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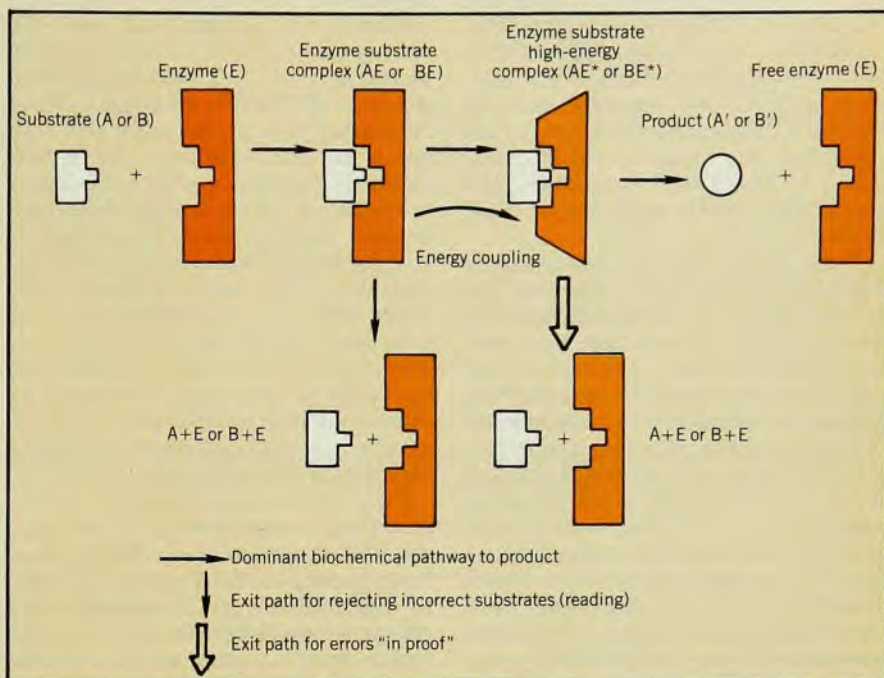
Proofreading by biological molecules detects "typos"

How does an enzyme know when it is making a mistake? The problem of accuracy in biosynthesis has been studied for a number of years. In DNA synthesis, for example, if too many errors occur a system cannot reproduce viable copies of itself. Too few and the system can never evolve. Solid-state theorist John Hopfield at Princeton has proposed¹ that many biological systems do "kinetic proofreading," a method of replication in which the system looks twice so that it can correct an initial mistake. Recently several groups have shown experimentally that such proofreading does appear to be taking place.

DNA is a long molecule with about 10^8 bases, which can be G, C, A or T. The instructions to replicate the molecule can be thought of as a sentence made of a four-letter alphabet in which there are 10^8 letters. Experimentally it is found that, in replicating, errors in the letters are made about 1 time in 10^8 .

Proteins, like DNA, are polymers. Each polymer unit is chosen from among 20 different amino acids. The protein is about 100 amino acids long, arranged in a particular sequence. The experimentally observed error rate in putting the right amino acids in the right place is about 1 in 10^4 .

Hopfield became interested a couple of years ago in the question of what causes the observed level of mistakes in biosynthesis. To distinguish between two substances A and B, one can think of a



A typical "kinetic proofreading" scheme for increasing fidelity, as proposed by John Hopfield. Discrimination is provided by the two exit paths, which have rates that are much faster for incorrect substrates than for correct ones. The energy coupling is essential, for without it, the reverse reaction from AE^* to $A + E$ becomes important, and the system ceases to proofread.

chemical reaction in which the error rate will vary as $\exp(-\Delta G/kT)$ where ΔG is the difference in free energy, k the Boltzmann constant and T the temperature. Because the true error rate appears

to be smaller than this quantity, the possibility of proofreading seems possible. While wondering about the problem, Hopfield, who was a student of Albert

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Magnetic-mirror performance challenges tokamaks

Results with the Lawrence Livermore Laboratory magnetic-mirror experiments over the past year and a bit are encouraging ERDA to push much harder in that direction, so that mirrors might share some of the funds tokamaks have been attracting. The results on 2XIIB are showing how to stabilize the mirror plasma, increase its value of beta and raise $n\tau$, the product of density and confinement time, considerably. Now Livermore has proposed building a new, \$94-million Mirror Experiment, MX for short. It is rumored that ERDA has requested the Office of Management and Budget to include MX in the FY 1978 budget.

