A "Two Steps Forward, One Step Back" Heavy-Ion Accelerator

By varying the equilibrium charge state of ions it may be possible to accelerate them back and forth through a tandem Van de Graaff many times, with a net gain in energy each time. Günther Hortig, Max Planck Institute for Nuclear Physics, Heidelberg, has proposed a design for such an accelerator. It would use the fact that over a rather wide energy range, ions passed through a gas stripper have a smaller positive equilibrium charge than ions passed through a denser stripper.

In other words, ions passing through a foil or dust stripper will acquire on the average a greater positive equilibrium charge than ions passing through a gas stripper. In Hortig's design, as shown in the figure, ions injected at left through a dust stripper will be attracted to the negatively charged terminal of a tandem Van de Graaff. Inside the terminal the ions pass through a gas "stripper" where their average positive charge is reduced by the addition of some negative charge. Thus as they leave the terminal and continue to the right along the beam tube, they are decelerated by the charged terminal more weakly than they were accelerated going toward the terminal. The result is a net gain in energy.

Next the particles are bent through 180 deg with an appropriately designed magnetic mirror, passing through another dust stripper where some negative charge is removed. The charged beam is now attracted back to the left to the terminal where it again passes through the gas stripper and again acquires some negative charge. With the reduced positive charge, the beam passes to the left and is decelerated, but not as much as it was accelerated. Again there is a net increase in energy.

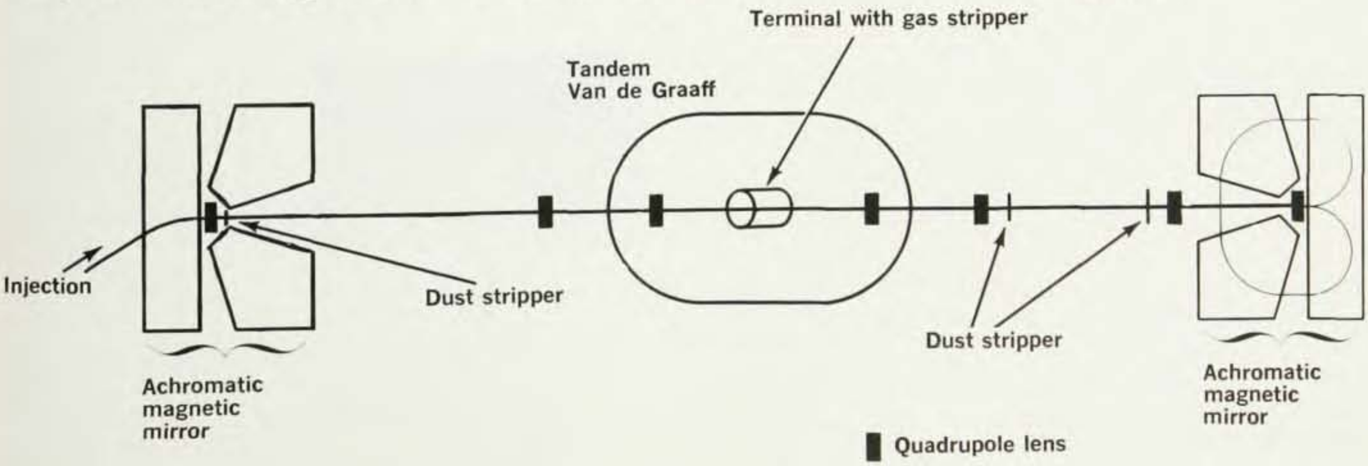
By bending the beam through 180 deg and directing it along its original trajectory, the entire process can be started again. Except for losses, the process can repeat as long as it is possible to add negative charge at the terminal and take it off at the ends of the accelerator. Each leg of acceleration will give more energy. Hortig estimates it may be possible to obtain 10-GeV uranium ions with such a device.

Successful operation requires a magnet that will bend particles of any energy through 180 deg, that is, it must be completely achromatic. The figure shows a design of such a mirror. Incoming particles pass through the gap between the two wedge-shaped magnets without being deflected. Then in the magnet H_1 the beam is bent through 180 deg; next the beam passes through the wedge H_2 which has a field half that in H_1. With this configuration particles of any energy can be bent through 180 deg and sent back along their original path.

To study how particles may be lost from the beam, Hortig has made a Monte Carlo calculation assuming injection of 25-MeV uranium ions and a terminal voltage of −4 MV. Under these conditions 30–40% of the injected beam was lost within the first few cycles. This loss occurs because at low energies the increase in velocity of the accelerated particles may be enough to compensate for the low density of the gas stripper with the result that a portion of the particles can lose more charge in the gas stripper than in the dust stripper. Such particles will undergo a net energy loss per cycle rather than a gain. Also at low energies there is some loss from scattering.

Critical losses can also occur by buildup of accelerations of the ions perpendicular to the beam axis. However, Hortig calculates that the same effect that accelerates the particles in the beam direction can also be used to decelerate the oscillations of the particles transverse to the beam direction. The charge changes of the traveling particles are controlled by

ACCELERATING HEAVY IONS pass through a dust stripper and a gas stripper, and then upon reflection by a magnetic mirror, pass through another dust stripper and the gas stripper, with net increases in energy in both passes.



the same media as before: gas and dust with only the modification that the regions far from the axis have to be held relatively free of dust. Under this condition, with help of the potential of the moving particles in the focusing-lens system, the energy of the oscillations will be damped.

