DIE MIKROSKOPISCHE

UNTERSUCHUNG DES PAPIERS

MIT BESONDERER BERÜCKSICHTIGUNG

DER

ÄLTESTEN ORIENTALISCHEN UND EUROPÄISCHEN PAPIERE

VON

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MIT 15 HOLZSCHNITTEN UND 1 LICHTDRUCK

WIEN

VERLAG DER KAISERL. KÖNIGL. HOF- UND STAATSDRUCKEREI

1887

THE MICROSCOPIC

EXAMINATION OF PAPER

WITH SPECIAL CONSIDERATION

OF THE

OLDEST ORIENTAL AND EUROPEAN PAPERS

BY

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With 15 woodcuts and 1 phototype

VIENNA
Published by the Imperial-Royal Court and State Printing Office
1887

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INTRODUCTION

The rich collection of documents from el-Faiyum (aka Faijûm), which is gathered in the Austrian Museum in Vienna in the collection "Papyrus Archduke Rainer," is known to contain four main kinds of writing materials:

1. animal skins, including leather;
2. parchments;
3. papyrus; and finally
4. papers.

Only the last-named writing materials form the subject of the investigations communicated in the following pages. These are papers in the modern sense[1] products that technology would more precisely describe as "felted" or "mould-made" papers.

The Faiyum papers[2] represent an extremely important body of material for investigation, perhaps the most important that has so far been available for resolving questions concerning the history of paper. These papers are the oldest that have yet been made accessible to exact scientific examination. According to reliable datings established by Professor Karabacek, they go back to the ninth century, and in individual cases probably even to the eighth century of our era.

The written characters on these papers are still well preserved; the cohesion of the fibers is generally very dense. Furthermore, a large portion of these papers is even now still in a condition suitable for writing. It could therefore be assumed from the outset, with some probability, that it would be possible to determine the fibers from which they were prepared, and to identify the substances with which they were written upon and with which they were sized.

[1]. A preliminary historical-antiquarian investigation of the Faiyum and Ushmunein papers, with reference to Arabic papermaking in general, has been undertaken by Professor Karabacek for publication in these Communications above, pp. 87–178.

[2]. Unless otherwise noted, the term "Faiyum papers" in what follows is to be understood as also including the Ushmunein papers.

It has in fact been possible, as I shall say here in advance, to solve the question of the fiber type, the sizing material, and the substance used for producing the written characters in a completely satisfactory manner.

As regards the fiber material first of all, the prevailing opinion would have led one to expect that it would prove to be cotton.

Even today the invention of rag paper is still almost universally placed in the fourteenth century, and papers of earlier date are declared to be cotton papers — that is, writing materials felted from unspun, raw cotton.

Contrary to all expectation, however, my microscopic investigations have furnished proof that not a single one of the Faiyum papers is a cotton paper, but that all of them were prepared from rags, chiefly linen rags.[1]

The art of making paper from rags is therefore much older than has previously been assumed. This discovery of mine also settles the question of the origin of this invention: the production of rag paper is neither an Italian nor a German invention, but an Oriental one.

This discovery prompted me to include in my investigations the question, much discussed in recent times, of whether there ever was such a thing as cotton paper at all. On the basis of very detailed investigations, I believe I may answer this question decisively in the negative.

By means of chemical tests, some of which were carried out with the aid of the microscope, I was able to show that the Arabs used starch paste for sizing their paper. In my view, this finding has an importance that should not be underestimated. First, it teaches that animal glue was not the oldest material by which "running" papers were made writable; rather, starch paste was. But from this fact it was also possible to demonstrate the connection between European papermaking and Arabic papermaking. I hope also to show that starch sizing, which is so easy to detect, may be used, with certain precautions, in determining the age of papers.

From these remarks alone it is already clear how the boundaries of my work expanded, and how, stimulated by observations made directly on the Faiyum papers, I turned to other material and thus gradually came into a position to provide a connected contribution to the history of paper, one in which several of the principal questions concerning the production of old papers find their answer.

[1] The first communication of this discovery was made in a lecture delivered by Professor Karabacek at the Austrian Museum on January 23, 1885. That lecture is printed in the Österreichische Monatsschrift für den Orient, 1885, p. 165 ff.

In the course of my investigations, results also arose quite naturally that go beyond the framework of a history of paper. I will briefly mention here some of the more interesting of these findings.

The starch used for sizing the Faiyum papers was often only half gelatinized. Part of the starch then remained almost entirely unchanged, by which the papers gained in quality in general, and especially in whiteness. To this circumstance we owe our knowledge of the kind of starch with which the Arabs sized their papers, and which they undoubtedly also used for many other purposes. As a rule, it was cereal starch — wheat, barley, or rye starch; oats and rice are completely excluded — and most probably wheat starch.

Since paste sizing could have been carried out either with starch — starch flour, amylum — or with the flour of the corresponding grain, as the latter is still occasionally used for that purpose,[1] it was natural to direct the microscopic examination toward deciding between these alternatives. This question could be resolved just as easily as securely. Since the presence of starch was already revealed by the iodine reaction, and since this constituent of flour shows less resistance to the action of water, air, etc., than most of the other constituents of flour, especially the cell walls, and since these latter were not to be found among the paper fibers, it follows that starch was used for sizing the paper, and not flour. Consequently, at the time when the Faiyum papers were produced, the manufacture of starch from flour must already have been practiced in Egypt, or in the Orient.

Some of the Faiyum papers are not sized with ordinary cereal starch — amylum from wheat, rye, or barley — but with another kind of starch, which, among all the kinds that must be considered according to our present knowledge of the cultivation of farinaceous plants in the Orient, agrees most closely with that of buckwheat. This observation suggests the conjecture that buckwheat, whose cultivation has previously not been traced farther back than the middle of the fifteenth century, may have been cultivated much earlier.

As already mentioned above, I have also extended my investigations to the ink with which the Faiyum papers were written. I was able to establish with certainty two kinds of ink: one whose principal constituent was iron tannate, and which therefore can hardly have been anything other than a gall-nut ink; and a second whose principal constituent proved to be fine carbon, probably prepared from soot or a similar material, and showing some resemblance to India ink.

More detailed studies of ancient spinning fibers directed my attention to mummy bandages, concerning which today hardly anyone doubts that they consist of linen fibers. Yet a critical examination of the available data shows that the result so far obtained is still not beyond objection. It has indeed been proved that this fabric cannot consist of cotton, but is composed of spun bast fibers; the strict proof of the linen nature of these fibers, however, has not yet been furnished. This is done in one of the following chapters, where several remarks will also be made on the material nature of papyrus.

[1] See Muspratt's Chemie. Encyklopädisches Handbuch der technischen Chemie, by Bruno Kerl and F. Stohmann, 3rd ed., vol. .

This introduction contains — in rough outline — what otherwise usually stands at the end of a treatise: the principal results of the investigation. I believed that I could not more effectively arouse the reader's interest in my detailed investigations, which by their nature are very dry, than by pointing out what the armed eye was able to read from the Faiyum papers.

The investigations needed to arrive at the results mentioned above, particularly those concerning the determination of the fiber material, also became much more extensive than one might suppose, and than I myself had initially intended. The existing methods of microscopic paper examination had to be tested anew for their reliability with regard to our extremely difficult object. This was necessary for two reasons: first, because paper of such great age does not offer nearly the same points of support for discovering the raw material from which it was produced as modern papers do — papers for which a literature extending into the smallest details acquaints us with all the relevant materials and all modes of preparation; and second, because the Faiyum papers are in such a strongly altered condition that papers in such a state had not previously been available for examination. It was therefore necessary to consider numerous conditions of paper fibers that had not previously been taken into account in such investigations.

The methods for determining the sizing material of papers have also received considerable advancement in this treatise.

The results of my work briefly stated in this introduction were first published in a preliminary notice, which was sent to press in June 1886 and appeared in the Communications from the Collection Papyrus Archduke Rainer.[1]

The part of the treatise concerning the Faiyum papers was for the most part completed in May 1886, as was the second chapter except for the expressly indicated additions. The procurement of the material for the final chapter, in which chiefly the question of the existence of the so-called cotton papers is decided, was the main reason for the delayed completion of the present treatise.

[1] Vienna, Imperial-Royal Court and State Printing Office, 1886, nos. 1 and 2, p. 45, under the title: "Microscopic Investigations of the Papers of el-Faiyum."

First Chapter

Historical Overview of Previous Research Relating to the Examination of Old Papers

The history of paper, especially with regard to the origin and development of European papermaking, has often been treated, and on several occasions in great detail. It would therefore be a very superfluous undertaking to set out this subject anew.

