[7]

The macromolecular crystallographic phase problem is much more severe and appears to be generally nonunique. This is because the intensity data usually cannot be measured at atomic resolution, so that, effectively, the image is not atomistic. The reduction in the number of data remains, however. Consequently, the phase (or the image) is indeterminate unless ancillary measurements (isomorphous replacement, anomalous dispersion and so on) are made or additional information (such as non-crystallographic symmetry) is available.

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The SSC vs Murphy's law

Proponents of the Superconducting Super Collider have defended[1] the viability of their design by noting the success of the Fermilab Tevatron, the only large superconducting accelerator now operating. They have specifically chosen the design of the SSC's magnets to follow that of the Tevatron's. The SSC, however, represents a tenfold increase in size, energy and cost over the Tevatron, achieved by a corresponding tenfold increase in the number of components. Thus, while there are 990 superconducting dipole and quadruple magnets in the Tevatron,[2] there will be 9456 such magnets in the SSC.[1] If we assume that the individual components of the SSC will have the same reliability as the corresponding components of the Tevatron, then for the purpose of failure analysis, the SSC can be thought of as ten Tevatrons connected in series, every one of which must be working for the whole system to work. It then becomes a trivial exercise in

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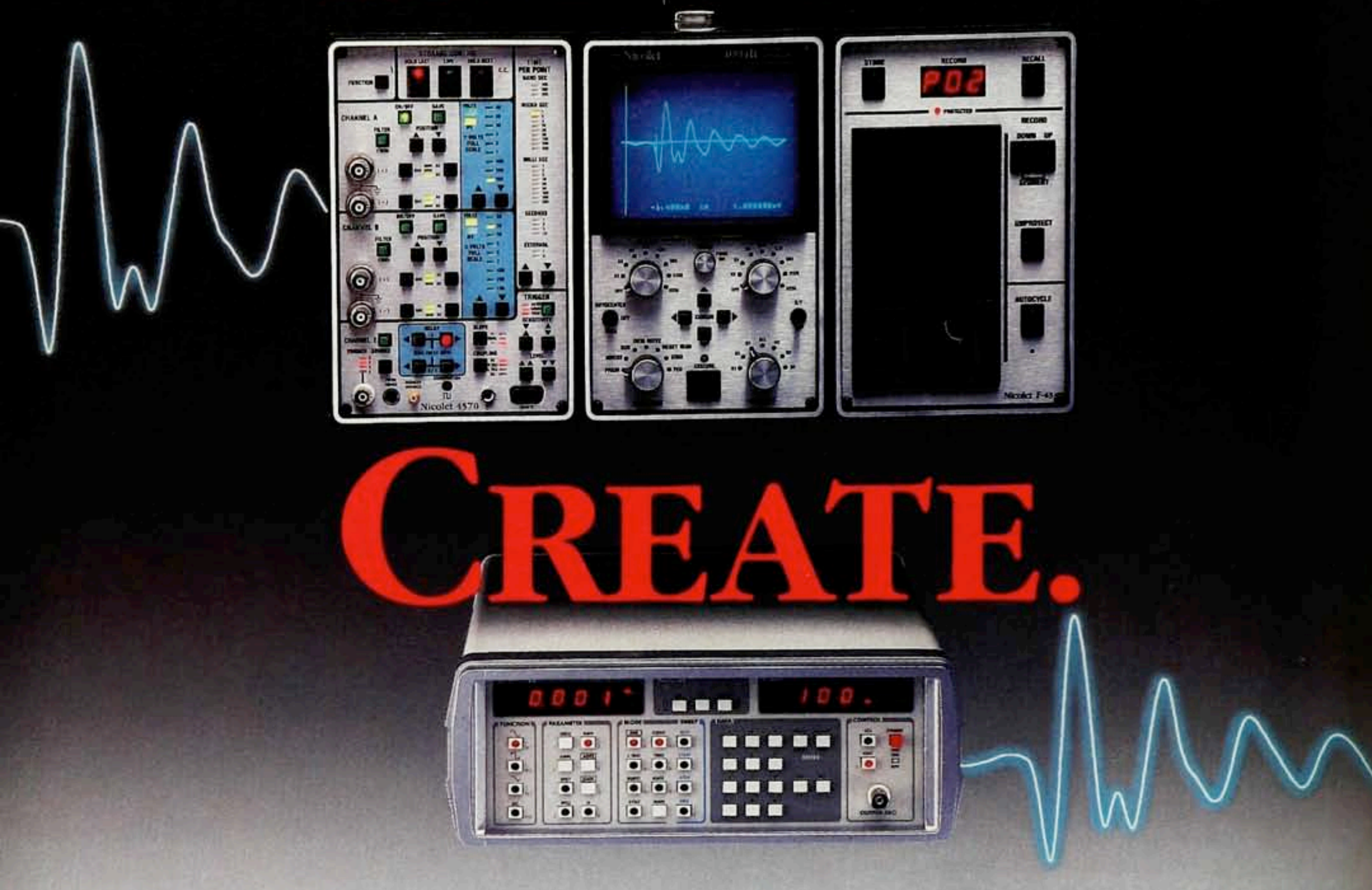

