PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Quasicrystalline Symmetry

L. H. Schwartz

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Quasicrystalline symmetry

By L. H. Schwartz

Institute for Materials Science and Engineering, National Bureau of Standards, Gaithersburg, Maryland 20899, *U.S.A.*

[Plate 1]

My remarks are intended as a follow-up to Dr Gilman's statement that we may expect to see more exciting new science (and technology) coming from the field of rapid solidification. Indeed one exciting new scientific area has already emerged, that of quasicrystalline symmetry. Almost immediately upon arrival at the National Bureau of Standards to head their Institute for Materials Science and Engineering, I was confronted by John Cahn and asked to approve release of a paper he characterized as somewhat controversial. Controversial indeed: this paper by Shechtman *et al.* included the first experimental evidence for icosahedral symmetry in a solid. In approving release, I followed a principle that I had long ago established for myself: if John Cahn is interested in a topic it is well worth my time to learn more about it. I include some figures intended only to stimulate the interest of those who are not yet aware of this subject, and extend apologies for my lack of detail to those who have followed the explosion of activity during the past two years: more than 100 related papers were published within the first year after the Cahn–Shechtman paper.

It all started with the diffraction pattern you see in figure 1, taken by Daniel Shechtman at NBS from a sample of melt-spun Al–15% Mn. The pattern shows sharp spots in reciprocal space indicating order in real space extending over large distances. It shows a tenfold rotational symmetry (later shown to be fivefold inversion) and it shows irrational spacing of spots along high-symmetry directions. When the sample is rotated by appropriate angles, other symmetries are seen as shown in figure 2, corresponding to the full symmetry of the icosahedral point group $\bar{\mathrm{m}}\ \bar{3}\bar{5}$.

This seems to contradict what we were all taught in elementary crystallography and an early criticism was that the sample contained microtwins. Many exhaustive tests have eliminated that possibility, but my favourite is a direct-space image via field-ion microscopy (figure 3) showing the fivefold axis. Thanks to Cahn and his many co-workers we now know that this sample exhibits long-range orientational order but no translational periodicity. It is thus not a violation of the elegant geometric crystallography that prohibits the presence of fivefold rotational symmetry in a periodic system. Instead it represents an extension of crystallography into a new régime.

For metallographers I present a sequence of photomicrographs showing the dendritic growth of this new phase in an Al matrix: figure 4, plate 1, exhibiting the fivefold axis of the point group and figure 5, plate 2, showing a twofold axis. Bob Shaeffer at NBS has constructed a three-dimensional model of this dendritic structure (figure 6) exhibiting all the metallographic features and the icosahedral structure.

In closing, I list just a few of the exciting developments that have occurred in this area in the few months after Shechtman's discovery.

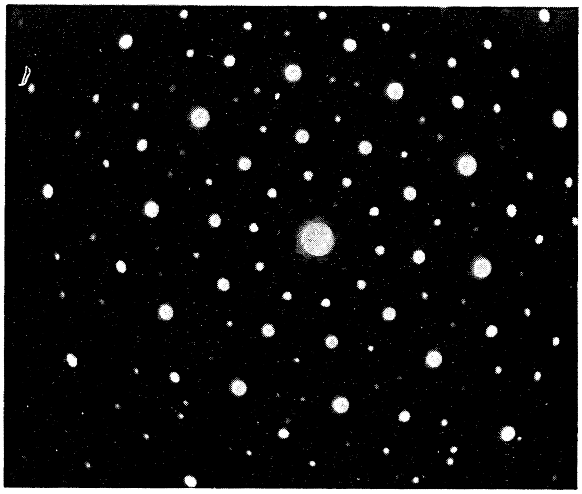

FIGURE 1. Diffraction pattern from melt-spun Al–15% Mn.

