are identical with the paraboloids produced on glass.

When copper containing grains of oxide is polished, it often happens that these grains become detached, and produce disconnected lines on the surface with the same character as those above described. This is one important difficulty in polishing copper.

The scratch, whether continuous or intermittent, produces a removal of amorphous material. In fig. 66 (125 diams.) a scratch made by a diamond on the face *p* of an iron crystal and partially erased by a subsequent polishing, has given a distinct curve to some Neumann lines, previously rectilinear. This curve seems to have involved something in the nature of a dislocation of the crystalline network, and appears difficult to explain by a process of purely crystallographic deformation.

Fig. 65.—File or emery paper scratches on a 9 per cent. Tin-bronze, imperfectly polished and etched. ×125.

We now pass to crystalline deformation.

Simple cleavages, like those of calcite, are hardly compatible with plasticity. There exists, however, a curious exception—that of iron,—which we have studied in detail with the help of Frémont, and recorded the *Revue de Metallurgie.*

Metallurgy.—The scratch may cause networks, for example, in zinc (fig. 67, 125 diams.). Two scratches in different directions have been made on the polished surface, produced by pouring the liquid metal upon glass. Upon each streak there are formed striæ, of which the points are turned in the opposite direction to the force applied, just as in glass. However, it is no longer here a question of "common" deformations. The lines, properly illuminated by oblique light, are shown to be formed by the intersections of two planes; their direction, constant on any one grain, changes on passing to the next grain, and varies also with the direction of the scratch. This is evidently a case of crystalline deformation, and especially of twinning, as shown by their outlines. These deformations, however, replace as nearly as possible the

Fig. 66.—Diamond scratch on Iron Crystallite, partly obliterated by subsequent polishing. ×125.

"common" deformations. The same photograph also shows slight curves of "common" origin, analogous to those of fig. 64.

Slip-bands are also very frequent. Fig. 68 (350 diams.) is an example of one in cast copper, and fig. 69 (250 diams.) another example in forged nickel. The network, which is here quite easily recognisable, existed previously. On lead (fig. 70, 150 diams.) the scratch, made on a thin plate, shows, besides slip-bands, large curved folds, recalling those of rubber (fig. 59).

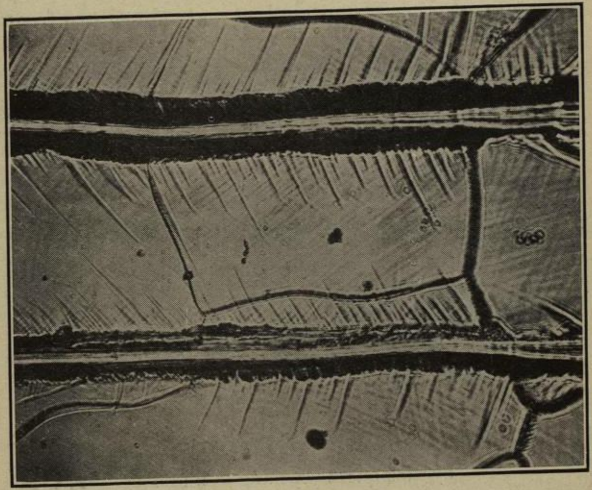

Fig. 67.—Two scratches made (in opposite directions) on Zinc, polished by casting upon a glass surface. × 125.

We have said that the scratch appears to be able to effect some modification of the crystalline network. Fig. 71 (100 diams.) shows, after partial repolishing, the bottom of a scratch on the face of an iron crystal: the scratch is parallel to one side of the square, and the corrosion figures have been brought out by etching for two minutes with a 12 per cent. solution of double chloride of copper and ammonium. These corrosion figures on the scratch are distinctly different from the adjoining square figures, and recall the channels in gelatine.