On the other hand, it seems to me plainly necessary in this treatise to examine the arguments on which opinions about the materials used for preparing old papers are based. By "old papers" I mean here the so-called cotton papers — chiefly those produced before the fourteenth century. For surely no one disputes that in the fourteenth century paper in Europe was produced from rags or scraps.[1]

In this treatise I shall show that irrefutable proofs for the views concerning the materials used in producing these old papers do not exist. I hope, however, to present sufficiently strong proof for the assertion that Arabic-European papermaking begins with rag paper, and that cotton paper never existed. These proofs are to be sought in the material examination of the paper, as was already recognized long ago; but they can be found only through the strict application of definite histological and partly chemical, including microchemical, methods of investigation. Many paper examinations, however, fell in a period when phyto-histological methods were still too little developed to permit a secure distinction between spinning fibers and paper fibers.

The beginnings of papermaking are, as is generally admitted, shrouded in deep obscurity.[2] But even the starting points of our European papermaking cannot be regarded as having been completely clarified.

It is commonly assumed, and by most parties regarded as proven, that the oldest felted papers were produced from raw cotton. The Arabs, at the time of the conquest of Samarkand in 704, are supposed to have learned the art of making paper from cotton; cotton paper is supposed to have been invented much earlier by the Chinese. According to the prevailing opinion, such cotton papers were brought to Europe very early and later were also produced there, until at the end of the thirteenth or the beginning of the fourteenth century they were replaced by "linen paper," that is, by felted papers produced from linen rags. The art of producing paper from rags is held to be a European invention, if we leave aside several hypotheses to be mentioned later.[3]

[1] See Wattenbach, Das Schriftwesen im Mittelalter, 2nd ed., Leipzig, 1875, especially p. 119.

[2] Compare Wattenbach, loc. cit., p. 114.

[3] See the articles by Keferstein and Fischer in Ersch and Gruber's Encyclopädie, section 3, part 11, p. 75 ff.

According to more recent historical research, the Arabs independently invented the method of preparing paper from cotton[1] and learned from the Chinese only the production of a finely fibrous mass suitable for papermaking and its formation into sheets — that is, in a certain sense, the principle of making felted papers. Since felted Chinese papers do not consist of cotton fibers, or hairs, but of bast cells from various plants,[2] this newer view also receives a certain factual basis.[3]

Farther below I shall discuss in detail the question of whether paper was ever made from raw cotton. Before doing so, however, I wish to correct an error that has not yet entirely disappeared. It has been said that before the use of cotton papers, the bast fibers of various tree species, chiefly on European soil, were used for making paper. According to an often-repeated statement by Petrus Venerabilis,[4] such a tree-bast paper — charta corticea — was still in use in France in the twelfth century.

According to several accounts, this tree-bast paper was supposedly a fibrous, sized mass, and therefore a kind of felted paper. In that case it would have to be regarded as a forerunner of our paper. But according to the statements of other authors, which have received more consideration, charta corticea was a writing material prepared after the model of papyrus, and therefore would be more comparable to papyrus than to our paper. Like true papyrus, prepared from the pith of the stem of Cyperus papyrus, tree-bast paper is said to have been composed of several crossed bast layers, united into dense, papyrus-like sheets by an adhesive substance and by mechanical working.

Only very few tree-bast-paper manuscripts currently still existing are cited,[5] among them one in the Imperial-Royal Court Library in Vienna, which, on the authority of Montfaucon,[6] Mabillon,[7] and Schwarz,[8] is regarded by several older authors as unquestionably genuine charta corticea.

[1] Karabacek, loc. cit., p. 165.

[2] In my book Technische Mikroskopie, Vienna, 1867, pp. 234–237, I give the results of my investigations of Chinese papers. These are partly pith papers and partly felted papers. In the latter I demonstrated the fibers of straw, especially rice straw, and of bamboo.

[3] It had already been doubted earlier whether the Arabs learned the production of cotton paper from the Chinese, for instance by Keferstein, who points out that the cotton paper of the Chinese is of Japanese origin and is not used for writing, but for wrapping and for making articles of clothing. Today, however, there can scarcely be any doubt that this is not cotton paper at all, but rather a paper that has been made on a large scale in Japan since ancient times from the bast fibers of the paper mulberry tree, Broussonetia papyrifera, and used for the most varied purposes.

[4] Compare Fischer, loc. cit., p. 84.

[5] Collected in Fischer, loc. cit., p. 84.

[6] Palaeogr., book I, ch. 2, p. 15.

[7] De re dipl., book I, ch. 8.

[8] De ornamentis librorum veterum, etc., dissertation IV, p. 112.

Since all statements concerning tree-bast paper are based on historical data and not on material examination, I subjected the object in question[1] to investigation. Court Councillor von Birk, Director of the Imperial-Royal Court Library, kindly allowed me to inspect this valuable manuscript, which consists of three fragments. Each of these fragments is composed of layers with parallel fibers, some of them pasted together obliquely. A careful examination with the aid of a magnifying glass showed that the fibers, or vascular bundles, run parallel and are separated from one another by broad parenchymatous tissue bands, so that the presence of a dicotyledonous bast — and only such a bast can be meant when "tree bast" is spoken of — is completely excluded. Only on a cursory view might one be tempted, from the oblique crossing of the fibers, to conclude that it was tree bast. But in some places one recognizes the perpendicular crossing of the fiber bundles, and this never occurs in dicotyledonous basts. Moreover, the crossing fibers lie at different levels, from which it already follows that this charta corticea is nothing other than papyrus.

Anyone who has once carefully looked at genuine papyrus will declare the fragments mentioned to be papyrus, and Court Councillor von Birk informs me that he has never taken this manuscript to be anything else. The matter was already so clear after examination with the magnifying glass that I did not think it necessary to seek further confirmation by microscopic examination. In the course of my investigations of the constituents of old papers I did not lose sight of the question of tree-bast paper, but I found no constituents of tree bark in either the Oriental or the European papers.

The statements about the existence, distribution, and properties of cotton papers sound very certain. Keferstein[2] believes that the following can be established securely from the sources. Cotton paper came from Asia to Europe in the ninth century. Until the eleventh century the Arabs supplied Europe exclusively with a paper made from raw cotton. In the eleventh century, the art of papermaking came through the Moors to Spain and spread from there through Italy to the rest of Europe. In the twelfth century this art underwent substantial improvements through the use of the wire mould in sheet formation. Throughout this period it is always raw cotton that is regarded as the sole raw material of papermaking, both in Arabia and in Europe.

Fischer expresses himself in a similar way. According to him, paper prepared from raw cotton remained in use until the middle of the fifteenth century, but was then completely displaced by paper prepared from linen rags. The invention of rag paper falls at the end of the thirteenth or the beginning of the fourteenth century. It remains undecided whether the invention of rag paper should be credited to the Germans or the Italians.

[1] Illustrated, described, and declared to be tree-bast paper, charta corticea, in Nessel, Catalogus Bibliothecae Caesareae, V, p. 105, from the year 1690.

[2] Loc. cit., p. 84 ff.

These assertions concerning the essential points are based on investigations carried out in the previous century by several scholars: Mabillon, Montfaucon, and chiefly Meerman. The results of their researches have remained valid down to our own time, as I shall have to explain more fully below.

The arguments used to support their statements were of two kinds: historical and material — that is, based on the properties of the paper substances. It will surely be admitted on all sides that the latter, the arguments derived from the nature of the paper, generally carry more weight than the former, provided only that the dating of the papers is completely secure. On the basis of material arguments, the assertion made can always be proved, or at least the degree of accuracy of the examination can be determined. If, for example, one were to conclude from the name charta bombycina applied to certain questionable papers that they were prepared from cotton, or if one wished to derive the same conclusion from the fact that cotton was cultivated in the region where these papers were produced, such a conclusion would be less compelling than if one had used the natural and therefore unchanging structural characteristics of cotton to determine the paper material.

I shall not enter into a critique of the historical arguments, but shall restrict myself to a critical discussion of the material examinations of old papers.

It was evidently above all the conspicuous long-fibered character of the old papers that led investigators to name cotton as the raw material of these writing materials.[1] One must place oneself in the position of the researchers who held this opinion in order to find their error pardonable. The old so-called cotton papers are all distinguished by their long-fibered character, whereas the papers produced in Meerman's time, that is, in the eighteenth century, were very short-fibered as a result of very extensive grinding, as were many other older papers. On one side stood very long-fibered papers; on the other, short-fibered papers. This suggested the idea that the difference was based on the material: the long-fibered papers were declared to be made from raw cotton, the short-fibered ones from rags. Meerman also expressly gives, as a mark of cotton papers, that they possess long fibers at the edges and, when not torn too violently, produce new edges that are very long-fibered.

