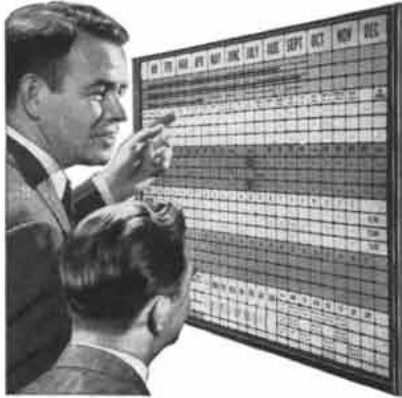


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war he became well-known as a writer on scientific and other topics for *Politiken*, the leading Danish newspaper. He is also known, under the pseudonym of Kumbel, as the author of numerous volumes of epigrammatical poems. These books have sold 175,000 copies.

The game of Hex occurred to Hein while he was contemplating the famous four-color theorem of topology. (The theorem, as yet unproved, is that four colors are sufficient to make any map so that no two countries of the same color have a common boundary.) Hein introduced the game in 1942 with a lecture to students at the Institute. In December of that year *Politiken* published an account of the game; it soon became enormously popular in Denmark under the name of Polygon. Pads on which the game could be played with a pencil were sold, and for many months *Politiken* ran a series of Polygon problems, with prizes for the best solutions.

In 1949 Aage Bohr, son of Niels, introduced the game at the Institute for Advanced Study in Princeton, where it quickly captivated students of mathematics both at the Institute and Princeton University. The game was commonly called John because it was so often played on the hexagonal tiles of bathroom floors. It did not acquire the name Hex until 1952, when a version of the game was issued under that title by the firm of Parker Brothers, Inc.

Readers who would like to try Hex are advised to make mimeographed copies of the board depicted at the bottom of the preceding page. The game can be played on these sheets by marking the hexagons with circles and crosses. If you should prefer to play with removable pieces on a permanent board, a large one can easily be drawn on heavy cardboard or made by cementing together hexagonal tiles. If the tiles are big enough, ordinary checkers make convenient pieces.

One of the best ways to learn the subtleties of Hex is to play the game on a board with a small number of hexagons. When the game is played on a two-by-two board (four hexagons), the play-

er who makes the first move inevitably wins. On a three-by-three board the first player may win easily by making his first move in the center of the board [see illustration at left at the bottom of this page]. There is no way in which his opponent can keep him from winning on his third move.

On a four-by-four board things begin to get complicated. The first player is sure to win if he immediately occupies any one of the four hexagons numbered in the illustration at the right at the bottom of this page. If he makes his opening play elsewhere, he can be defeated. An opening play in hexagon 2 or 3 ensures a win on the fifth move; an opening play in hexagon 1 or 4, a win on the sixth move.

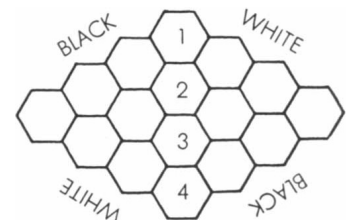
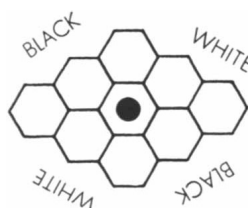
On a five-by-five board it can still be shown that, if the first player immediately occupies the hexagon in the center, he can win on his seventh move. On larger boards the analysis becomes enormously difficult. So far as I know no one has fully analyzed the possibilities in a game of Hex played on a six-by-six board. Of course the standard 11-by-11 board introduces such an astronomical number of complications that a complete analysis seems out of the question.

It is for this reason that game theorists find Hex particularly interesting. There is no procedure which will assure a win on a standard board, but there is an elegant proof that a winning strategy exists for the first player on a board of any size! The proof seems to have been discovered independently by Hein and several mathematicians both here and in Europe. The following is a condensed version of the proof (it can be formulated with much greater rigor) as it was worked out in 1949 by John F. Nash, now assistant professor of mathematics at the Massachusetts Institute of Technology.