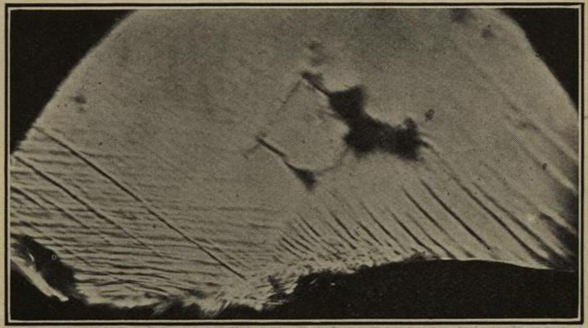

Fig. 68.—Slip-bands in cast Copper. × 350.

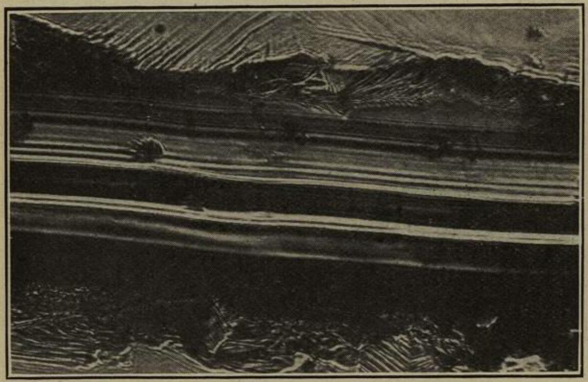

Fig. 69.—Slip-bands in forged Nickel. × 250.

Fig. 72 (125 diams.) gives similar results. It shows the bottom of a deep furrow, which has been left by imperfect polishing. This scratch traverses a grain of iron of unknown orientation, possibly the twin laminæ of a crystal cut along the face *p*.

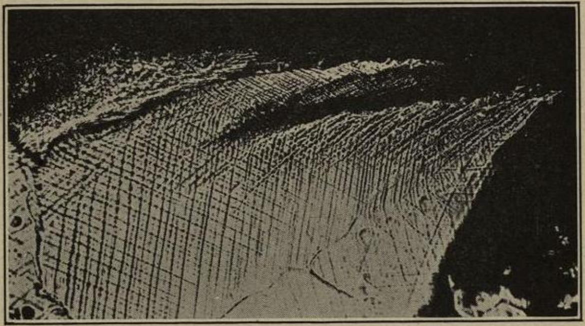

Fig. 70.—Slip-bands in Lead. × 150.

Fig. 71.—Bottom of scratch in an Iron Crystallite. × 1200.

Etching was effected with a 5 per cent. solution of picric acid in alcohol. The twin grain is recognised by its much lower degree of polish. The curious fact is that the bottom of the scratch presents, almost on this grain, the aspect of a face *p*, and on the face *p* the appearance of another face differing from *p*.

Again, in a bronze containing 9 per cent. tin, etched with an acetone solution of picric acid and quinone[1]—a solution which colours the grains light yellow to dark brown, according to their crystalline orientation—the faint scratch left as the result of incomplete polishing differs in colour in different grains. At the same time this trace is covered with striæ such as are found in zinc, but which are here revealed by etching (fig. 73, 800 diams.), and are very probably slip-bands.

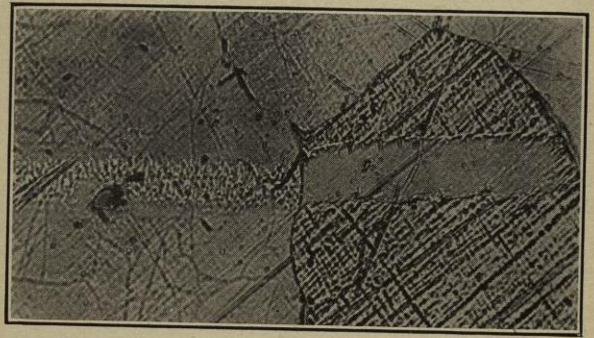

Fig. 72.—Scratch traversing twin crystals in imperfectly polished Iron. × 125.