No weight at all, however, can be placed on this sign. From the other spinning fibers — flax, hemp, etc. — a fiber mass can very easily be produced, by chemical or mechanical means, or by a combination of both, that rivals the finest raw cotton in length of fiber. Indeed, by procedures now called cottonizing, the most varied bast fibers can be transformed into a very delicate, supple, white, cotton-like mass.

[1] See chiefly: Gerardi Meerman et doctorum vivorum ad eum epistolae atque observationes de chartae vulgaris seu lineae origine, edited and furnished with a preface by J. van Vaassen, The Hague, 1767.

Thus, in judging the long- or short-fibered character of papers, an important factor overlooked by Meerman must be considered: how the raw material was treated in order to produce the paper pulp.

We have no reliable information of any kind about the procedures used, before the introduction of "paper mills," to transform the raw material into paper pulp. Probably the paper mill was preceded by a very primitive paper stamper, which attacked the fibers only slightly and, above all, only slightly shortened the naturally very long bast fibers. Now there is no other essential difference between so-called cotton paper and later rag papers than this: that the fiber of the former is much better preserved in length than that of the latter, while it often appears crushed and swollen. The conjecture therefore suggests itself that the fiber of the so-called cotton papers was obtained by stamping.

In any case, however, the paper mill was preceded by a papermaking process based on another principle, one that did not reduce the fibers as much as later became the case. This fact can undoubtedly be used in many cases for determining the age of papers, as I shall explain more fully in a later chapter.

The often considerable swelling of the fibers present in the so-called cotton papers leads me to conjecture that, for producing the paper pulp, chemical means were used in addition to mechanical ones, and that these may also have served to give the fiber mass greater softness.

Be that as it may, the length of the fiber cannot be used as a distinguishing mark between paper produced from raw cotton and paper produced from rags.

I now turn to the other marks of cotton papers given by Meerman. They are said to be coarse, thick, parchment-like, somewhat brittle, and also to combine a yellowish color with a certain gloss. But all these properties, except for the color, are not based on qualities of the cotton fibers, but on procedures that occurred in papermaking, especially sizing.

As for the color, all plant fibers undergo, with time, a "yellowing," namely a partial humification. It is therefore very understandable that the so-called cotton papers, being older, will show stronger yellowing than the later unquestioned rag papers. It may also be that some procedure used in the production of the so-called cotton papers helped to accelerate humification. But in no way can one infer from the color of the so-called cotton papers that they were produced from raw cotton.

By contrast, Meerman describes rag paper as whiter, thinner, more flexible, and stronger, which of course proves nothing either. Only the statement that yarn threads, and formed constituents of woven fabrics in general, can still be found in rag papers may be regarded as a genuine mark of rag papers. Yet even this mark is not reliable, at least insofar as yarn threads are completely absent in all better rag papers — that is, they have been broken down into fine fibrils and incorporated into the paper pulp.

The part of Meerman's studies relating to the material examination of papers is therefore not conclusive on the main point. His hypothesis that papers produced from raw cotton preceded rag papers is not supported by a single fact. On the other hand, those of his determinations in which he inferred rag papers from the presence of yarn threads are correct.

Nevertheless, the assertions of Meerman and his followers became so dominant, despite the inadequacy of the reasoning, that all contrary opinions that appeared from time to time were rejected out of hand as incorrect. So firmly did people adhere to the Meermanian dogma that even in important cases the dating of a paper was regarded as decisive for its substance, and material examination was omitted. The most memorable case of this kind is the following. In 1788 Schwandner[1] announced that in the Imperial Court Library in Vienna there was a document of Frederick II, dating from the year 1243 — according to later, more exact determinations, from the year 1228 — that was written on rag paper.

F. J. Bodmann, from the authenticity of the document established by the Göttingen Society of Sciences, inferred that the date alone constituted proof against Schwandner, since at the time when the document was issued there could not yet have been rag paper. Bodmann never saw the document in question, and yet his assertion has remained in force down to the present day.[2]

Ducarell also places the production of rag paper earlier than Meerman. In his view, there are codices in England from the years 1282 to 1347 that are written on linen paper. He also makes the very apt remark that he knows no one in England who can properly distinguish linen paper from cotton paper.[3]

The more recent palaeographical authorities still stand, in the essential questions of the history of paper, on the Meermanian position: they all assert the existence of cotton paper as the predecessor of rag paper. Thus, to name only the most prominent representatives of this field of research, Sickel[4] and Wattenbach[5] in the German lands, Wailly[6] in France, and Gloria[7] in Italy.

Among the authorities named, Sickel seems to have felt most strongly the inadequacy of the doctrine that had become dominant. In papers that, by their age, still fell within the period of "cotton papers," he found certain peculiarities that pointed to rag papers. This led him to assume mixed papers, prepared from cotton and rags.

[1] See his work: De charta linea antiquissima ex cimeliis biblioth. august., Vienna, 1788.

[2] Compare, among others, J. L. A. Huillard-Bréholles, Introduction à l'histoire diplomatique de l'Empereur Frédéric II, Paris, 1859, p. 70, where Schwandner's statement is likewise presented as an error. I note in advance that I was able to examine microscopically this document, which has become famous in our question. I succeeded in preparing yarn threads from it, thereby proving beyond all doubt that the paper in question was made from rags, and further showing that this paper, like the Faiyum papers, consists of linen fiber and is strongly sized with starch paste. See below in the last chapter.

[3] Compare Ersch and Gruber, loc. cit., p. 87.

[4] Historische Zeitschrift, XXVII, p. 447.

[5] Das Schriftwesen im Mittelalter, 2nd ed., 1875, p. 114 ff.

[6] Éléments de paléographie, Paris, 1838.

[7] Compendio de paleografia e diplomatica, Padua, 1870.

Proofs concerning the paper fibers are still lacking in their writings, although some of these researchers do appeal to the well-known statements of Schleiden[1] and Reissek[2] on the distinguishing characteristics of spinning fibers. These, however, are not sufficient for the secure examination of papers, as I shall show in the next chapter.

The named scholars and other more recent researchers have brought to light much that is valuable on other points concerning the history of paper. From these results of historical investigation I single out only one, which is closely connected with the discussions that follow later.

It had already once been made probable, with reference to a passage in Petrus Venerabilis — Petrus Cluniacensis — that rags may have been used for papermaking as early as the twelfth century. Wattenbach also mentions this,[4] but further expresses the conjecture that Egypt, which in ancient times supplied the West with paper — papyrus — may have been the homeland of rag paper. On this point he says:[5] "The Englishman Yates, in his Textrinum antiquorum, p. 385, has cited from the report of Abd-ul-Latif, a physician from Baghdad who traveled through Egypt around the year 1200, a passage proving that at that time mummy bandages were there processed into paper, though only into wrapping paper; and according to more recent investigations these mummy bandages are all linen…. According to Yates, an Oriental manuscript was written on linen paper as early as around the year 1100."

My investigations have confirmed Wattenbach's conjectures insofar as the Arabs in Egypt did in fact use linen fibers, already utilized in spun form, for papermaking. But much earlier still they were producing good writing papers which, compared with those mentioned by Yates, must already be described as highly refined products.

Wattenbach[6] also sets out the chief places of papermaking and from them infers the Arabic origin of paper. By scientific method I shall furnish proof that the oldest European papers agree essentially with the Faiyum papers, not only as regards the fiber but also as regards the sizing. In this I find further support for the assumption that European papermaking is to be traced back to an invention of the Arabs.

Even the most recent investigations relating to the question of cotton papers have not brought about a decision. On one side stands Briquet[7] with the assertion that cotton papers never existed, and he bases this chiefly on microscopic investigations of precisely dated papers from the eleventh to the fourteenth century. These microscopic investigations were carried out partly by Briquet himself, and partly, at his request, by Brun, Professor of Medicine in Geneva.

[1] Die Pflanze und ihr Leben. Leipzig, 1848.

[2] Denkschriften der kaiserlichen Akademie der Wissenschaften zu Wien, mathematical-natural science class, vol. IV.

[3] Compare, for example, Ersch and Gruber, loc. cit., p. 85.

[4] Against this, Huillard-Bréholles explains the passage of Petrus Cluniacensis differently; he thinks that it concerns not rag paper, but parchment.

[5] Loc. cit., p. 117.

[6] Compare loc. cit., p. 119, where it says: "The earliest chief places of paper production clearly show its origin among the Arabs"; and p. 120: "From the Arabs the word razmah, bundle, was also adopted with paper: Spanish resma, Italian risma, French rame, English ream, German Ries."

[7] Briquet, "La Légende paléographique du papier de coton," Journal de Genève, 1884.