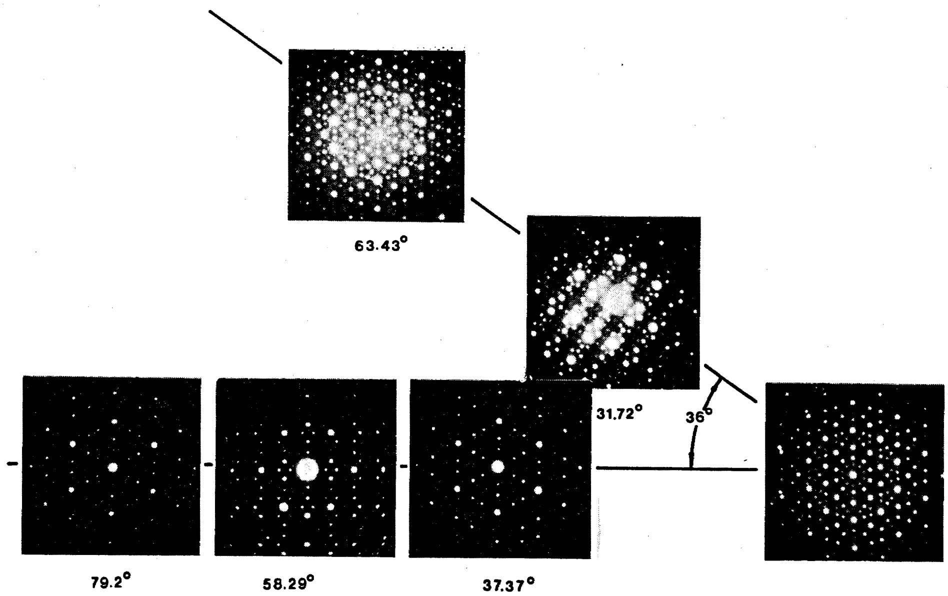

FIGURE 2. Other symmetries from sample in figure 1.

1. Theoretical work already in progress on non-crystallographic symmetries has been stimulated and papers on so-called quasicrystallinity are pouring forth from the physics and mathematics communities.

2. Experimental work has uncovered many more systems exhibiting icosahedral symmetry, one exhibiting a tenfold rotational axis and one exhibiting a stable icosahedral phase (Al–Cu–Li) in contrast to all other examples, which appear to be metastable.

3. Combinations of theory and experiment have led to a method for analysing the diffraction patterns to obtain structural information and these structural determinations are now beginning to appear in print.

4. Theoretical understanding of these structures appears likely to lead to a more tractable

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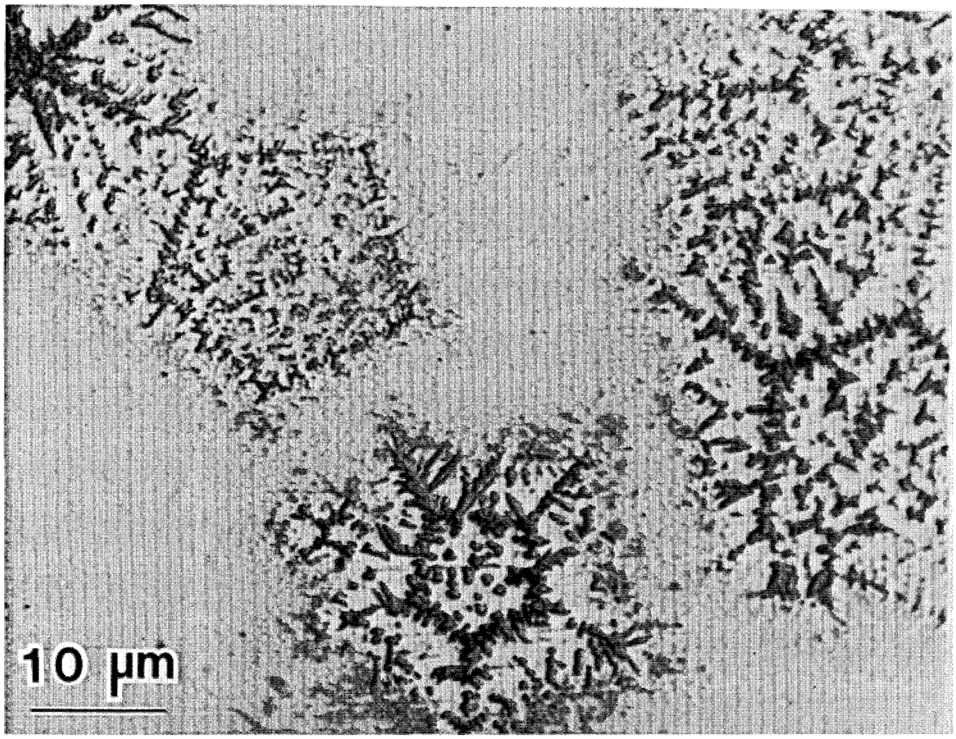

FIGURE 4. The fivefold axis of the point group in an Al matrix.