Phenomena of this kind in transparent bodies can be studied better under polarised light. A plate of gypsum, thin enough to give chromatic polarisation, exhibits the trace of a scratching point by a coloration differing from the general colour. We have seen,

---

[1] A solution which has already been used is better than a fresh solution.

for example, such traces as mauve on a blue field, red on a green field, or inversely.

In conclusion, we see that rubbing down leaves behind it not only a surface still marked by visible striæ, but beneath this surface a layer of a certain thickness where the material is hardened, that is to say, modified by "common," "crystalline," or "mixed" deformations. This layer, which we propose to call the dermis, cannot be ignored, since the finest emery paper produces it. Its thickness is, however, proportional to the size of the emery particles. The part played by successively fine emery papers is to substitute, for these relatively deep scratches, smaller and smaller scratches, and to reduce the dermis to a minimum corresponding with the finest emery paper used.

Fig. 73.—Scratch in 9 per cent. Tin-bronze, subsequently etched and showing slip-bands. × 800.

FINISHING.

The object of finishing is to render the polish mirror-like. It is carried out by rubbing with an impalpable powder, either dry or moist, held by some convenient medium upon a disc more or less rapidly revolved. There are many different kinds of powder, rouge, tripoli, carbonate of lime, etc. In metallurgical laboratories, however, alumina and chromium oxide, levigated by the Schlœsing method according to the directions of Le Chatelier, tend to become almost exclusively used. The general practice is to spread them on cloth carefully freed from grease and moistened to the required consistency by a jet of water from a vaporiser. By these means there can be obtained upon metals which are not too soft a perfect mirror-like polish. If the attempt is made to explain this result, the first notion which presents itself to the mind is that finishing is simply the continuation of the primary polishing, and only differs from it by the tenuity and mobility of the powders used after the emery. There would be substituted for the visible streaks invisible streaks, and the dermis produced by fine emery would be removed without being replaced by a thinner skin. This view probably contains a portion of the truth, but it may be doubted whether it is sufficient and complete. The perfection of the polishing is, as a matter of fact, apparent only. The dermis is masked, but it persists and can be rendered evident by the chemical and mechanical methods of developing it:—

1. **Chemical Developers.** — When a polished metallic surface is etched by a given reagent, it is seldom that, for at least a certain period (if the attack be neither too slight nor too intense), one cannot observe traces of scratches which were previously more or less invisible.

Fig. 72, of which mention has already been made, shows, after etching, an appearance of coarse polishing, whereas before this operation it had a fairly well polished surface.

The bright surface of a bronze (9 per cent. tin), heat tinted, is, after polishing, much less perfect than before the heating, for oxidation reveals, by colorations varying from that of the mass, polishing scratches more or less hidden before.

Beilby describes a particularly well-defined example. When the face of a recent cleavage facet of calcite is etched for ten or fifteen seconds with very dilute hydrochloric acid (0·2 per cent. HCl), the etched surface, although somewhat waved and irregular, does not show any structure. If, however, before etching, the finger, covered with soft leather, be drawn across the cleavage surface, the acid rapidly reveals hidden streaks, made by the leather, although these streaks were completely invisible before the action of the acid had taken place.

2. **Mechanical Developers.**—Beck Guerhard has shown that Luders lines, obtained, for example, by punch-marking a steel plate and then removing the impression by subsequent polishing, reappear when the plate is subjected to another form of deformation. Frémont has brought this experiment out in a very striking manner. He cold-stamped a bar of steel with letters, effaced the marks with a file, and repolished the surface until no impression could be detected. Under slight compression the letters again became easily legible. This is, of course, a macroscopic test. The microscopic phenomena are similar.