On the other side stands Paoli,[1] who represents the prevailing view and bases himself on microscopic investigations carried out by Caruel, Professor of Botany in Florence, together with his then assistant Dr. Mori, at the instigation of Lupi; the latter likewise stands on the prevailing side in the question of cotton paper. The botanists named examined papers from the twelfth to the fourteenth century and state that in none of them did they find even a trace of linen fiber, but only cotton throughout.

This was the state of the matter when I began my investigation of the Faiyum papers. At that time the history of the subject was entirely unknown to me, and I approached the scientific examination of these papers without prejudice in any direction.

I believe I can show in the next chapter that the histological problem into which the question of old papers has sharpened is completely solvable. I am of the opinion that the research results given in later chapters now exclude all doubt concerning the materials from which old papers were produced, and that the question of the origin of our papers has been solved as simply as it has securely.

The examination of paper is more difficult than it appears. If before me the solution of the relevant fundamental questions was not successful, this is probably because earlier investigators did not understand how to apply the full range of those scientific methods required to reach definitive results. Researchers of the historical school will have to concede that they do not possess the qualifications for solving such difficult, purely scientific questions; both Professor Lupi and Professor Paoli have openly stated this in their writings.[2]

All the more readily, then, will one regard the material examination of paper as a subtle specialized question requiring particular study, especially since even botanists have erred in such investigations. I shall later show that Caruel, whom we hold in such high esteem as a researcher in many fields of botany, arrived at erroneous results in his evidently only occasional examination of the papers mentioned above. But Briquet's microscopic studies, carried out in collaboration with Brun, also cannot withstand sharper criticism, although I must fully agree with his conclusions concerning the non-existence of cotton papers.

[1] Paoli, "Carta di Cotone e carta di lino," Archivio storico italiano, vol. XV, 1885.

[2] Thus Lupi says, in Paleografia, 1875, concerning the microscopic examination of paper fibers — I translate from the original: "Nevertheless, I believe it is better and safer to trust a party that examines as professional botanists do, rather than to rely on one's own observation, which, however exact and complete it may be, never reassures opponents as much as the word of a specialist…." Paoli, loc. cit., remarks that he will not enter into a dispute with the microscopists, since he must declare himself incompetent in relation to them.

Second Chapter

The Development, Present State, and Reliability of Microscopic Paper Examination

1. The technical distinction of papers before the appearance of the so-called rag substitutes

So long as the European paper industry used no fiber material for preparing its products other than rags, there was no occasion, at least from the technical side, to examine paper raw materials. Until the end of the last century, the rag material also remained fairly uniform. If we set aside the use of woolen rags — silk and several other animal materials need not be considered at all because of the insignificance of their use — which served only for producing so-called blotting paper, then these raw materials for papermaking consisted essentially of only a single kind of plant fiber: linen fiber already used in woven fabric — linen fiber, flax fiber; the bast fiber of Linum usitatissimum.

It is true that in earlier centuries Indian trade brought cotton fabrics to many countries of Europe; but only from the year 1772 onward did people in England begin to make fabrics from raw cotton,[1] and only from that time onward did cotton rags become a significant raw material of modern papermaking, gaining ever greater importance. What was processed in European paper mills from cotton fabric before that time is of little importance in comparison with the linen material.[2] The same applies to the fabrics made from hemp fibers — bast fibers of Cannabis sativa L. — and nettle fibers that were then used for papermaking.

Linen-rag papers and cotton-rag papers produced in the same manner differ, on the whole, not insignificantly in their external properties. There is also abundant testimony that they can be distinguished outwardly from one another — by mere appearance, by the "feel," by the form of the tear, etc.

This may formerly have had some justification, namely before the introduction of machine-made paper. At the present high state of the paper industry, which grants finishing by sizing and filling a far-reaching influence on the quality of the final product, no expert will any longer concede this.

Be that as it may, until the middle of our century there was, from the technical side, no need to demonstrate the paper materials in the finished product by strict scientific investigation. Any examinations that may have been made remained confined to crudely empirical methods.

[1] Evidence for this I gave in the work Die Rohstoffe des Pflanzenreichs, Leipzig, 1873, p. 330 ff.

[2] One immediately recognizes the contradiction between these facts and the prevailing view of palaeographers, who put forward the assertion, already emphasized several times, that before the fourteenth century raw cotton formed the only, or at least the most important, paper material even in Europe. But even at the beginning of our century, the amount of cotton — formerly spun — appearing in European papers was still very small in comparison with linen fiber. I shall return to this subject in the final chapter.

2. Microscopic examinations of ancient textiles and papers up to the middle of our century

On the part of historical researchers, the question of the raw materials of old papers arose often, even before the age of our machine-paper industry, and frequently went hand in hand with the question of the materials of old spun fibers and woven fabrics.

Such examinations were carried out partly in a crudely empirical way with the naked eye, and partly with the aid of the microscope. Macroscopic examination could of course lead to no secure result; but even the microscopic examinations still had so many defects that their results can be granted either no certainty at all or only conditional certainty.

I need not discuss here the wholly worthless examinations of old papers made by mere visual inspection, since I have already disposed of this subject in the preceding chapter. As for the older microscopic examinations of papers and spinning fibers, I will examine the value of only the relatively best work on the subject. I shall show that even this could not lead to incontrovertible results, and that it was more the investigator's tact than the reliability of the method that led him onto the right track. I mean the well-known treatise by James Thomson and Francis Bauer on mummy cloths and papers.

As is known, the fiber of mummy bandages was long held to be cotton. In this, people appealed to the often-cited statements of Rouelle, Larcher, and J. R. Forster. These, however, rested on mere visual inspection and by no means on the microscopic examination absolutely indispensable for distinctions of this kind — an examination that could have been brought to bear all the more easily on the question at hand since, a century earlier, Leeuwenhoek,[1] so highly deserving in microscopic research, had already made known the most striking distinguishing characteristics between cotton and linen fiber.

Only through the important writing of Thomson in the Annals of Philosophy for the year 1834[2] was the opinion that had prevailed until then overthrown, and the view now prevailing — supported by microscopic findings — established: that the fiber of these fabrics is linen and not cotton.

Today we can examine the arguments on which Thomson based his view more sharply than was possible then, and reduce them to their true value. So far as I know, the arguments used by Thomson to support his statements have never been subjected to an objective critique based on histological experience.

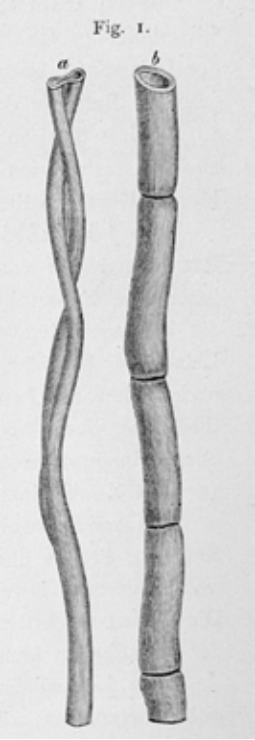
[1] Philosophical Transactions for 1678.

[2] Published in German, with corrections and additions, in Liebig's and Wöhler's Annalen der Chemie und Pharmacie, vol. 69 for the year 1846, under the title "Über das Gewebe an den ägyptischen Mumien" — "On the Fabric on Egyptian Mummies."

If I say that Thomson's assertion concerning the material of mummy garments must be upheld, perhaps my intention to enter into a critique of his arguments will be considered superfluous. But surely that would be wrong.

For I shall show that the signs then used are decisive only under assumptions that were not made at the time; that they would fail completely in examining the Faiyum papers; indeed, that they prove insufficient for paper examination in general.

Thomson himself was not a microscopist. On the question of the fiber of mummy bandages, he sought the judgment of Francis Bauer, who not only microscopically examined numerous mummy fabrics sent to him, but also drew them from the microscope.[1] The microscopic images of cotton and linen fiber are appended to the cited treatise. The former is represented as a thin, flattened tube twisted spirally around its axis; the latter likewise as a thin-walled, but cylindrical, straight, extended, and jointed tube. On the basis of Bauer's description, Thomson compares the linen fiber with the reed: like the reed, it is jointed — see Fig. 1.



According to our present very exact knowledge of the morphological conditions of the two fibers named, we can say that Bauer described cotton incompletely, but linen fiber incorrectly. The latter is so thick-walled that the cavity of the individual cell, or fiber, often appears reduced to a dark line.

The regular articulation that Bauer attributes to linen fiber is completely absent from it. Nor do the constrictions so prominently expressed in his drawing exist; rather, in mechanically worked fiber there occur, in narrow zones, raised areas to which I shall return later.

Since the cotton fiber in fabric is very often twisted, and often in a highly conspicuous way — a peculiarity completely lacking in the fibers that constitute mummy fabrics — Bauer could infer from his observations that the fiber in question could not be cotton. Beyond this, however, on the basis of his observations he would only have been justified in saying that the fiber was probably a bast cell belonging to a dicotyledonous plant. What species this plant was would first have had to be decided by further investigations.