The 2XIIB machine is a pulsed-field mir-

ror experiment, in which the mirror separation is 1.5 meters. The typical central field is 5–7 kG, and the field at the mirrors is twice that; that is, the mirror ratio is 2:1.

In July 1975 the first of three significant experiments with 2XIIB was completed. Prior to that time, the initial plasma in the predecessor experiment, 2X, was created by capture in time-of-flight of a hot plasma injected by a gun. With the installation of neutral beams, which were developed over several years by a joint Livermore–Lawrence Berkeley Laboratory collaboration, the approach changed. Deuterium ions are accelerated across a three-grid structure operating at

20 kV. The ions pass through deuterium gas and undergo charge-exchange reactions. Because the beam is a mixture of atoms and molecules (and ions), the resulting beam is a mixture of 6-, 10- and 20-keV neutral atoms. The beam is focused to a 10×20 cm spot, three meters away. Twelve such beams are used, six on each side, stacked in a vertical array in a magnetic field running horizontally. The twelve beams have a total equivalent current capability of about 600 A. However, most of the experiments have been run at 200–300 A.

Earlier experiments had produced a stable plasma with an average ion energy of 1–2 keV and an $n\tau$ of $10^{10} \text{ cm}^{-3} \text{ sec}$. In

July 1975 Frederic H. Coengsen, W. F. Cummins, B. G. Logan, A. W. Molvik, W. E. Nexsen, T. C. Simonen, B. W. Stallard and W. C. Turner produced¹ a stable plasma up to 13 keV mean ion energy (a mixture of energies 9–18 keV). Their value for $n\tau$ was $7(-2, +5) \times 10^{10} \text{ cm}^{-3} \text{ sec}$.

The experimenters had managed to stabilize the drift cyclotron loss-cone instability, first discussed theoretically in 1965 by Marshall Rosenbluth (Institute for Advanced Study) and Richard F. Post (Livermore). In this mode, the instability occurs because low-energy ions are missing. In 1967 Post suggested that by supplying the missing portion of the ion population, the plasma could be stabilized. In the 2XIIB experiment, the amount required was only about 1% of the density.

The technique they used was to supply cold plasma from a gun, shooting the stream along the magnetic-field lines; the gun operated in a low-voltage, long (millisecond) pulse mode. The cold plasma is automatically warmed by the instability fluctuations themselves to a temperature that quenches the noise in the system.

Being able to produce and maintain a dense, energetic plasma in a steady-state magnetic-mirror field has been a major problem. Last October, in a second experiment, Coengsen and his collaborators found² that the streaming plasma used previously for stabilization would also serve as a suitable target plasma for neutral-beam injection in a quasi-dc magnetic field. Thus, the Livermore workers believe they now have a method adaptable to superconducting dc magnets. In this second experiment, essentially the same parameters were obtained as in the July experiment.

In a third experiment, done in February, Coengsen and his collaborators used a gas box beyond the mirrors; this gas box had a small slit, which conformed to the field lines in that region. Plasma streaming through the gas emitted by the box caused the gas to ionize, creating the needed low-energy plasma ions. After the stream is cut off, if the gas box is used, the plasma density, instead of falling off, continues to build up to $1.2 \times 10^{14} \text{ cm}^{-3}$, a factor of three or more above earlier values. This level was maintained for as long as the sources could be operated (5 msec). The volume-averaged plasma beta (the ratio of plasma pressure to external magnetic pressure), as measured with diamagnetic loops and from the cyclotron frequency, is about 0.7 with a peak value substantially above this. As Post explained to us, at the highest operating condition, the Livermore group had an energy density for the plasma comparable to the energy density of the field at the time when the field had decayed to about 5 kG.