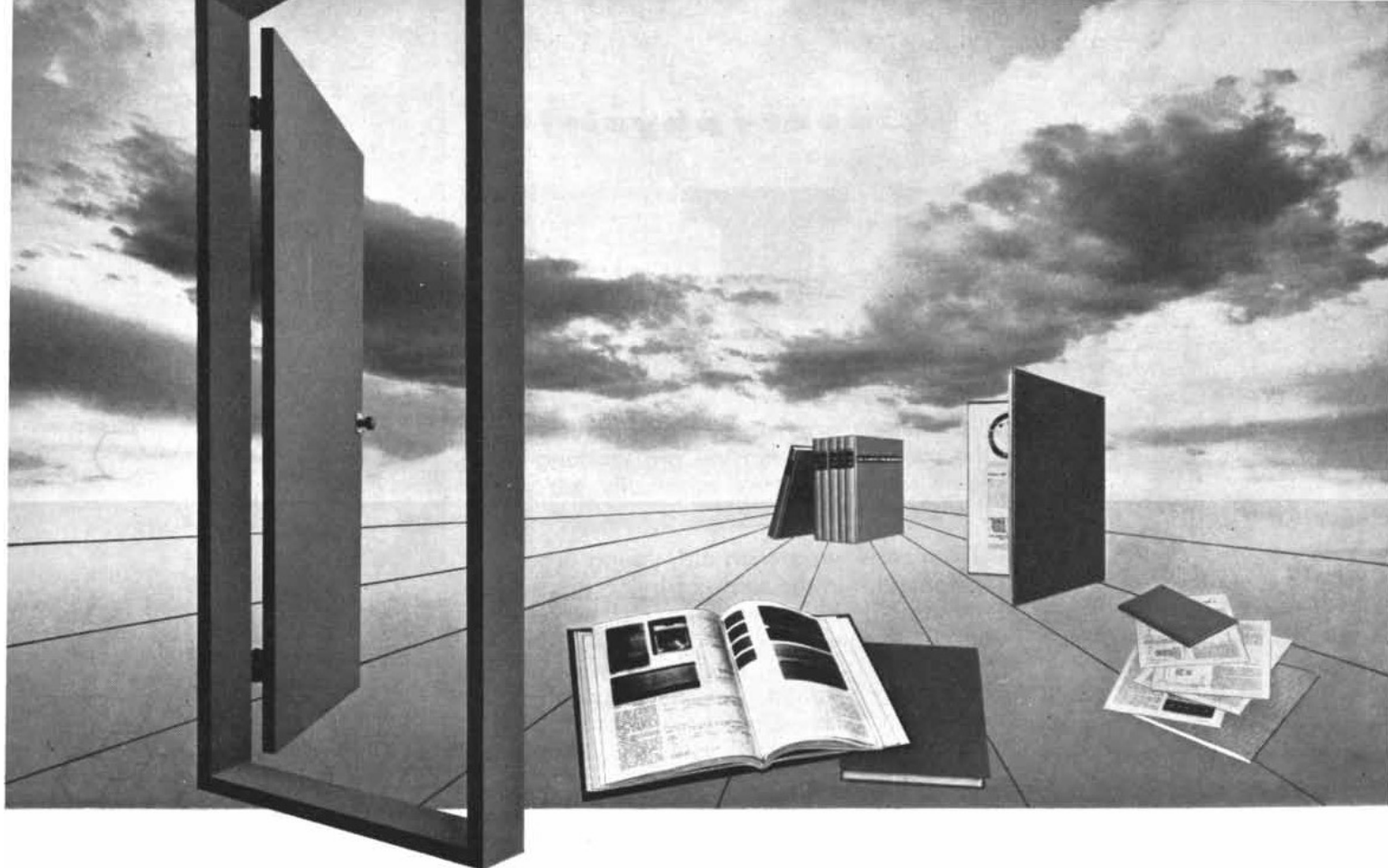
1. Either the first or second player must win, therefore there must be a winning strategy for either the first or second player.

2. Let us assume that the second player has a winning strategy.

3. The first player can now adopt the



About first moves on three-by-three and four-by-four Hex board



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M. H. Rice, R. G. McQueen, and J. M. Walsh, Solid State Physics—Advances in Research and Applications, Vol. 6 (In Press).
- PRECISION FLASH X-RAY DETERMINATION OF DENSITY RATIO IN GASEOUS DETONATIONS
R. E. Duff and H. T. Knight, J. Chem. Phys. 25, 1301 (1956).
- POLYMORPHISM OF IRON AT HIGH PRESSURE
D. Bancroft, E. L. Peterson, and S. Minshall, J. App. Phys. 27, 291 (1956).
- IMAGE QUALITY CRITERIA DERIVED FROM SKEW TRACES
F. A. Lucy, J. Opt. Soc. Am. 46, 699 (1956).
- VISIBLE RADIATION FROM HELIUM IN A STRONG SHOCK WAVE
G. E. Seay and L. B. Seely, Jr., Bull. Am. Phys. Soc. II, 1, 227 (1956) (Abstract).