Fig. 74 shows, under a magnification of 400 diameters, a face of an iron crystal in which the latent streaks in the dermis had been made by a diamond scratch. Another face of the same crystal (fig. 75, 250 diams.), has undergone deformation by the pressure of a knife blade on the adjacent face parallel to the sides of the section: the latent streaks again reappear; these, however, must not be confounded with the more distinct parallel striations caused by the deformation itself. The latter are the foldings *in situ* of the Luders lines. The chemical etching

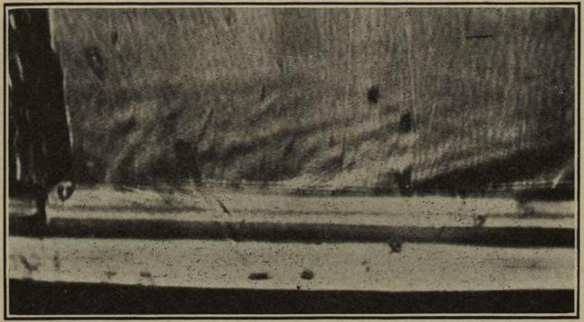

Fig. 74.—Latent scratches in the dermis revealed by a diamond scratch. × 400.

Fig. 75.—Deformation due to pressure of knife edge in Iron Crystallite shown in fig. 74. × 250.

effaces them instead of accentuating them, as it does the latent streaks.

Fig. 76 (1000 diams.) shows a dead soft steel which had been polished on a new dry cloth. Certain grains are well polished; others are more scratched than they would have been by rough polishing. The dermis has been laid bare. It is a question whether the dermis on the well-polished grain has been removed or left intact: both alternatives are possible. Whichever it may be, the difference in the appearance of the grains depends upon the respective crystalline orientation. The thickness of the dermis is a function of this orientation: on partially repolishing a scratch made upon a face of a crystal of iron cut from a twin crystal, and etching with picric acid, it will be seen that the effect of the scratch is more pronounced on all the different faces. It takes longer, also, to polish these faces, a result which agrees with the theory of Bravais and Mallard,

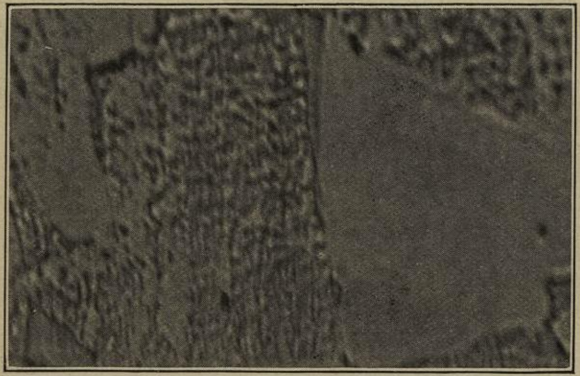

Fig. 76.—Dead soft steel polished on a dry cloth, revealing the dermis. × 1000.

which assumes, in the cleavages, planes of maximum reticulated density. It is shown, therefore, that polishing does not, ordinarily, remove the dermis, and, on the other hand, that the dermis does not appear upon a properly finished surface. We have thus a suggestion of a superficial layer differing from the dermis itself.

The existence of such a layer is quite feasible. In the first place, the skin of a solid, by the very fact of its position, differs for some millionths of a millimetre in thickness from the subjacent materials, and it has been said that certain metals give off vapour *in vacuo* at temperatures much below their melting-point. Even if this superficial layer did not naturally possess distinctive properties, it certainly acquires them through the action of polishing. The first effect of etching a polished section is to reveal a granular structure, which Beilby denominates "spicular," which neither resembles the structure of the dermis nor the actual structure of the body under examination This pellicle we may call the "epidermis." Beilby states, as the result of observations, several of which have received independent confirmation by the authors' own experiments, that the superficial molecules become mobile under the influence of friction, form waves on the surface, and then constitute a thin viscous layer—analogous to liquids,—and, like them, regulated by the laws of surface tension. These little waves find their level, as do those made by the hairs of a brush upon a freshly painted surface, and when the friction ceases they constitute an amorphous epidermis or "spicules" (flattened granules), the thicknesses of which are of molecular dimensions resulting from the tearing of the pellicles.