Fig. 1.
Magnification 400.
a cotton fiber; b linen fiber from a mummy bandage.
After Francis Bauer, from Thomson's treatise on the fabric on Egyptian mummies.

[1] It is still gratifying for us today to cite honorable testimony from that time concerning the achievement of our countryman S. Plössl as a maker of microscopes. Thomson says, loc. cit., p. 5, that Bauer gives preference to the microscope of Plössl, with respect to magnification and purity of image, over every other one he had occasion to use.

Nevertheless, the result stated by Thomson and Bauer must be described as rightly guessed. It was later never again called into doubt, and no one has yet furnished the proof that was still to be expected. Franz Unger[1] did indeed acknowledge the correctness of Bauer's determination, but in his treatise, which touches on the subject only briefly, the more detailed histological proof is lacking.

If Unger's list of the plants of ancient Egypt is complete, then, provided that this great plant anatomist found only the dimensions of the fiber in question to agree with those of linen fiber, there is no doubt that the mummy fiber was the bast cell of flax.

But a positive proof in so important a question does not seem without value. I therefore wish to communicate briefly here my observations on this point, so far unpublished.

In 1866 I received from my esteemed friend and colleague Professor Reinisch pieces of mummy fabrics that he had acquired on his first Egyptian journey. The fibers revealed with the greatest certainty all those peculiarities that I shortly afterward described in my Technical Microscopy as characteristic of linen fiber. In addition — and precisely this is decisive in the question — after laborious examinations I had prepared from these mummy bandages tissue fragments that agreed completely, partly with the epidermis and partly with the wood tissue of the flax stem, so that botanically no doubt whatever can remain concerning the origin of the mummy-cloth fiber.

There were two different kinds of mummy bandages of which Professor Reinisch gave me samples. One kind was a fine, light-yellowish, extremely well-preserved fabric; the other was a coarse, deep-brown, brittle product. The bandages of the first kind formed the inner wrapping of the mummy in question, and those of the second kind the outer wrapping.

The linen fiber of the former is of astonishing purity and in many places is still so well preserved as if it had just been prepared out of the flax stem. It is mechanically less attacked than the linen fiber of modern fabrics, which first of all suggests an extraordinarily careful method of fiber separation. In this fabric I found none of the accessory constituents of flax fiber, but I did find them in the fabric of the second kind.

I return to Bauer's microscopic examination. He says[3] that, on the basis of the microscopic characteristics found, he can also distinguish linen fiber from cotton fiber in paper. I cannot concede this, for in paper the fibers are already in such a mechanically altered condition that, to distinguish linen and cotton fibers, one must use features that remained entirely unknown to him. If one tries, for example, to examine the fibers of the Faiyum papers according to Bauer's criteria, one is left completely at a loss.

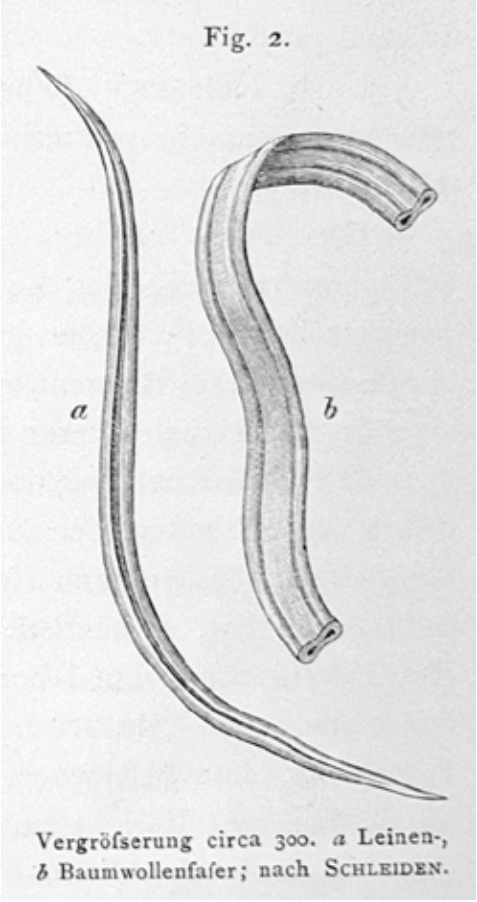
[1] "Botanische Streifzüge auf dem Gebiete der Culturgeschichte. IV. Die Pflanzen des alten Aegypten," Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, mathematical-natural science class, vol. 38, 1859. Compare especially the offprint, p. 64.

[2] Vienna, 1867, p. 108 ff.

[3] Loc. cit., p. 6.

All papers whose fibers have been examined on the basis of the characteristics indicated by Bauer, which became so well known, must be regarded as having been determined uncertainly.[1]

3. Microscopic examinations of spinning and paper fibers by Schleiden, Reissek, and Schacht from the years 1848 to 1853



Since even in more recent technological and palaeographical works reference is still made to these writings as the most reliable accounts of the microscopy of fibers,[2] it should not be superfluous to examine the criteria used by the named authors to distinguish paper fibers.

Fig. 2.
Magnification approximately 300.
a linen fiber; b cotton fiber; after Schleiden.

In his well-known book Die Pflanze und ihr Leben — The Plant and Its Life — Schleiden expresses himself very briefly on the distinction between cotton and flax. He says:[3] "Cotton forms very long but thin-walled cells, and therefore in the dry state it collapses into a flat band with somewhat rounded edges, and does not, like the bast fibers, form a cylindrical thread of equal thickness throughout — Fig. 2. By this sharp difference one is placed in a position to recognize immediately under the microscope any admixture of linen with cotton, and even in the fabrics with which the Egyptian mummies are wrapped to determine their origin."

By comparing the characteristics set out above by Bauer and Thomson with those emphasized by Schleiden, one sees immediately — as is also apparent from the illustration — that the latter had before his eyes only the uninjured bast cell of flax, whereas even broken and hackled flax, and still more the spun fiber, already presents quite a different image under the microscope. The description of the bast cell of flax and of cotton is otherwise also still very imperfect and quite insufficient for paper examination. The illustration of the flax cell is, apart from its abnormal shortness, so vague that it could serve as an example of almost any other bast cell.

[1] Two figure plates are appended to the German translation of Thomson's essay, from the year 1849, from which I cite here. One gives the microscopic image of cotton fiber, the other that of linen fiber. The text does not refer to these drawings, which are much better than Bauer's illustrations. These two plates are signed by C. Varley and W. Kelsall.

[2] For example, by Wattenbach, loc. cit., p. 114, where Schleiden's Die Pflanze und ihr Leben and Reissek's treatise, named later, are cited.

[3] Loc. cit., p. 46.

Reissek[1] devoted a very detailed treatise to the spinning fibers — flax, hemp, nettle fiber, and cotton. It was aimed primarily at the developmental history of the relevant cells, but with respect to the bast cells, which according to him are supposed to be intercellular formations, it is entirely unsuccessful.

His description of the fibers is already more complete than that of Bauer and Schleiden, since he already points to the morphological changes — longitudinal striation, formation of tears, formation of nodes — that flax undergoes through breaking and hackling. But since he himself admits that cotton can also be straightened and thick-walled, while he failed to notice its cuticle, it becomes clear that mixed fabrics, or paper still more, cannot be examined with certainty for their fibers according to his characteristics. According to Reissek, linen fiber is sometimes, at least in places, entirely solid, which has not been confirmed by any later observer.

According to Reissek's scheme, the fibers named can be detected with certainty, at least on the whole, in well-preserved fabrics, but not in paper.

The first to advance paper examination on the basis of histological experience was the eminent plant anatomist Hermann Schacht. In his book Die Prüfung der im Handel vorkommenden Gewebe durch das Mikroskop und durch chemische Reagenzien — The Examination of Commercial Fabrics by the Microscope and by Chemical Reagents, Berlin, 1853 — he devoted a separate, though brief, chapter to the examination of paper.[2]

Schacht still bases the distinction of paper fibers throughout on the original properties of the cells — for example, the bast cells of flax, the cotton hair, etc. — which he described in earlier chapters more thoroughly and more correctly than all his predecessors, especially cotton, whose cuticle he rightly uses as a distinguishing feature. The important phenomena of destruction in paper fibers were not yet considered by Schacht. He can therefore determine the fibers in paper only when they still carry their original morphological character. In this author we also already find the first indications concerning the detection of straw and wood fibers in paper. At that time, however, these substitutes had not yet gained firm footing and still produced very poor products; for example, Schacht then obtained for examination, as straw paper, only ordinary packing paper.