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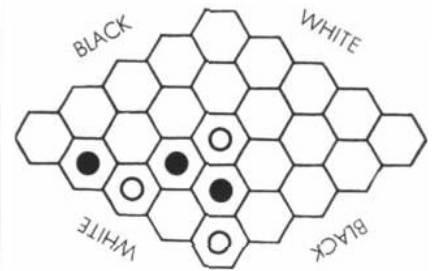
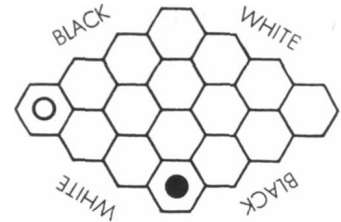
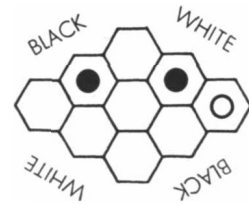
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Three problems of Hex

following defense. He first makes an arbitrary move. Thereafter he plays the winning second-player strategy assumed above. In short, he becomes the second player, but with an extra piece placed somewhere on the board.

4. This extra piece cannot interfere with the first player's imitation of the winning strategy, for an extra piece is always an asset and never a handicap. Therefore the first player can win.

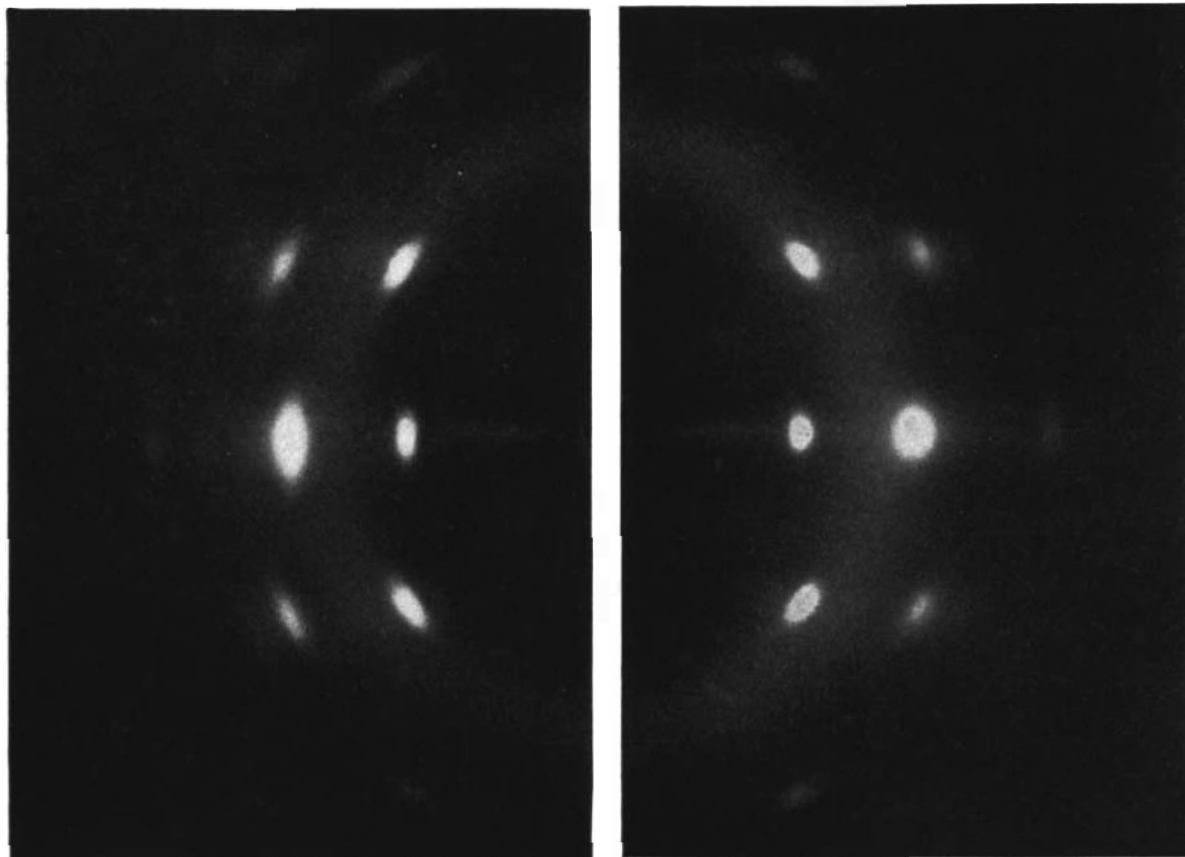
5. Since we have now contradicted our assumption that there is a winning strategy for the second player, we are forced to drop this assumption.

6. Consequently there must be a winning strategy for the first player.

There are a number of variations on the basic theme of Hex, including a version in which each player tries to force his opponent to make a chain. According to an involved proof devised by Robert Winder, a graduate student of mathematics at Princeton, the first player can always win this game on a board which has an even number of cells on a side, but he can lose on a board with an odd number.