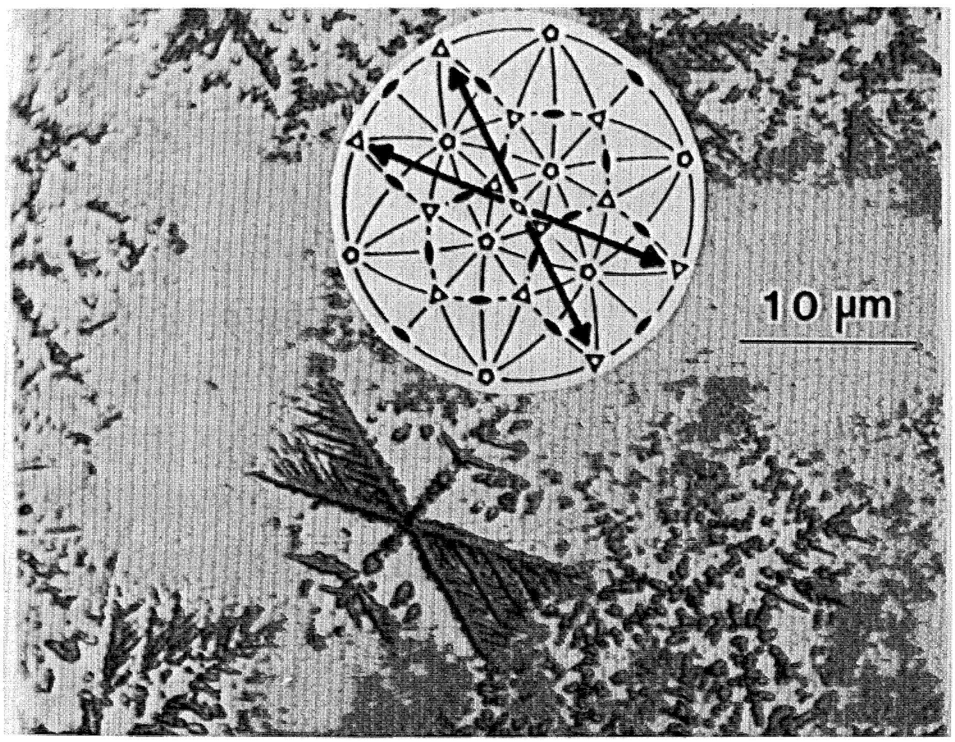

FIGURE 5. The two fold axis of the point group in an Al matrix.

(*Facing p.* 440)

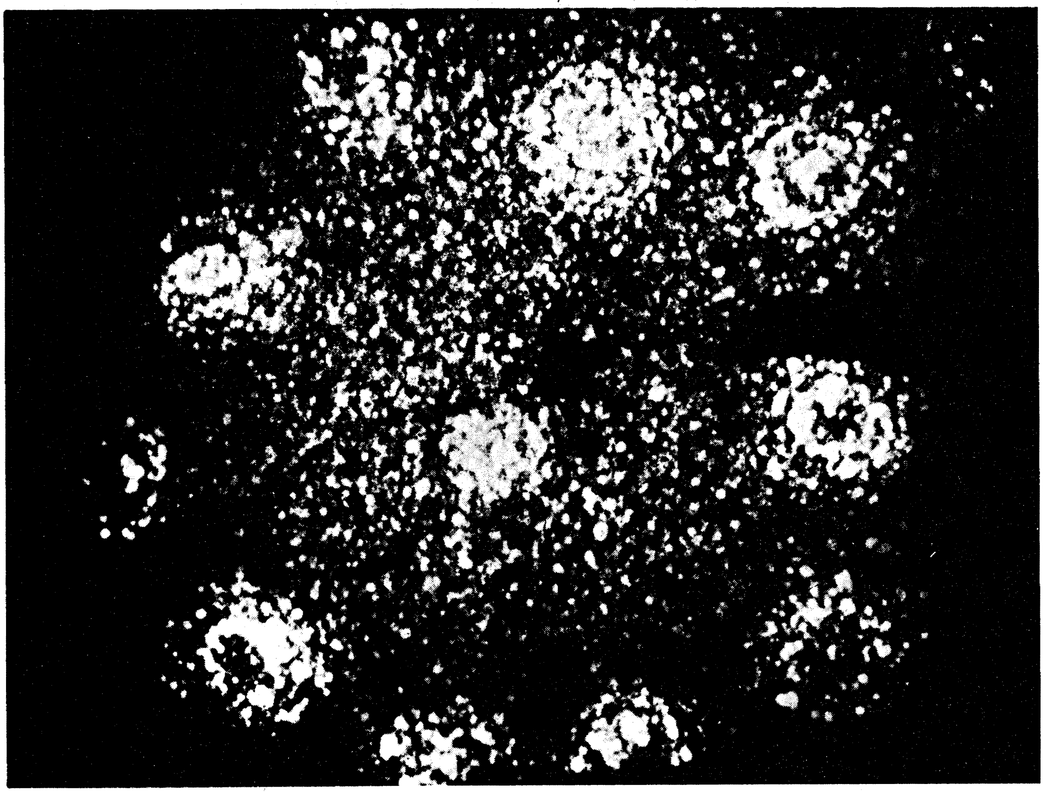

FIGURE 3. Direct-space image showing the five axes.