4. Microscopic examinations of paper fibers undertaken since the introduction of rag substitutes

The demand for more exact methods for determining paper fibers arose only about a quarter of a century ago, when the enormously increased consumption of paper urgently demanded substitutes for rags.

[1] Siegfried Reissek, "Die Fasergewebe des Leins," etc., Denkschriften der kaiserlichen Akademie der Wissenschaften, vol. IV, 1852.

[2] Berlin, 1853, pp. 43–50.

There had indeed already been noteworthy attempts in the previous century to use the most diverse plant materials for papermaking. But only after many unsuccessful experiments did it become possible to make several vegetable raw materials, already earlier recognized as usable, serviceable for the stated purpose in a rational and profitable manner. Through the industrial use of these rag substitutes, European papermaking was, as is well known, completely transformed.

In the production of many papers made with the addition of such substitutes, the inferior value of the fiber had to be concealed by sizing and filling, and this circumstance in particular called forth the need for microscopic paper examination.

The most important of these rag substitutes are, as is known: wood — ground wood, or mechanical wood pulp, and chemically isolated wood fiber — straw, including esparto, the leaves of the grass Stipa tenacissima, and various modern spinning fibers, especially jute, often in the form of waste. Ground wood is always processed mixed with rag paper stock; the others are usually so processed.

The first attempts to carry out the microscopic examination of paper according to scientific principles — that is, supported by histological characteristics of the cells constituting the papers — came, as I mentioned earlier, from Schacht. But his investigations fell in a period in which substitutes had entered only in the crudest form, or merely as objects of experiment.

I undertook my own investigations on this subject in a more favorable period, at the beginning of the 1860s, when the large-scale introduction of substitutes was bringing about a complete transformation of the paper industry.

At that time — favored precisely by the moment — I was in the fortunate position, through comprehensive and systematically conducted studies, to provide the foundations for a microscopic examination of modern papers. I may add that the microscopic distinction of paper fibers based on my studies has so far been regarded as sufficient; for, as far as I know, even in the most detailed works and treatises devoted to paper and paper examination, no one has gone beyond the criteria I set up. From the most competent quarter the importance of microscopic paper examination has been fully recognized. Nevertheless, in some technical circles the opinion is widespread that one can examine papers for their raw material with sufficient certainty by chemical investigation. I have already, on occasion, opposed this erroneous view. I must do so still more emphatically in this treatise, in which, among other things, I have set myself the task of testing the degree of accuracy of the methods used to determine paper fibers. For this purpose I shall first communicate the results of the original works relating to the subject and, so far as seems necessary, examine them critically.

[1] Compare chiefly the work of Jacob Christian Schäffer: Neue Versuche und Muster, das Pflanzenreich zum Papiermachen und anderen Sachen wirtschaftsnützlich zu verwerten, Regensburg, 1766. There also are historical references to earlier attempts of this kind.

My first studies on microscopic paper examination were published under the title "Microscopic Examination of Paper Fibers" in 1864 in the Österreichische botanische Zeitschrift.[1] In these studies, the precision of microscopic examination, both as against crudely empirical and chemical examination, is demonstrated, and it is shown how the fibers of rag papers can be distinguished from those of wood and straw papers on the basis of histological characteristics. Soon afterward there followed a detailed microscopic examination of maize-fiber products,[2] in which the chief emphasis was placed on recognizing the Auer maize papers then widely distributed in Austria, produced from the husk leaves of the maize plant.

After the publication of the detailed investigations just mentioned, I attempted in my work on technical microscopy[3] to give a systematic overview of the microscopic examination of paper. In the relevant section, attention was directed first of all to modern European handmade and machine-made papers; in an appendix, however, the microscopic characteristics of the very remarkable Japanese and Chinese papers were also precisely described, as was finally the papyrus of the ancients.

In this, not only the characteristics of the paper fibers came into question, but also the detection of sizing, fillers, and the most common coloring materials.

Special attention was devoted to the phenomena of destruction in paper fibers. If plant fibers took part in the composition of paper in an unchanged state, as they occur in the dead but otherwise unaltered plant parts, the examination of paper for fiber would generally offer little difficulty. But the fibers of papers produced from rags were first used in woven fabric, and even before that had already been altered, though only insignificantly, by spinning, weaving, and possibly twisting. Once they had become paper raw materials, they underwent other, often very profound, changes. clarified some of the more important changes in form that linen and cotton fibers suffer through the mechanical attacks occurring in the Hollander, and I succeeded in distinguishing even very badly damaged cotton fibers from bast fibers of flax of this kind.

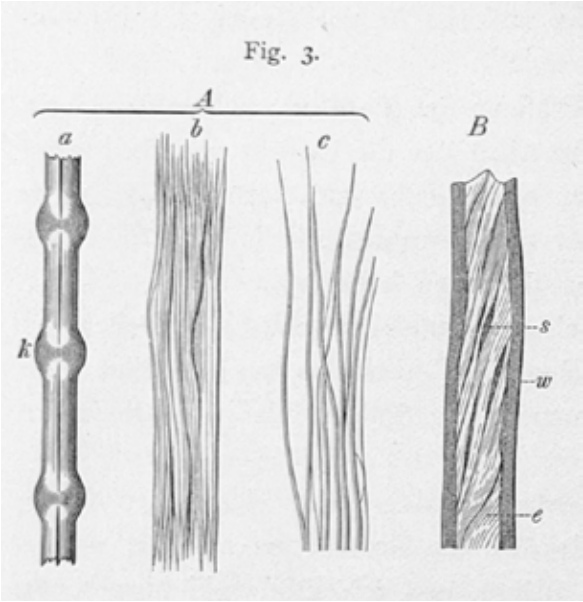


Fig. 3.
Magnification 300.
A. Mechanically attacked linen fiber.
a with node, from twisted yarn.
b, c split and frayed fragment of a linen bast cell from paper.
B. Mechanically attacked cotton fiber, fragment.
w cell wall; s fissures; e cuticle.
From Technical Microscopy, p. 221.

[1] Edited by Dr. A. Skofitz, no. 3, pp. 65–77. Reprinted in full in the well-known work by Dr. W. F. Exner, Die technischen Eigenschaften des Papiers, Vienna, 1864.

[2] Dingler's Polytechnisches Journal, 1865, vol. 175, p. 225 ff.

[3] Einleitung in die technische Mikroskopie, nebst mikroskopisch-technischen Untersuchungen, Vienna, Braumüller, 1867, pp. 218–239.

In my work The Raw Materials of the Plant Kingdom[1] I confined myself to the characterization of paper fibers, without going into the conditions in which they occur in the manufactured product, and without further consideration of sizing, filling, and coloring. Nevertheless, this chapter also contains much information useful for the examination of papers, since jute, which had meanwhile come into use in papermaking, was characterized there; furthermore, the fiber of Japanese papers and wood fiber were discussed more thoroughly than in my earlier writings.

In the meantime, some of the rag substitutes whose characterization had been attempted in the writings named — especially wood in the ground state — acquired such great importance as paper raw materials that the desire arose to replace the still difficult, and often complicated, microscopic examination with simple chemical reactions.

In an essay published by Schapringer[2] in 1865, such an attempt was undertaken with considerable success; and both his procedure and several analogous chemical tests that appeared later are still in use today for certain purposes.

Going back to earlier observations by Runge, A. W. Hofmann, and others, according to which colorless salts of aniline and other similar organic substances color fir wood intensely yellow, he showed that a solution of aniline sulfate colors not only fir wood yellow, but also other coniferous and deciduous woods tested by him, and that this reagent can be used to demonstrate the presence of wood fiber in paper.

Compared with the laborious microscopic examination, which presupposes detailed histological knowledge, Schapringer's method appears very advantageous. One need only put a drop of a solution of aniline sulfate on the paper to be tested; if the latter turns yellow, one concludes that wood fiber is present. But two serious objections can be raised against the reliability of this method, which I expressed on the occasion of a detailed microscopic examination of esparto papers.[3] The reagent named does not indicate wood, but rather, as I first demonstrated, woody substance — lignin — a substance, or according to more recent investigations to be named later, a mixture of substances, which belongs among the most widespread bodies in plant tissues. Thus, as I showed, elder pith, the fibers of the yellow turnip, the inner fibers of any herbaceous plant, or, to speak of papermaking materials, jute, are colored just as intensely yellow by the reagent as wood. A paper produced from jute would, according to the evidence of Schapringer's test, have to be regarded as a paper rich in "wood substance," and a straw paper as a paper adulterated with "wood substance."

Against the unconditional reliability of this, and indeed of all chemical methods for detecting paper fibers, the following circumstance also speaks. One of the principal tasks of papermaking consists in the purification of the fiber material — more precisely, in the removal of all bodies occurring in the fiber alongside cellulose, $C_6H_{10}O_5$,

[1] Leipzig, Engelmann, 1873. Chapter "Paper Fibers," pp. 446–461.