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elementary probability theory to predict the reliability of the SSC from the known performance of the Tevatron.

Experience with the Tevatron is limited. During the period of operation, the "availability" of the Tevatron—that is, the fraction of scheduled up-time that the Tevatron was actually available for experiments[1]—was 64.4%. We would thus predict an availability for the SSC of $(0.644)^{10}$, or 1.2%, which is obviously unacceptably low.

Thus, because the SSC will have ten times as many components as the Tevatron, the reliability of the individual components, and in particular of the superconducting magnets, is more critical for the SSC than for the Tevatron. The SSC will have nearly 10 000 magnets and each time any one of them needs to be replaced, the whole machine will be down for a full seven-day week.[1] However, because both the peak field strength and the variation in field strength over a cycle will be larger for the SSC magnets than for the Tevatron magnets, it is even possible that the magnets of the SSC will be less reliable than those of the Tevatron.

The moral of the story is that even in the absence of budgetary constraints, we cannot continue to build larger and larger particle accelerators *ad infinitum*. Sooner or later, Murphy's law of complex systems—"The larger and more complicated a system is, the more likely it will be to break down and the harder it will be to fix when it does" (R. D. Murphy, private communication)—will intervene to impose its own constraints.

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THE ASSOCIATE DIRECTOR OF THE SSC CENTRAL DESIGN GROUP REPLIES: Robert Yaes has pointed out, in effect, that reliability will be a serious problem for the SSC, with its 10 000 superconducting magnets. His point is well taken, and it has been well taken since the very beginning of the R&D program that was undertaken to develop a design for this new, proposed accelerator. Yaes may rest assured that we have made and are making appropriate Bayesian analyses of the simultaneous availability of 10 000 such magnets under various conditions of individual reliability. Among the most important design parameters for these magnets will be reliability and lifetime. We are confident that in spite of the large number of individual parts, the SSC collider rings will perform with a duty factor that is quite comparable to that of current-day accelerators. It's not easy, but we are confident that it can be done.

My guess is that if Yaes applied the same reasoning he has used in the case of the SSC to the step from the Bevatron to the Proton Synchrotron at Brookhaven or from the Proton Synchrotron to the initial, 400-GeV accelerator at Fermilab, he would come to much the same conclusion in each case, that is, that the next step in size would never work. Perhaps one of the important contributions to technology stemming from each of these steps in accelerator construction has been the development of highly sophisticated systems that operate at a comparably high level of reliability.

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Einstein and Germany

The article "Einstein and Germany" by Fritz Stern (February 1986, page 40) is spendidly evocative, but can we be sure that it represents in every way the facts as they are known? I say this because much mythology has grown up about Albert Einstein's life, and most secondary souces—including Alan D. Beyerchen's book, which Stern used—are not always reliable. For the evidence of this and other statements in this letter, see my article "Einstein, general relativity and the German press, 1919–1920."[1]

One such myth concerns Einstein's fame in Germany immediately after the solar eclipse announcement in November 1919 and the idea that this fame was connected with the fact that Germany in its humiliation was looking for an acceptable hero figure. (Stern writes, "The new hero appeared, as if by divine design. . . .") I have not been able to find any evidence for such a view in the contemporary German press, which—in contrast to the British and American press—treated Einstein with dignity and without sensationalism.

A more serious error in Stern's article concerns the 1920 edition of Philipp Lenard's book on relativity. This did not contain anti-Semitic remarks, and Einstein himself, in writing to Arnold Sommerfeld on 11 September 1920,

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