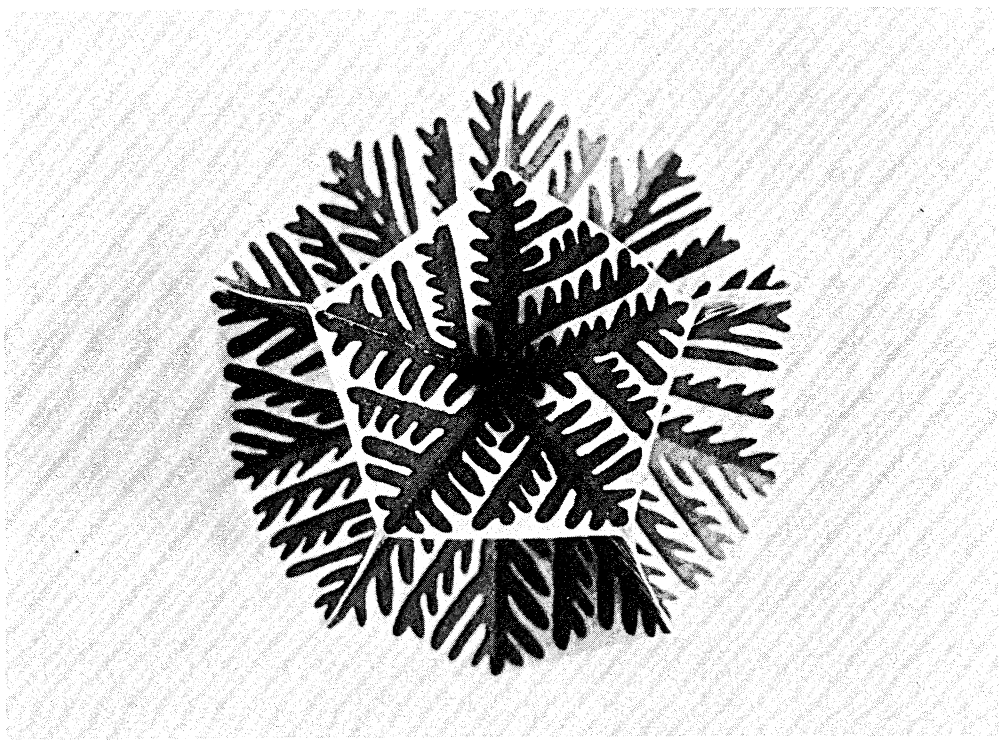

FIGURE 6. A three-dimensional model of the dendritic structure.

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way to handle the many examples of modulated long-period structures that occur in many minerals and alloys.

5. New evidence suggests that grain boundaries in some aluminium alloys may be decorated with icosahedral material: thus a very important practical impact of this scientifically exciting subject may have already been found. We expect that many other examples of practical importance will follow as the subject receives further investigation.

Reference

Shechtman, D., Blech, I., Gratias, D. & Cahn, J. W. 1984 *Phys. Rev. Lett.* **53**, 1951.

