of the Knight shift K_s in the superconductor. On the basis of this criterion, one estimates that at 1.45°K ν_s is about 0.9% less than the resonance frequency in the normal metal, i.e., $K_s \approx 1.5\%$.

Saturation effects in the superconducting line should cause a decrease in intensity without change of shape.[8] At 1.45°K, partial saturation of the superconducting line, though not of the normal one, could indeed be observed at available power levels (see Fig. 1). This leads to an order of magnitude estimate of $T_1 \approx 0.1$ sec for

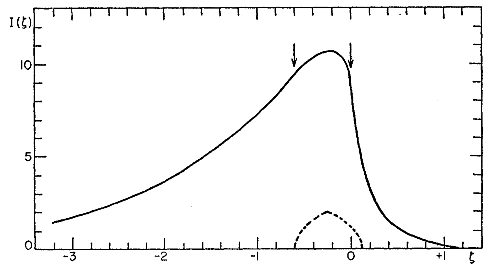

FIG. 3. Solid curve: The result of superposing the nuclear resonance absorption curves due to individual superconducting spherical particles, using for their size distribution one of our poorest (i.e., the actual sample used in the experiments contained a somewhat larger proportion of small particles). Microscopic broadening effects, such as those responsible for the width of the normal line, have not been taken into account in constructing the curve and would tend to smear it out a bit. ζ is related to the frequency ν by $\zeta = 30(\nu - \nu_s)\nu_s^{-1}$, where ν_s is the resonance frequency in a sample with infinite penetration depth. The arrows indicate the extrema on the experimentally measured derivative curve. Dotted curve: Contribution to the solid curve of particles with $0.3 < a' < 0.4$ (a' = ratio of radius to penetration depth).

the nuclear relaxation time in superconducting Hg at 1.45°K; from the Korringa relation[9] one calculates $T_1 \leq 0.01$ sec for the normal metal at this temperature. At 2.03°K, the superconducting line could not be saturated.

More quantitative experimental work, needed for the theoretical interpretation of the results, is in progress. We wish to thank the department of meteorology, and in particular Miss B. Tufts, for generous help with the electron microscope and Miss N. Knudsen for assistance with the preparation of the samples. Numerous discussions with Professor A. B. Pippard and Dr. G. F. Dresselhaus are gratefully acknowledged.

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Storage-Ring Synchrotron: Device for High-Energy Physics Research*

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AS accelerators of higher and higher energy are built, their usefulness is limited by the fact that the energy available for creating new particles is that measured in the center-of-mass system of the target nucleon and the bombarding particle. In the relativistic limit, this energy rises only as the square root of the accelerator energy. However, if two particles of equal energy traveling in opposite directions could be made to collide, the available energy would be twice the whole energy of one particle. Kerst, among others, has emphasized the advantages to be gained from such an arrangement, and in particular of building two fixed-field alternating gradient (FFAG) accelerators with beams interacting in a common straight section.

It is the purpose of this note to point out that it may be possible to obtain the same advantages with any accelerator having a strong, well-focused external beam. Techniques for beam extraction have been developed by Piccioni and Ridgway for the Cosmotron, and by Crewe and LeCouteur for lower energy cyclotrons.

In the scheme proposed here (see Fig. 1), two "storage rings," focusing magnets containing straight sections one of which is common to both rings, are built near the accelerator. These magnets are of solid iron and simple shape, operating at a high fixed field, and so can be much smaller than that of the accelerator at which they are used.[1] The full-energy beam of the accelerator is brought out at the peak of each magnet cycle, focused, and bent so that beams from alternate magnet cycles enter inflector sections on each of the storage rings. In order to prevent the beams striking the inflectors on subsequent turns, each ring contains

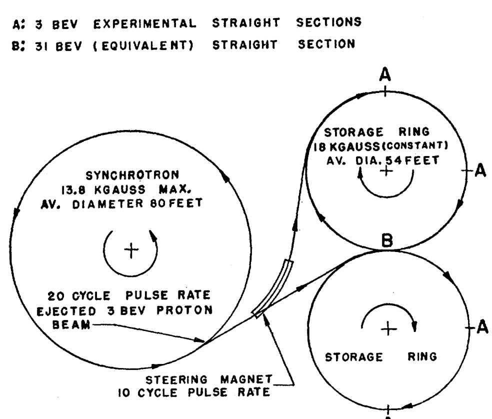

FIG. 1. Plan view of particle orbits in a hypothetical arrangement of storage rings at a 3-Bev proton synchrotron.

a set of foils, thick at the outer radius but thinning to zero about one inch inside the inflector radius. The injected beam particles lose a few Mev in ionization in the foils; so their equilibrium orbit radii shrink enough to clear the inflectors after the first turn. After several turns, the beam particles have equilibrium orbits at radii at or less than the inside edge of the foils.

