

money, found in Scandinavia, from Tibet and Siam.

I would add here that some historians have made too much of Viking raids; overlooking the fact that piracy implies plunder, and plunder implies trade. It is fairly clear that many raids during the eighth century were in fact persistent struggles to secure control of the still highly lucrative Frisian trade and trading stations.

(3) Alcuin spent fifteen years in Aachen, at the home of Charlemagne, whose not unfavourable attitude towards the eastern Arabs is shown by his correspondence and diplomatic exchanges with Haroun-al-Raschid. Aachen was within fairly easy reach of Frisia (much the same territory as modern Holland, where Arabic coins have been found).

(4) In Alcuin's time scholars were more closely associated with commercial activities than might be supposed. The great monasteries of the eighth and ninth centuries were among the largest traders of the time in certain lines. Those which were situated on or near the north European rivers often owned fleets of barges, ships for coasting voyages, and permanent depots for their traffic. They also sent agents to distant cities to buy and sell on their behalf. Arabic coins must not infrequently have passed through the hands of some of these officials; and as there is evidence that at least a few Arab traders travelled from the East far into northern latitudes, it is not inconceivable that they sometimes (however rarely) made actual contact with monastic agents in the West.

My purpose here, however, is not to enter the region of hypothesis, but to indicate a possible field for research which has not yet been adequately explored.

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Orientation of Oxide Films on Metals

It was suggested by Tammann¹ in 1922 that the different rates of oxidation exhibited by iron crystals of different orientations can best be explained by a fixed orientation relationship between the lattice of the iron crystal and the lattice of the oxide film. During the succeeding years, fixed orientation relationships have been demonstrated for reaction products of many kinds, such as recrystallisation structures, products of transformation in the solid state, Widmanstätten figures and others; in view of the general occurrence of such orientation relationships, it now seems more than likely that oxide (and other) reaction films grown on metal crystals will upon analysis also be found to exhibit fixed orientation relationships. Indeed the results of Finch and Quarrell², published during the course of our work, seem to prove that films of zinc oxide on zinc, and magnesium oxide on magnesium possess such a relationship, though the analysis does not seem to be complete. We have been successful in demonstrating a fixed orientation relationship for wüstite ("FeO") films grown on iron, and for cuprous oxide films grown on copper.

Wüstite, "FeO", was grown on single crystals of hydrogen-purified, remelted electrolytic iron, by heating at 700° C. in a mixture of hydrogen and water vapour of appropriate composition. Several samples, cooled at a rate which prevented sensible decomposition of the phase, showed, upon X-ray analysis of orientation, the existence of a simple orientation

relationship between the oxide film and the base metal. This orientation relationship is as follows: the cube or (100) plane in "FeO" lies parallel to the cube or (100) plane in the iron; the [110] direction in the (100) plane of "FeO" lies parallel to the [100] direction in the (100) plane of Fe. That is, the cube planes are parallel, but the cube axes in these planes form an angle of 45°. "FeO" has a sodium chloride type of structure with the iron atoms forming a face-centred cubic lattice, the side of which is 4.29 Å. The iron atoms on any cube face form small squares (defined by [110] directions), the side of which is 2.99 Å. Iron is body-centred cubic, with the side of the cell 2.86 Å. The atoms on the cube faces of the two phases, in conjunction in the manner stated, are thus nearly in coincidence. It follows that three orientations of "FeO" can form on each iron crystal, one on each cube face; these are distinct orientations, for the three "FeO" lattices on inspection will be seen not to be continuous. This orientation relationship suggests that the formation of "FeO" from iron consists in the expansion of the body-centred cubic cell of α -iron to form a body-centred tetragonal cell of axial ratio 1.414, which is identical with the face-centred cubic cell of the iron atoms in "FeO". The oxygen atoms in solid solution in α -iron are probably interstitial; they may also be so considered in "FeO".

In another experiment, cuprous oxide was grown on a single crystal of copper by oxidation in air. This film is almost entirely cuprous oxide, for only an extremely thin film of cupric oxide is formed. Simultaneous determinations of the orientation of the underlying copper crystal and the cuprous oxide film showed that the cube axes in both crystals lay accurately parallel. The copper atoms in cuprous oxide form a face-centred cubic lattice, and the oxygen atoms form an interpenetrating body-centred cubic lattice; the side of the unit face-centred cubic lattice of copper atoms in cuprous oxide is 4.26 Å., whereas that in pure copper is 3.61 Å. In this case, therefore, the oxide film is formed merely by an expansion of the copper lattice without change in orientation. Thus only one orientation of cuprous oxide will form on a single crystal of copper. The orientation relationship described is the more nearly perfect the thinner the film; as the film becomes thicker the perfection in orientation is progressively lost, owing largely, no doubt, to distortion effects coming from the large difference in volume. At a thickness of 0.002 in., little evidence of preferred orientation remains. Even in the thinnest films there is evidence of lattice distortion, coming probably from the necessity for adaptation in lattice dimensions at the interface, similar to that found by Finch and Quarrell for metallic films deposited on platinum.

How useful these orientation relationships might be in explaining the differences in rates of oxidation on different crystal faces is at the moment quite uncertain. Work now current in our laboratory may, however, lead to definite issue on this point.

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¹ *Stahl und Eisen*, 42, 617; 1922.

² *NATURE*, 131, 842, June 10, 1933. *Proc. Roy. Soc., A*, 141, 398; 1933.