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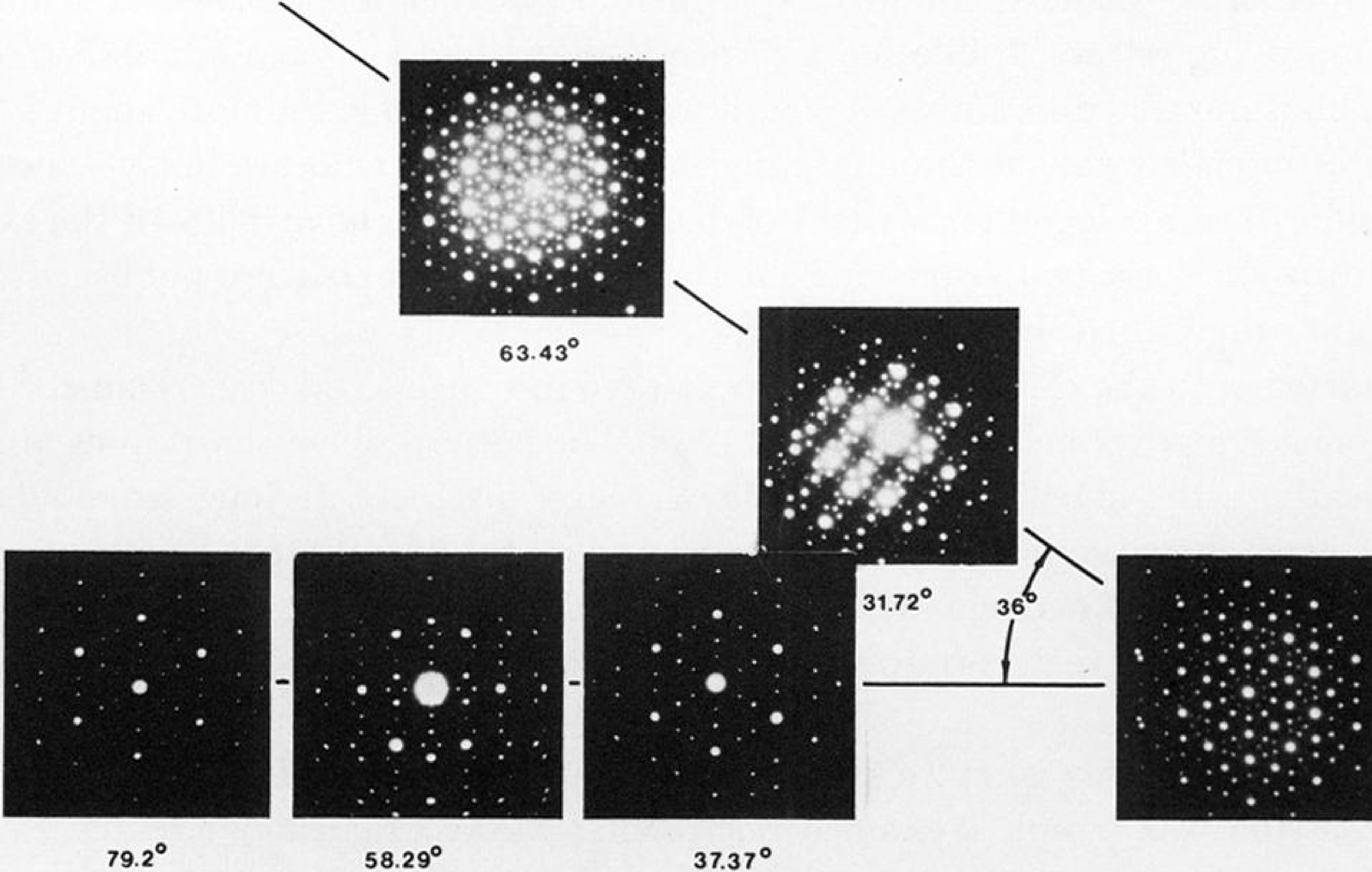

FIGURE 2. Other symmetries from sample in figure 1.

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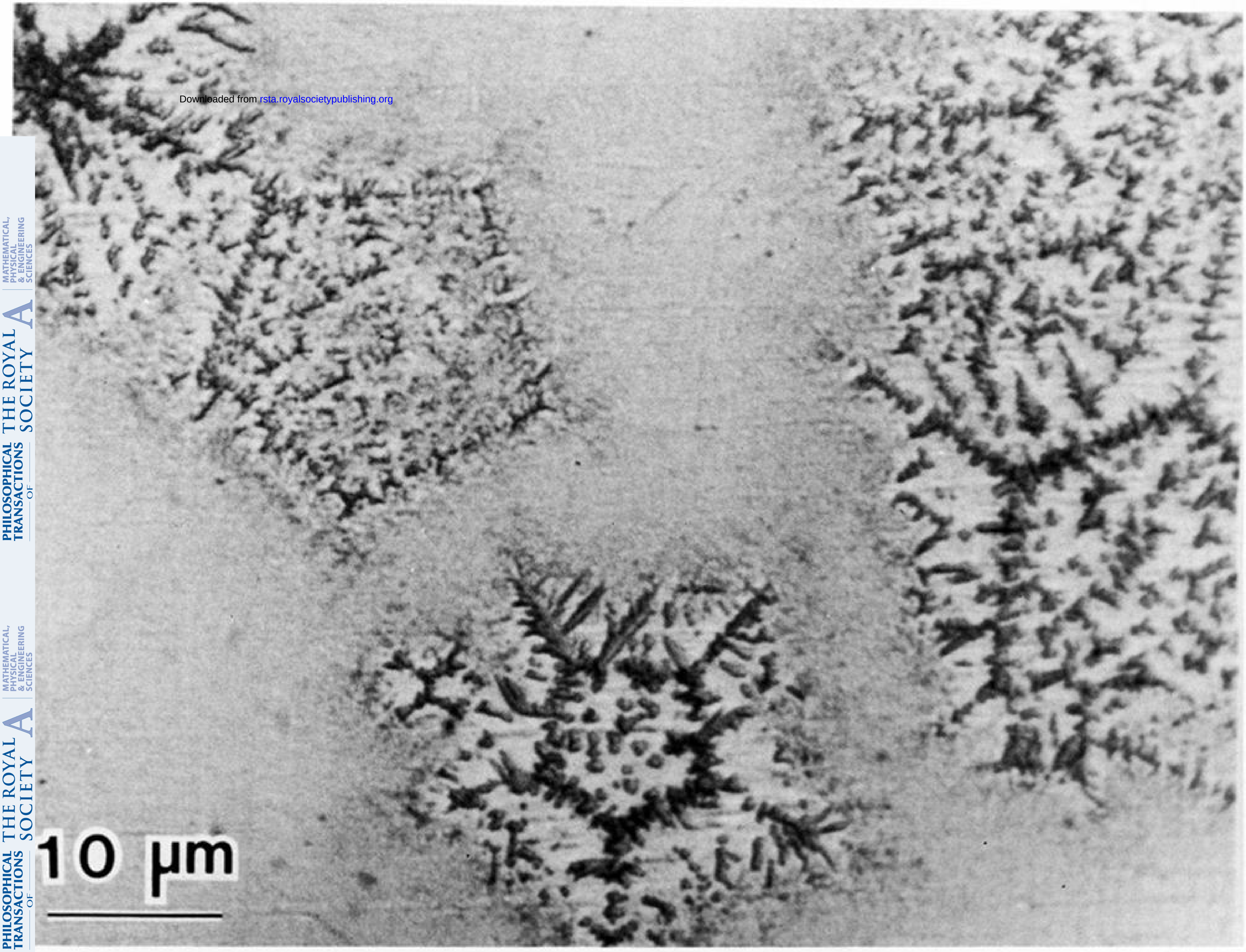