[2] Wochenschrift des niederösterreichischen Gewerbevereines, XV, p. 326.

[3] Wochenschrift des niederösterreichischen Gewerbevereines, 1865, XXVI, p. 597 ff.

above all woody substance. This is done, as is known, by bleaching, treatment with alkaline lyes, etc.[1] Since wood, for its transformation into paper pulp, has no longer merely been reduced mechanically by the grinding process, but also separated chemically into its tissue constituents, a wood paper containing no woody substance is nothing unusual. In these papers, neither aniline sulfate, nor phloroglucin, which reacts still more sensitively to lignin and which I was likewise the first to use for histological purposes,[2] nor any other body reacting in an analogous way, produces a reaction pointing to wood. These reagents show only ground and incompletely bleached wood pulp, and even this not with absolute certainty, as I explained earlier. Thus the microscope will always be necessary in order to demonstrate with certainty wood fiber, or indeed the quality of any paper fiber.

I shall now briefly examine to what extent works on chemical and mechanical technology, and especially works devoted to paper and its manufacture — to which one usually turns when the methods of paper examination are at issue — take microscopic paper examination into account, and how reliable these sources are.

Works on technology generally stand on a higher scientific level than the existing special works on paper-making, although the practical merit of the latter should not be denied.

Of works in the latter category I will consider only the more recent ones, since the authors of the older writings found no usable materials concerning the examination of paper.

C. Hofmann's large work, published in German and English editions,[3] contains only scant and insufficient information on our question. The fibers are described as round — linen and hemp fibers — and more or less striated, or as flat — cotton — etc., without more precise statements about the characteristic morphological peculiarities and about the conditions in which the fibers occur in paper. No illustrations of the fibers are appended to the text.

The situation is somewhat better in this respect with the likewise very detailed work of Dr. L. Müller.[4] At least one of the wood fibers — spruce — of paper is well illustrated by a drawing. On the other hand, the statements concerning the other fibers are insufficient for determining the fibers. For example, the esparto fiber illustrated on p. 104 shows none of the peculiarities so easily found and usable with complete certainty for identification, and could easily lead one to other fibers.

[1] It may not be without interest if I note that the substance indicated in wood and in woody tissues generally by aniline sulfate, by the phloroglucin mentioned below, or by another "lignin reagent," is, according to investigations carried out in my laboratory by Dr. Max Singer, vanillin.

[2] Since I drew attention to the remarkable property of phloroglucin, after the addition of hydrochloric acid, to color even slightly lignified tissues an intense red-violet, this reagent has been used with particular preference for paper examination. Unfortunately, however, the conditions under which the reaction is reliable are very often not taken into account.

[3] Praktisches Handbuch der Papierfabrikation, Berlin, 1875.

[4] Die Fabrication des Papiers, 4th ed., 1877.

Professor Egbert Hoyer, in his book Paper, Its Nature and Its Examination, treats the recognition of paper fibers much more thoroughly. His statements indeed do not go beyond, in any point, the characteristics set out in the detailed works mentioned above; but everything is reliably reproduced. The only fault to be found is that the author takes no account at all of the destructive forms of the fibers, so that the fibers of all papers produced from more strongly ground fibers cannot be determined either by means of his descriptions or by means of his illustrations.

The handbooks of chemical and mechanical technology, as already noted, generally go deeper into the scientific examination of paper than the works just named, and by their effort to trace the data presented back to sources, they also provide a higher degree of reliability.[2] Yet even these works do not go beyond the sources named earlier.[3]

As regards the reliability of microscopic paper examination, apart from several occasional remarks of mine on the subject, nothing yet exists. I enter into this subject, which seems important to me, not only in order to provide a measure for the accuracy of my results relating to the Faiyum papers, but also in the hope that these critical reflections of mine may benefit later paper examinations.

Only a few papers can be recognized with some certainty, even with the naked eye, in regard to the material used for their production. These are the so-called Chinese rice papers and the papyrus of the ancients.

The former bear their name incorrectly, for they are not prepared from the rice plant,[4] but are artfully cut from the pith of Fatsia — Aralia — papyrifera Miq., belonging to the Araliaceae. In the country of production they are used for painting with watercolors, and they are well known through the characteristic Chinese paintings frequently encountered among us as well. Among us this paper is used for making artificial flowers and other objects. This Chinese paper is recognizable even with the naked eye by its parenchymatous character, which understandably appears much more clearly with the magnifying glass and the microscope.[5] Confusion with other objects is not to be feared, since this paper cannot be imitated and similar papers do not exist.

Papyrus, as is known, appears as a mass that is streaked lengthwise and crosswise. This characteristic peculiarity is explained partly by the anatomical structure of the stem from which this writing material was produced, and partly by the manner of production.

[1] Munich, 1882.

[2] Compare, for example, Stohmann's excellent article on paper in Muspratt's Technische Chemie, loc. cit., p. 653 ff.

[3] Later note: In von Höhnel's recently published Mikroskopie der Faserstoffe, Vienna, 1887, chapter "Paper," essentially nothing new is to be found either.

[4] By contrast, many of the well-known Chinese wallpaper papers consist of the fibers of rice straw. See Wiesner, Technische Mikroskopie, p. 235.

[5] More detailed information on the texture of this paper is to be found in my work Rohstoffe, p. 460.

The stem or trunk of the papyrus plant — Cyperus Papyrus — consists of pith traversed by strands, or vascular bundles, and of an epidermal tissue thickened by bast strands. This latter tissue was removed from the stems, and the pith was prepared for making papyrus in such a way that it was cut lengthwise into finger-wide strips, which were joined together lengthwise and crosswise, then smoothed and compressed by hammering. Thus it is explained why the strands that occur parallel in the stem cross one another in papyrus. By means of the microscope one can recognize both the texture of the vascular bundles and, after suitable pretreatment, that of the very characteristically joined parenchyma cells connecting them.[1]

On this occasion I may be permitted to draw attention to several peculiarities of papyrus recently found by me, which — so far as I know — have not yet been observed, and which may not be unwelcome as a contribution to the knowledge of the method of preparation of these writing materials.

The papyri I examined[2] give no conspicuous reaction upon the addition of aqueous iodine solution. But if they are first subjected to the action of ordinary hydrochloric acid and only afterward treated with iodine solution, then a more or less deep blue coloration of the whole solid substance, or at least of the liquid, appears.[3] Under the microscope, deep-blue flakes can be recognized. Evidently a kind of starch paste was used for gluing together the sheets or strips cut from the papyrus pith, and this paste is indicated by the iodine reaction. In the cells one occasionally still finds well-preserved, small, roundish starch grains, which of course belong to the papyrus plant. The quantity of these grains disappears in comparison with the paste mass, which adheres externally to the tissue everywhere. The gelatinization of the starch used was always so complete in the papyri I examined that the plant from which the starch used for preparing the paste came could no longer be determined.[4]

All felted papers — handmade and machine papers — can, like papyrus, already be recognized macroscopically as such, even if they appear completely smooth and homogeneous,

[1] I gave the microscopic characteristics of papyrus in Technische Mikroskopie, Vienna, 1867, p. 238. The papyrus then used for examination — Papyrus Usertesen, approximately from the middle of the second millennium B.C. — I owed to the kindness of Professor Reinisch. Each of them consisted of three layers that could easily be detached from one another. Compare Karabacek, loc. cit., p. 163.

[2] The following objects served for my experiments: samples from the Collection Papyrus Archduke Rainer, about from the seventh to ninth century; further, from the collection of the Institute for Austrian Historical Research: "Fragment. Papyr. bullae saec. IX," "Pap. Cod. lat. ante ann. 400 script." From the same collection: "Papyrus discs from the botanical garden in Vienna from the year 1859" and "Modern papyrus from Palermo." These last two do not give the iodine-hydrochloric acid reaction. The "modern papyrus" was therefore prepared in a different way from the papyrus of the ancients.

[3] Why starch paste is not indicated here directly by aqueous iodine solution, but only after pretreatment with hydrochloric acid, will be explained below in discussing the sizing of the Faiyum papers.

[4] According to some of our observations, it appears as though, instead of pure starch, a starch-rich waste product of flour preparation may also have been used as an adhesive in papyrus preparation.

namely by the fibrous condition of any torn edge. After soaking in water they fall apart directly, or after treatment with dissecting needles, into little fibers.

I have already explained that the quality of the fiber cannot be established with absolute certainty by chemical means, and it remains now only to determine the degree of accuracy to which microscopic examination leads.[1]

Microscopic examination makes it possible to demonstrate the following paper materials immediately and with absolute certainty:

1. straw fiber,
2. wood fiber,
3. bast fiber of dicotyledonous plants,
4. cotton.