After the reader has played Hex for a

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These two photographs compare the x-ray diffraction patterns of natural rubber (*left*) and a new synthetic rubber produced by the Firestone Tire and Rubber Company (*right*). As the patterns suggest, the new man-made high polymer successfully duplicates the structure of the polymer synthesized by the *Hevea* tree.

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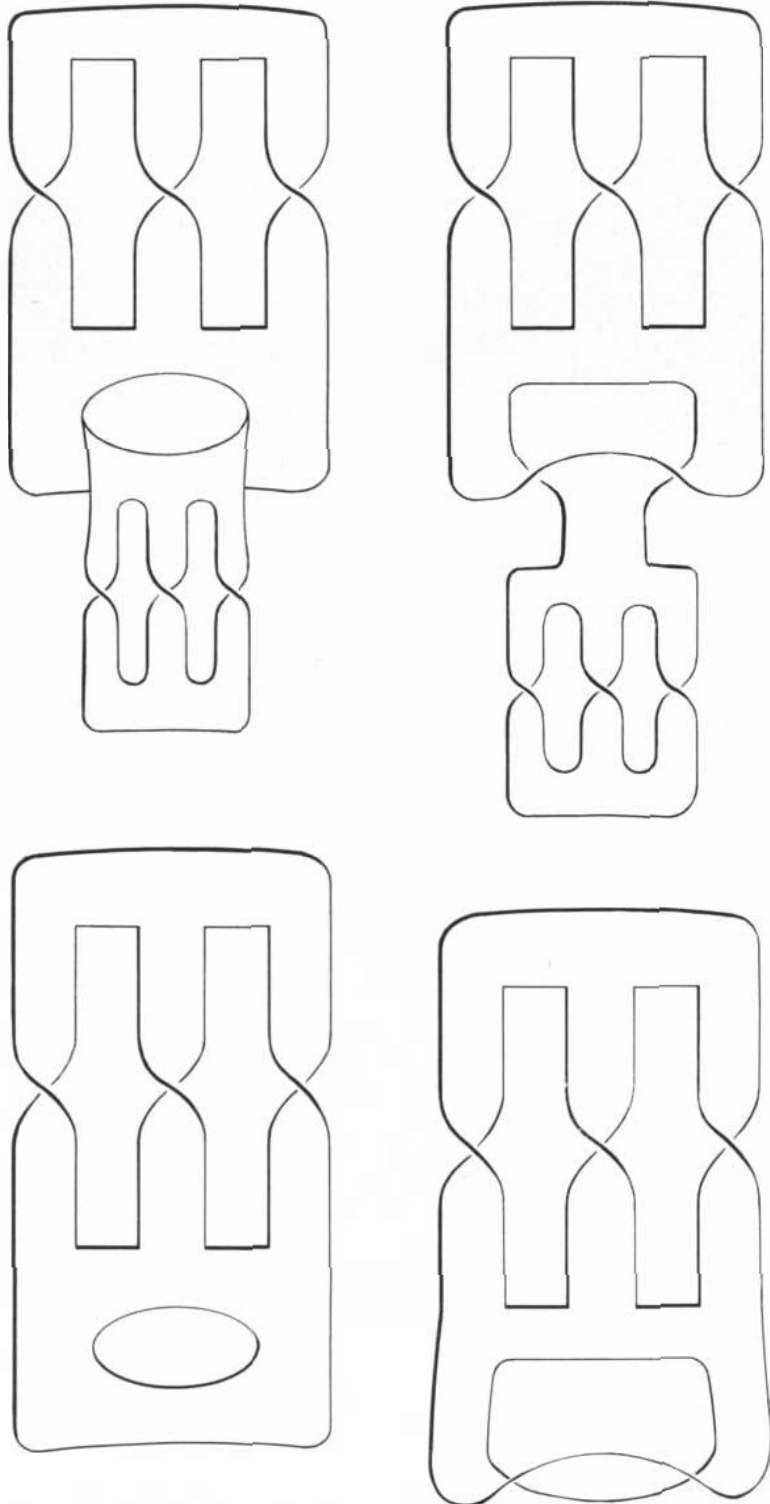
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while, he may wish to tackle three problems devised by Hein. These are set forth in the three illustrations at the top of page 148. The objective in all three problems is to find the first move that will ensure a win for "white." The solutions will be published in this department next month.

Last month this department presented pictures of 12 of the 16 topological models that can be made with surfaces with no more than two edges, and edges which are a simple closed curve or a single knot. Readers were challenged to make the other four models. They are depicted below.



Four topological surfaces which the reader was challenged to make last month