FIGURE 4. The fivefold axis of the point group in an Al matrix.

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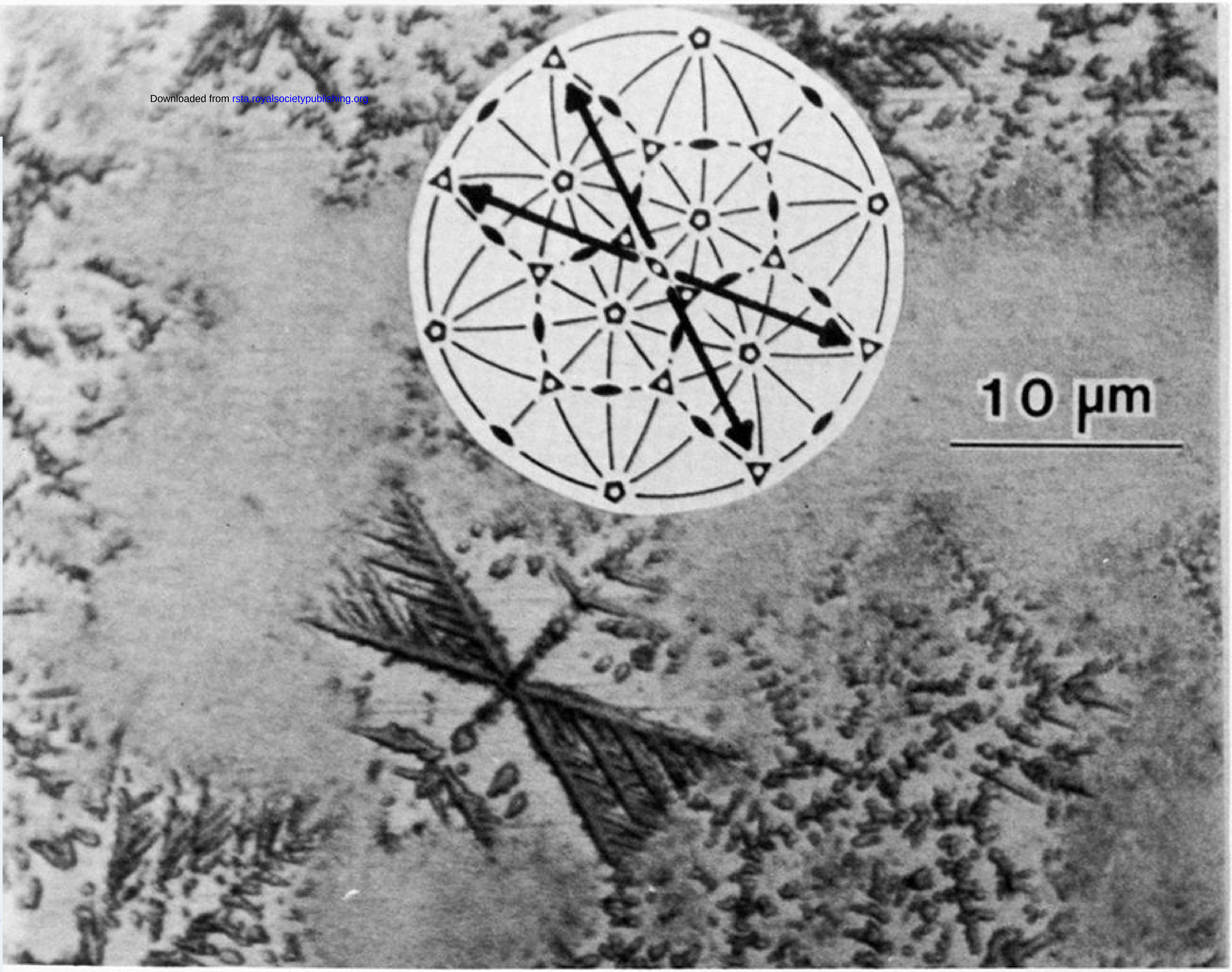