Field reversal. Having a high-beta plasma has two advantages in mirror ex-

periments. One is very efficient utilization of the magnetic field—lots of confinement for just a little field. A second factor is that high beta makes the mirror well even deeper than before the plasma was there. This had led Livermore to consider using in the mirror program an approach resembling the Astron concept, developed by the late Nicholas Christofilos. In field reversal, the electric currents within a confined plasma become so intense that they literally reverse the direction of the magnetic field inside the plasma, relative to its direction with no plasma present. In Astron field reversal was to be achieved by trapping a ring of circulating electrons (at many MeV) between mirrors. Although the experiments of Christofilos and his collaborators at Livermore did not actually reach field reversal, experiments at Cornell University, by Hans Fleischmann and his collaborators, who used a different technique, have not only demonstrated that field-reversing (greater than 190%) electron rings can be produced but also that their lifetime can exceed 1.3 msec.³ In attempting field reversal with the Livermore mirror, the experimenters would use only the plasma-ion currents.

Field reversal would be one way to improve mirror confinement. Other ways are also being considered. The motivation: to enhance the Q value of the mirror fusion reactor. Q is defined as the ratio of fusion power released to heating power input to the plasma. Within practical limits on the mirror ratio, Q is expected to be 1.0–1.5. Livermore would like to get this value up to 2 or higher; this would still further improve the economic picture for mirror fusion reactors. Another enhancement approach is to apply strong rf fields to the plasma at the mirrors. A third approach is to string mirror cells in series so that ions escaping out the end of an interior cell would have a chance of being trapped again before they reached the end cells.

The proposed MX would be a scaled-up experiment expected to increase plasma temperature fivefold over 2XIIB, to 50 keV, within a factor of two of anticipated reactor requirements. Field strength at the center would be 20 kG, four times that of 2XIIB; coils would be superconducting niobium-titanium. The distance between mirror points would be 3.4 meters. Like 2XIIB the mirror ratio would be 2:1. The vacuum vessel would be 9 meters in diameter. Neutral-beam injection would be provided by roughly two dozen injectors. The device is expected to have the capability to accommodate field reversal if that proves feasible. The primary power supply would be 220 MW, operating quasi-dc, pulsing with a duty cycle of 10%, with a pulse duration up to 30 sec.

Anticipated cost is \$94 million, including an office building.

Post anticipates that $n\tau$ would increase by an order of magnitude, to about 10^{12}

$\text{cm}^{-3} \text{ sec}$. For a mirror reactor, which would use direct conversion, one would need $n\tau$ to be between 10^{13} and $10^{14} \text{ cm}^{-3} \text{ sec}$. MX is roughly the Livermore equivalent of the Tokamak Fusion Test Reactor, now under construction at Princeton University. The TFTR is expected to reach an $n\tau$ of $10^{13} \text{ cm}^{-3} \text{ sec}$, about an order of magnitude away from that required for ignition operation.

MX has been recommended by ERDA's Fusion Power Coordinating Committee. Rumor has it that Robert Seamans, who heads ERDA, has asked OMB to put MX in the FY 1978 budget. If the President and Congress approve, MX could be doing plasma experiments in 1981.

—GBL

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Electron beams yield high-power microwaves

Over the past ten years intense relativistic electron-beam accelerators (300 kV–10 MV) have been developed that yield 10^4 – 10^6 amperes/pulse with pulse durations of tens or hundreds of nanoseconds. With this new tool at hand, experimenters have been trying to convert the electron-beam energy into microwaves. By re-viving the old devices (travelling-wave tubes and magnetrons) developed a quarter of a century ago and applying the new electron-beam technology, orders of magnitude higher power have been obtained. For example, very recently George Bekefi and Thaddeus Orzechowski (MIT) have produced¹ microwave bursts in the gigawatt range with a conversion efficiency of electron energy into microwave energy of about 35%.

The cyclotron-maser systems developed by Jay Hirshfield (Yale University) and Jonathan Wachtel (Yeshiva University) allow the electron beam to gyrate about a magnetic-field line. Creating a population inversion in the transverse momentum of the electrons provides the free energy needed to drive the instability, causing maser action. This concept was developed further by Victor Granatstein and Moshe Friedman (Naval Research Laboratory) and by John Nation and Yuval Carmel (Cornell University). Granatstein and Melvin Herndon (NRL), Nation and Carmel used this technique in the early 1970's to obtain peak powers of 1 GW for 3-cm (10 GHz) microwaves; efficiency was very low—a few percent. Granatstein, R. Parker and Friedman