Who made the baseball?

After reading your article on the baseball magnetic field (PHYSICS TODAY, November, page 70) I noticed that several original and important contributions from our British colleagues had gone unmentioned. In particular, it had been my impression that the baseball-coil concept had been developed at Culham several months before discussions of this design at Livermore. In attempting to clarify for myself the developments that led to the outcome of this now popular baseball design, I have reconstructed something of an informal history of its evolution from minimum-B origins that, I believe, will interest your readers. I have not myself been a contributor to minimum-B concepts, but my visit to the Culham laboratory from August 1963 through the following July provided me with a vantage point of the developments in the UK and the US that was perhaps unique.

Prompted by the observation of M. S. Ioffe (Kurchatov Institute) that a mirror plasma could be stabilized by the application of longitudinal current-carrying rods, J. B. Taylor (Culham) developed a theory of plasma confinement in mirror-multipole magnetic configurations (minimum B) in the spring of 1963. Shortly thereafter, it was shown by Jean Andreoletti (Fontenay) and Harold P. Furth (Livermore) that minimum-B stabilization could also be accomplished in axially symmetric magnetic configurations. By this time a flurry of excitement had developed over possible coil configurations that would give rise to a minimum B. At an international mirror-machine conference held at Fontenay-aux-Roses in July 1963 the Fontenay group presented models of elliptical coils, which, when oriented with their major axes perpendicular, generated a minimum-B field. At Livermore, Walton Perkins observed that three pairs of circular coils, when arranged with the three axes of the pairs orthogonal, produced a minimum-B field in the interior region. It was widely recognized that an axially symmetric minimum B could be generated with a current-carrying rod running along the axis of a pair of cusp coils. (This "stuffed cusp" configuration had been proposed by the NYU group as early as 1958.) In the summer of 1963, Perkins had superimposed a hexapole field upon a simple mirror field to stabilize the simple mirror plasma. Perkins observed that the hexapole winding could be accomplished by linking the hexapole rods at alternate ends with azimuthal connectors so as to provide a continuous serpentine-like conductor. In discussions in the late summer and early fall, Perkins and Furth recognized that such a serpentine conductor, either hexapole or quadrupole, with all current elements lying on the surface of a cylinder, would in itself generate a minimum-B configuration without need for additional mirror coils.

Towards the end of that summer the Culham laboratory had already committed itself to building Phoenix II, a quadrupole superimposed on a conventional mirror field. By this time the direction of further minimum-B developments at Livermore and Culham had already begun to diverge. At Livermore primary emphasis was placed on axially symmetric systems of the Andreolleti-Furth type, and extensive theoretical and engineering studies ensued. Meanwhile at Culham the emphasis shifted toward elucidating the currents and field configuration associated with the quadrupole-mirror minimum B.

From this emphasis the coil configuration that was ultimately to become known as the baseball coil was evolved at Culham in the fall and winter of 1963. Informal conversations among members of J. B. Taylor's theoretical division and D. R. Sweetman's Phoenix group developed two different lines of thought leading to what later came to be known at Culham as the "tennis-ball winding." It was noticed that the quadrupole-mirror configuration was schematically equivalent to current elements flowing along the twelve edges of a cube, arranged in such a way that the current elements in two faces of the cube provided a mirror, and the current elements in the other four faces provided two orthogonal cusps. Examination of this configuration shows that two of the current elements in each mirror face are redundant, and the minimum B can be accomplished by a single continuous current element lying along eight edges of a cube. This rectilinear configuration is similar to the cylindrical configuration of Perkins and Furth, but neither of these coil designs provides a suitable minimum B, mainly because of their poor mirroring properties. It was necessary to recognize that by warping the coil so as to bring the mirror current elements closer together the mirroring properties could be improved. At about this same time the theoretical division at Culham had been pursuing the separate question of what coil configurations would generate spherical constant-B surfaces. From these two lines of thought and after several months of theoretical analysis and numerical computation, the tennis-ball winding evolved sometime in the late winter or early spring of 1964. In May I attended a colloquium at Culham in which the speaker outlined the recent development and in his presentation made use of several models of coils, including the tennis-ball winding.

Late in June, V. K. Neil of Livermore paid a visit to Culham and was informed of the tennis-ball developments, which he in turn communicated back to Livermore by letter. On receipt of the Culham letter at Livermore, it was recognized immediately that the tennis-ball winding offered the possibility of easy beam access for a type of wide-angle neutral injection fashionable at the time. At this time the Alice group had successfully stabilized their mirror plasma by addition of a 12-rod Ioffe winding, had abandoned the axially symmetric designs and was studying the possibilities of a mirror-quadrupole system. After hearing of the British developments, a study program was initiated to explore the field configuration and Lorentz ionization properties of the tennis-ball winding and from this study program there later developed the design for the Alice baseball coils.

The above discussion of a particular scientific invention and approach to controlled thermonuclear research is, I believe, an illuminating and instructive example of the course of an international scientific-technical development. Whether the "baseball" (née "tennis-ball") field or the simpler mirror quadrupole geometry will prove experimentally the most profitable approach remains for the future to determine.

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Prolongation of life

I believe as Feinberg in his recent article that appeared in the November issue of PHYSICS TODAY that sometime in the future mankind will eliminate aging and also death. Feinberg, however, seems to leave one with the feeling that the solutions to the technical problems of life prolongation should be hastened as they would make voyages to far interstellar areas more probable and such voyages would be a major contribution of science to humanity.

My view is that the religious and social institutions may not be able to change rapidly enough to cope with the developing social problems such as the regulation of births to prevent the population from becoming larger than the availability of food supply and standing room. Even now the world per-capita food supply is decreasing because of rapid increase in population.

Feinberg should also bear in mind that if science is to serve all of humanity, it must be more closely coupled with its consequences to all of society. I believe that if this is not done, the death of our new freedoms of intercourse in return for death immunity is a high price. You can have it.

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In connection with Feinberg's article one additional point seems worth noting. Recent experiments on the biological role of ice (see, for example, the article by N. H. Grant, *Discovery*, August) have indicated that some impor-