FIGURE 5. The two fold axis of the point group in an Al matrix.

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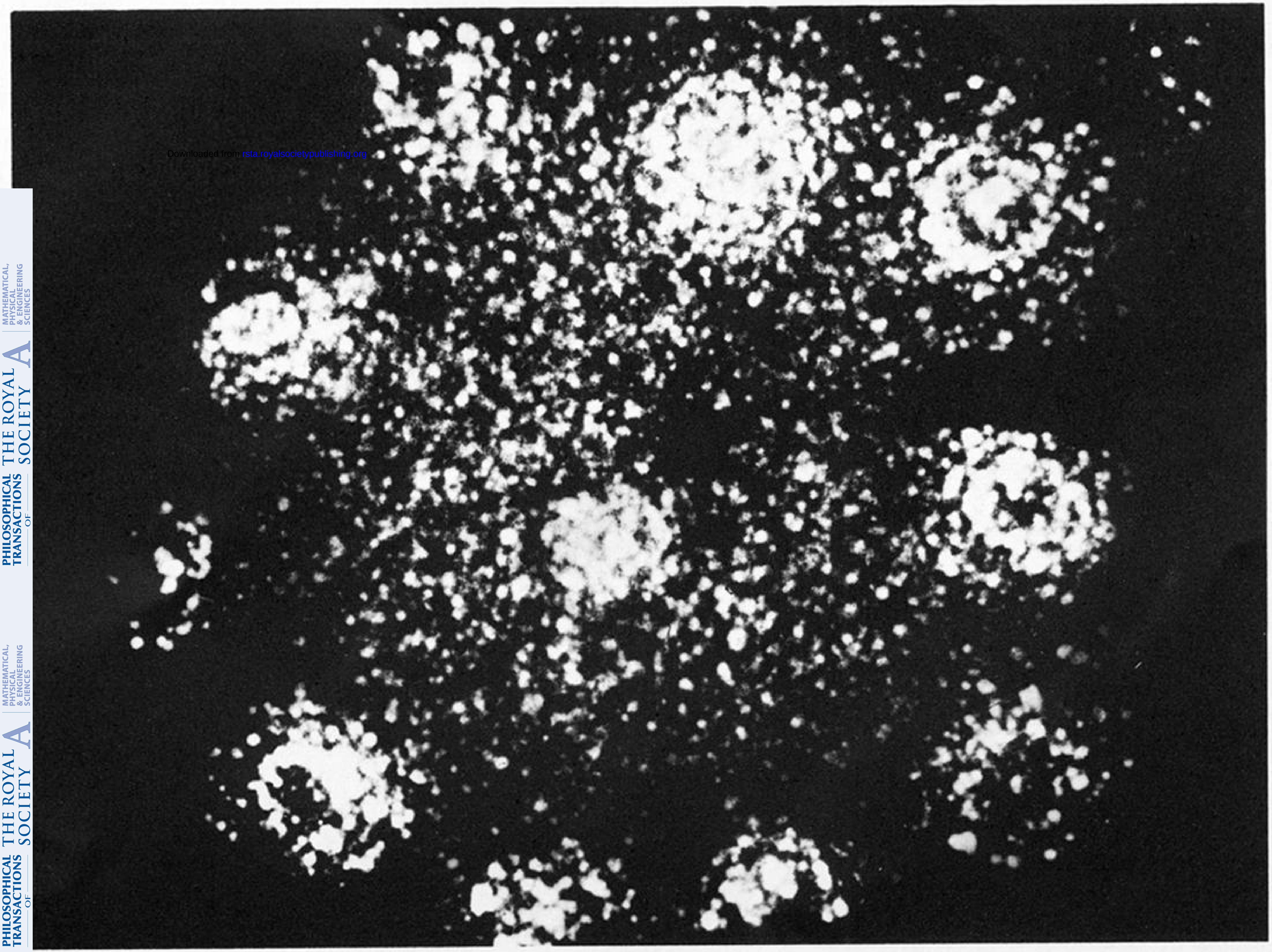

FIGURE 3. Direct-space image showing the five axes.