It seems probable (1) that two solids, of which at least one is polished, tend, when pressed together, to adhere to one another by their superficial layers, that is to say, to penetrate each other; (2) that, on rubbing together two polished bodies, the more or less adherent superficial layers tend to separate.

The first proposition is supported by the well-known experiment of Spring upon the caking of powders and other bodies by compression. In regard to the same class of facts, we are indebted to Margot for a very original research upon the adhesion of aluminium, magnesium, and other solids, or liquids, to glass, quartz, and other minerals. One of these experiments, that of pouring zinc on glass, we have in particular confirmed. The separation of the metal leaves either a continuous or discontinuous pellicle on the glass. The continuous pellicles, slightly etched by hydrochloric acid, show a cellular structure. The discontinuous pellicles consist of circular particles arranged in lines (fig. 77, 50 diams., illuminated by transmitted light): if this be etched by hydrofluoric acid, the glass loses its polish at points under each zinc blotch, although the etching is homogeneous where the zinc had not adhered. This phenomenon seems very difficult to explain. Margot discusses different hypotheses, particularly that of the intervention of metallic oxides, which might act as a vehicle, but could come to no definite conclusion. Here we are in an unexplored region, where chemistry, physics, and mechanics intermingle and become incorporated just like the aluminium, zinc, etc., and the glass.

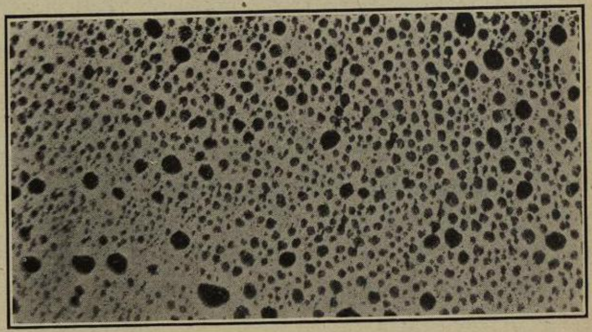

Fig .77.—Zinc cast on glass and etched by hydrochloric acid, showing the cellular structure. × 50.

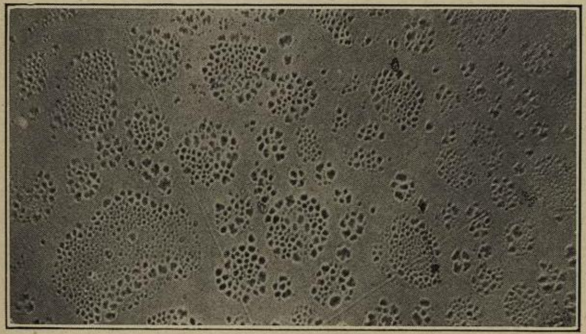

Fig. 78.—Same as fig. 77, line etched by hydrofluoric acid. × 150.

The removal of material, by friction, during the finishing stage, from the softly rounded outlines of scratches, results, according to Beilby, in the spreading of the epidermis into the little cavities, even in comparatively fragile metals such as antimony. We have obtained, in the same way, results of another kind. If the end of a wooden ruler be caused to slide over a glass plate dusted with electrolytic iron in powder, and sufficient force be applied, particles of iron become incrusted in the glass in lines of fracture, which revealed themselves as arcs of circles regularly spaced, with their concave sides opposite to the direction of movement. This is exactly what happens when glass is scratched by a body of equal or greater hardness. One might say that electrolytic iron, the mineralogical hardness of which has given rise to some discussion, comes under this head. Identical results, however, have been obtained

Fig. 79.—Electrolytic Iron polished by friction. × 200.

on substituting for iron a surface of polished copper, the only known impurity of which consisted of slight proportions of oxides (the hardness of the oxide is itself much lower than that of glass). Figs. 79 and 80 illustrate these experiments. Fig. 79 (200 diams.) represents the case of electrolytic iron, and fig. 80 (75 diams.) that of copper. The intermittent fracture of the glass in a series of rounded scratches, which, in the preliminary polishing, are the result of planing action, depends in this case upon the incrustation and the piling-up of the epidermis. The results are practically the same in both cases.