The possibility exists of storing a number of beam pulses in these storage rings, since space charge and gas scattering effects are small at high energies. Preliminary calculations have been carried out on a hypothetical set of storage rings for the 3-Bev, 20 cycle per second Princeton-Pennsylvania proton synchrotron. Since the storage rings would be simple and almost entirely passive devices, their cost would be small compared with that of the accelerator itself. It was estimated that a pair of storage rings operating at 18 000 gauss with a 2 in.$\times$6 in. good-n region would weigh a total of 170 tons. The magnet of the synchrotron itself would weigh 350 tons, and would be of much more complicated laminated transformer iron. In the event that one could obtain an average current of 1 microampere from the synchrotron, and an average particle lifetime of a few seconds for the storage rings, there would be about 1000 strange-particle-producing reactions per second at each of two beam crossover points, for an estimated 1.5-millibarn total cross section. The center-of-mass energy, 7.8 Bev, would be equivalent to that of a 31-Bev conventional accelerator. If storage rings could be added to the 25-Bev machines now being built at Brookhaven and Geneva, these machines would have equivalent energies of 1300 Bev, or 1.3 Tev.

If only one storage ring were used, tangential to the accelerator itself, the interaction rate would be reduced by a factor S/D, where S is the average number of beam pulses stored in each ring, and D is the fraction of time the accelerator beam is at full energy. The interaction rate would be proportional to S^2 if two storage rings were used.

The advantage of systems involving energy-loss foils is that they provide an element of irreversibility; with foils, the area in phase space available to a particle can be made to decrease with time. This makes it possible to insure that particles once injected will never subsequently strike the injector, no matter how long they may circulate in the storage ring. Preliminary work with a stabilized electronic analog computer indicates that foils may also allow the stable and irreversible capture of roughly half of the circulating particles by a fixed-frequency rf system, which in turn may allow the storage of a large number of beam pulses in each storage ring. It appears that a thin hydrogen jet inside the equilibrium orbit of a conventional synchrotron would, in some energy ranges, reduce radial betatron oscillations even when scattering is taken into account.

The major difficulties in the use of storage rings with foils may result from the amplification of radial betatron oscillations by the foils. Quantitative calculations of this effect have been carried out on the analog computer. It was found that the effect would be serious unless the initial injection to the storage rings could be very precise. However, calculations were also made on a system involving a second foil placed at the inner limit of the good-n region. This foil would move the particle orbits inward as soon as betatron oscillation became serious, and would then continue reducing the betatron oscillation amplitude until the foil itself was rotated out of the median plane. During the long interval (about 0.1 second, or 600 000 turns) before the next beam pulse, the betatron oscillations would continue to be reduced by a thin hydrogen "target" jet also at the radius of the second foil. The process of orbit shrinkage would stop when the particles were captured in stable synchrotron phase by a low-power fixed-frequency rf system; the reduction in betatron oscillations due to the hydrogen would continue. The rf system would define an equlibrium orbit just outside the radius of the hydrogen jet, so that particles whose betatron oscillation amplitudes had been reduced to low values would circulate in a high-vacuum region, where the mean lifetime for nuclear interactions would be long. When the moving foil returned to assist in the acceptance of the next beam pulse, all particles that had been captured by the rf in previous pulses would have small oscillation amplitudes, and so would miss the foil. In this way particles from many beam bursts could be concentrated in a small region, with very little deviation in energy or position.

The author takes pleasure in acknowledging very helpful discussions on this subject with Dr. M. G. White and Dr. F. C. Shoemaker. The assistance of Dr. I. Pyne in setting up problems for the GEDA computer of the Princeton engineering school is also very gratefully acknowledged.

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[1] Between the dates of submitting this letter and its publication, it has come to the author's attention that the basic idea of a storage-rung synchrotron has also occurred, at about the same time, to W. M. Brobeck of the Berkeley accelerator group, and to D. Lichtenberg, R. Newton, and M. Ross of the MURA group.

Multiple Ionization in Xenon Following Internal Conversion

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THERE has perhaps been an insufficient appreciation of the damage that can be produced in the electron structures of atoms as the result of the creation of a vacancy in an inner shell. We have recently applied the methods of magnetic analysis[1] to the stable Xe^{131} atoms that are produced following the isomeric nuclear transition of Xe^{131m} (12-day half-life), and find the distribution in charge given in Table I. In a transi-