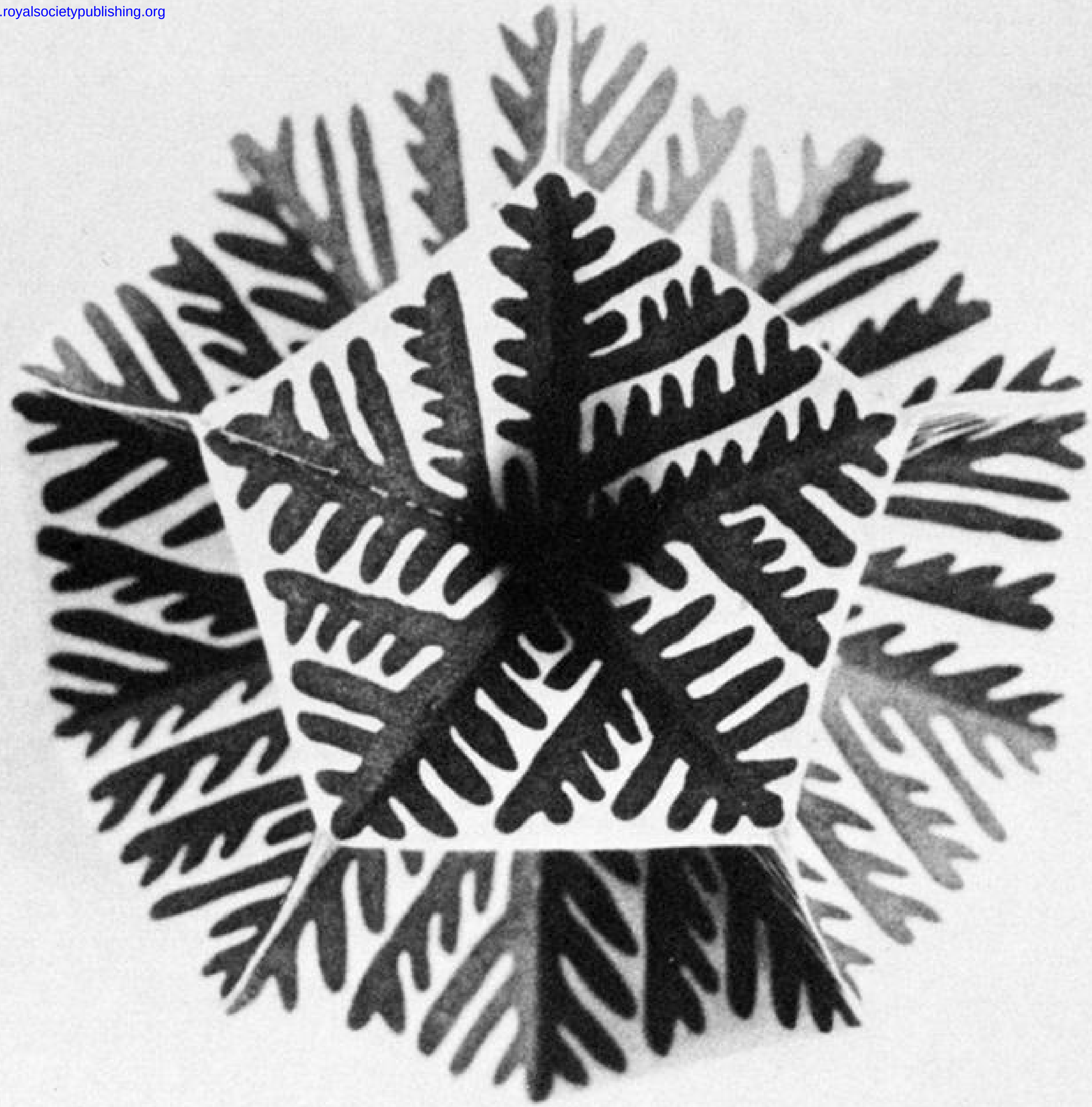

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FIGURE 6. A three-dimensional model of the dendritic structure.