The causes are decidedly different, although it may be perhaps difficult to establish between them a definite line of demarcation.

Taking into account these considerations and the foregoing facts, the finishing of the polishing may be explained in the following manner:—

The bodies to be polished and the damp, aluminous cloth must be considered as two bodies, A and B whose epiderma penetrate each other under pressure,

Fig. 80.—Copper polished by friction. × 75.

and mutually remove one another when subjected to rapid movement. If A and B were the same, the surface of A would be incrusted with B and that of B with A, until equilibrium were established. If, however, the penetration of B into A is less easy than that of A into B (which may be effected by making the movement of B more extended in area), B would be able continuously to remove molecules of A which will have penetrated it without its own molecules having time to penetrate the surface of A. It may be said that the body A, which maintains its individuality intact, is the polished body, while B, which takes up A, is the polishing body. If, however, this be true, it should be possible to transpose the order, and one may often succeed in doing so, sometimes involuntarily, by modifying one of the factors, pressure, speed, or moisture, with a given powder and metal.

When the final polishing of iron with alumina is effected, it is sufficient for moisture to be lacking to make the alumina adhere to the metal in smears which are difficult to remove (fig. 81, 250 diams.). The iron has polished the damp, alumina-covered cloth. In this case, however, the layer of alumina is neither very adhesive, nor is the penetration deep. All that is necessary to remove the difficulty is to sprinkle a little water on the polisher and to continue polishing.

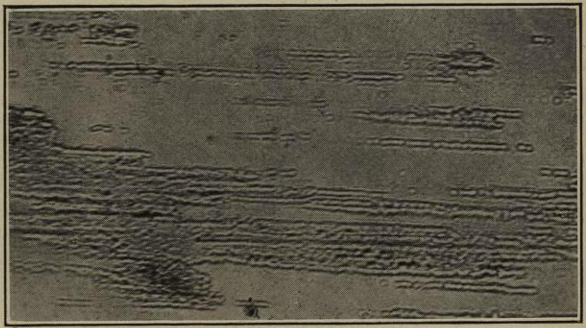

Fig. 81.—Streaks of iron left on alumina polishing cloth. × 250.

It is not the same with rouge. When we used this material before the introduction of alumina by Le Chatelier, we noticed that, with sufficient pressure, the metallic surface, when the plate was allowed to become too dry, presented to the naked eye an opalescent appearance in vertical light, and under oblique light, thin surface colours. At the same time the surface illuminated by a Nachet prism became somewhat dull under the microscope. The iron was deeply and evenly incrusted. Alumina behaves with red copper almost as rouge does with iron. Oxide of chromium prepared by the calcination of ammonium bichromate, and levigated according to Le Chatelier's receipt, incrusts copper still more easily, and can only be employed when very wet.

Incrustation depends upon the rapidity of rotation of the disc. This is an interesting subject for investigation, which would have been made but for the fact that the speed of the apparatus we employed was incapable of being greatly varied.

Nachet has described to us the trouble caused at times by the incrustation of glass by rouge. Up to the present time the incrustation of the bodies to be polished by the polishing agents has appeared to be accidental, and owing either to mistakes or to technical negligence. As, however, often happens, this accident may be utilised and made to furnish a method of investigation.

In an alloy exhibiting several phases, as, for example, steel, the carbide known as cementite can be polished whilst the iron itself—the ferrite—is incrusted with dry rouge. Arnold has employed this method to resolve pearlite, a mixture of ferrite and cementite in laminæ; and Frewen Jenkin sent one of the authors several years ago some beautiful photographs of discs prepared in that way. Fig. 82 represents a cemented steel, rubbed by hand on dry "sulphate" rouge sprinkled on filter paper. The large bright spaces are independent cementite, which begins