At high energies the gas and dust strippers become equal in stripping efficiency. The result is that the dust and gas strippers produce equilibrium charges that are about the same. Under these circumstances, no further acceleration is possible. Upon extrapolation of the curves of charge equilibrium as functions of energy, it has been estimated that the maximum energy is about 50 MeV/nucleon.

Peter Rose of High Voltage Engineering Corporation is interested in developing such a heavy-ion accelerator. He feels that stripper design is the most crucial problem. Foil strippers would work except that they have very short lifetimes in energetic heavy-ion beams, so he looks upon dust strippers as a hopeful approach. HVEC has built a couple of such strippers. (Van de Graaff was working on this problem before his death.) The first design was crude and was basically a Ferris wheel that rotated in the beam with dust falling from one cup of the wheel to the next one below. A second model used a vibrator with a spoonful of dust on it. These models lasted only an hour or so before the dust dispersed. Nevertheless, they showed that dust strippers are possible and effective.

Rose is proposing capturing a cigar shape of charged dust in an rf field. This procedure would have the advantage of localizing the dust near the beam axis, thereby satisfying the condition necessary for damping transverse components of momentum. The Hortig accelerator design works in favor of dust strippers because they could be located outside the acceleration region. Consequently, bad effects from dispersed dust would be reduced. Rose feels that the problem of designing a good stripper definitely is solvable and that once this obstacle is overcome the accelerator can contend seriously with the Omnitron (PHYSICS TODAY, May, page 64) as a heavy-ion accelerator.

Helium-3 Dilution Makes Millidegree Temperatures

A new kind of refrigerator for cooling below 0.1°K holds great promise for cryogenics. Over the past year several groups have built He^3-dilution refrigerators that can cool samples continuously below 0.2°. Although adiabatic-demagnetization methods have traditionally been used to cool below 0.3°, the new refrigerator is much simpler to use. At the April American Physical Society meeting John Wheatley (formerly of the University of Illinois and now at the University of California, San Diego) reported that his continuously operating He^3-dilution refrigerator had reached 0.020° and his single-cycle device had reached 0.0044°.

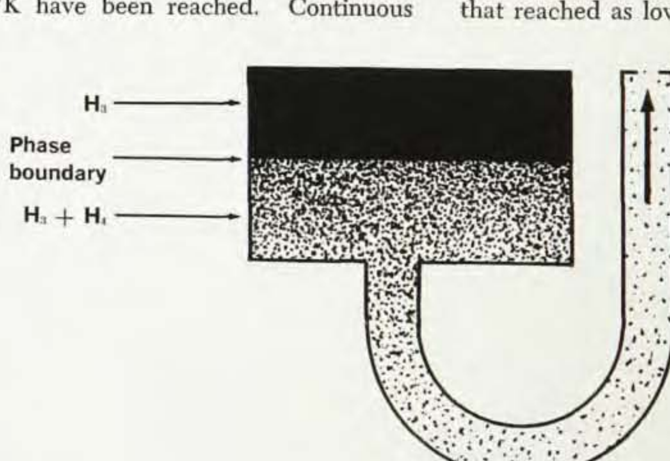
Heinz London of Harwell, England, first proposed a He^3 cooling cycle in 1951. He suggested that He^3 atoms dissolved in He^4 behave in many ways like a gas. Introduction of more He^4 into the system would cause cooling in analogy to adiabatic gas expansion.

Then in 1956 G. K. Walters and William Fairbank found that below 0.087° He^3-He^4 mixtures separate into two distinct phases. Pure He^3 floats on top of a dilute solution of He^3 in He^4. It became apparent that one could devise continuous and more powerful cooling cycles in which He^3 atoms would move across the phase boundary; the process is analogous to evaporation of a liquid into a gas.

Refrigeration occurs when He^3 dissolves out of the pure He^3 phase into the liquid He^4. The latent heat absorbed as the He^3 goes into solution does the cooling; the He^4 acts only as a carrier. This procedure is a marked advance over a conventional evaporation refrigerator, which can not be operated effectively below about 0.25 °K because the He^3 vapor pressure decreases exponentially with decreasing temperature.

Both single-cycle and continuously operating refrigerators have been built. In single-cycle operation one just allows the He^3 to diffuse through the He^4 column and boil out into a vacuum at a higher temperature until the He^3 reservoir is depleted. In this way temperatures as low as 0.0044 °K have been reached. Continuous refrigeration is achieved by returning the He^3 atoms to the reservoir after they evaporate from the He^4. The recirculated He^3 carries heat and also some He^4 back into the reservoir. The heat and the effects of the He^4 have so far limited cooling by continuous refrigeration to approximately 0.020°K.

Several possible cooling cycles were suggested in 1962 by London, G. R. Clarke, E. Mendoza and H. E. Hall. Two years later a group at Leiden (P. Das, R. de Bruyn Ouboter and K. W. Taconis) reported the first attempt to build such a refrigerator. In 1965 groups at Manchester and Dubna independently succeeded in building the new device. Hall, P. J. Ford and K. Thompson at Manchester built one that reached as low as 0.065° and re-



REFRIGERATION is caused by latent-heat absorption as He^3 dissolves in liquid He^4