1. Straw fiber

This is so certainly and also so easily recognized in paper because, alongside and partly also on the bast fibers that form the essential constituent of this rag substitute, highly characteristic histological elements occur. These are well-preserved epidermal cells, and also constituents of vascular bundles — annular and spiral vessels. Since this discovery, hundreds of papers prepared from straw have probably been examined by me and my students; but in not a single one were the epidermal cells lacking. The reliability of this criterion has also not been disputed by anyone.

As an example of a paper prepared from straw, I cite the second edition of the well-known work by Wattenbach, frequently cited in this treatise, The Writing System in the Middle Ages. I microscopically examined all copies of this work that I could find in Vienna,[2] and in every fragment of about one square millimeter surface area numerous epidermal cells were found, as well as many vessel fragments alongside the bast cells of the straw and rag fibers.

The bast cells and vessels of the various kinds of straw do not differ greatly in their properties. The epidermal cells, however, offer such secure points of distinction in form, size, and inner structure that one can decide, for example, with complete certainty whether the paper was prepared from rye straw or esparto straw. These are at present the kinds of straw most frequently used in papermaking in Europe. But the detection of rice straw — in genuine Chinese wallpaper papers, etc. — maize husk leaves, and straw from oats, wheat, or barley also presents no difficulty.[3]

On the basis of these distinguishing characteristics, it could be proved with certainty that rye straw, together with rags, formed the raw material for producing the paper of the second edition of the above-mentioned work by Wattenbach.

[1] In the following discussion I entirely disregard animal fibers, since they are wholly unsuitable for producing felted writing materials.

[2] Mr. medical student Konrad Büdinger assisted me in this in a way deserving thanks.

[3] On the detection of straw species in papers: Wiesner, Technische Mikroskopie, pp. 223–227.

2. Wood fiber

Wood fiber can be recognized in paper by the microscope with the same certainty as straw fiber. But determining the species of wood encounters difficulties in many cases and is sometimes not feasible at all, for two reasons. First, the number of wood species to be considered is very large, and understandably the probability of identification generally becomes smaller the more the number of species to be compared increases.

But another circumstance also comes into consideration. In papermaking, in some cases to which I shall draw attention below, certain cell forms indispensable for determining the species of wood are lost.

Both coniferous and deciduous woods are used for papermaking. It will be possible without difficulty to decide whether the fibers of one or the other are contained in a paper to be examined. One need only note that the wood of conifers is vessel-free,[1] whereas that of deciduous trees contains vessels more or less abundantly, and that these so characteristically formed vessels are present in a readily recognizable state even in strongly ground papers.

The question, usually not very important, of which species of wood was used for producing a particular paper is easily and securely decided, for example, in ordinary papers produced from "ground wood pulp," whose raw material in Europe is to be designated as spruce and fir wood, or the wood of poplar and linden. Spruce and fir wood fibers are very easily distinguished from one another by the medullary-ray cells, which are never lacking in "ground wood pulp" and in the paper produced from it. On the other hand, in many papers consisting of wood fibers prepared by chemical means, this question can no longer be solved, because in such papers the medullary-ray cells, remarkably, are completely absent.[2] The two named genera of deciduous trees can be recognized in the paper mass without difficulty. By contrast, the determination of the particular deciduous species is hardly practicable or is altogether impossible. Thus, a distinction between the wood of our common poplar species — Populus alba, nigra, and tremula — can no longer be made with certainty under the microscope. Indeed, I do not go too far when I say that distinguishing willow wood — better sorts of willow wood are used in papermaking — from that of poplars in paper will not succeed. Among American papers produced from deciduous wood, I have found many to be indeterminable.

3. Bast fibers of dicotyledonous plants

Bast fibers are easily distinguished from most other fiber-shaped elements of plant tissues by their length, strong thickening, and simple structure; considered by themselves, they could be confused only with the libriform fibers occurring in wood. Such confusion cannot occur in the examination of textile objects and papers, however, since the vessels and tracheids accompanying libriform fibers would immediately reveal their true nature.

[1] Strictly speaking, the stem of conifers also contains vessels, but only in the narrow zone surrounding the pith. The mass of these structures — which, moreover, are very inconspicuous compared with the vessels of deciduous trees — simply disappears in relation to the wood fibers, so that the probability of encountering conifer vessels in microscopic paper examination is nearly zero.

[2] For example, in wood paper produced according to the process of A. Ungerer. Compare Wiesner in Dingler's Polytechnisches Journal, vol. 201, p. 158.

The bast fibers of dicotyledons unite in the stems of these plants into such homogeneous bundles that confusion with those of monocotyledons need not be feared, especially when paper is involved. If a monocotyledonous bast fiber were present — as, for example, in straw — the remains of accompanying tissue constituents, vessels, tracheids, pith cells, etc., would account for its origin.

Thus one will be able, with the greatest ease and certainty, to determine whether a fabric or a paper consists of the bast fibers of dicotyledonous plants or not. But no one is served by this determination alone; one wants to know which dicotyledonous plant supplied the fiber for the product. When this question is posed, difficulties arise that are usually not sufficiently considered.

To mention a nearby example: one usually contents oneself with declaring the bast fiber of a fabric to be linen fiber if it is long, cylindrical, and thickened almost to the disappearance of the lumen. But there may be hundreds of plant species whose bast fibers agree with linen fiber in the characteristics named. If the question is delimited in a definite way — for example, if it is asked whether the fabric to be examined consists of linen or cotton fibers; or whether the textile object to be examined was produced from linen or jute fibers — then it can generally be answered with complete certainty. But if the question is posed quite generally, its solution is achieved quickly and securely only when, alongside the bast cells, other constituents of the spinning plant also occur: particles of bark or fragments of wood. It is understandable that the hope of finding such accessory constituents becomes smaller the more carefully the product was prepared. In coarse linen yarns one often encounters such tissue remains; in fine batistes, however, one will seek them in vain.

I now wish to examine how far, by taking into account the finest structural conditions of the bast fibers, their dimensions, and their behavior toward reagents, one is nevertheless able to recognize the quality of a bast fiber in paper.

In general, recognizing the fiber of a modern fabric or paper of definite provenance will be easier than that of a textile object or paper of unknown origin or great age, because in the latter cases the number of possibilities concerning the quality of the fibers is far greater than in the former. If, for example, one is dealing with a modern spun fiber or fabric made from plant fibers in the German Empire or in Austria, then only the following four fibers chiefly come into consideration: linen, cotton, hemp, and jute. In the second rank, ramie or China-grass fiber would still have to be considered. But even in this apparently simple question, many difficulties arise that are usually left unconsidered. It is quite easy to distinguish cotton from bast fibers, and jute from flax and hemp; but to keep flax and hemp apart requires numerous laborious measurements and other tests. Indeed, a very thorough researcher, Professor Cramer in Zurich, holds the opinion that the bast cells of hemp cannot be distinguished from those of flax.

According to the prevailing opinion, the bast cell of hemp can be distinguished from that of flax. This was the position, as already mentioned above, of Schacht and Reissek; and it is also my position, although I consider it necessary to use characteristics for distinction that were not yet taken into consideration by the two researchers named. Essentially, hemp and flax fibers are constructed in the same way; but the former is usually thicker and has a wider lumen than the latter. To establish the differences in thickness, it is necessary to determine the maximum diameter of each fiber and to derive the most frequent values from the numbers thus obtained. If one has intact fibers before one, the distinction succeeds, though after lengthy measurements; but if the fibers are strongly mechanically attacked or swollen by macerating agents, then the detection of hemp or flax fiber becomes uncertain, indeed often altogether impracticable, unless the inner membrane, which on the whole differs in flax and hemp, is still preserved enough to be used for distinction. In that case the following can easily be established.

The inner membrane of the linen fiber is usually an exceedingly narrow tube, which resists the action of cuprammonium hydroxide for a long time and remains preserved as a tube bent back and forth in a spiral or worm-like manner, though in stretches also straight, while the rest of the body of the cell wall is already completely dissolved. See Fig. 4. The inner membrane of the hemp fiber is usually broader and, after the action of cuprammonium hydroxide, commonly appears as a transversely folded tube.[1]
See Fig. 5.

Fig. 4.
Magnification 400.
Fragment of a linen bast cell after treatment with cuprammonium hydroxide.
i inner membrane.
i' i' inner membranes of the linen fiber remaining after the action of cuprammonium hydroxide.

Fig. 5.
Magnification 400.
Fragment of a hemp bast cell from very well-retted hemp, completely freed from woody substance, after treatment with cuprammonium hydroxide.
i inner membrane.

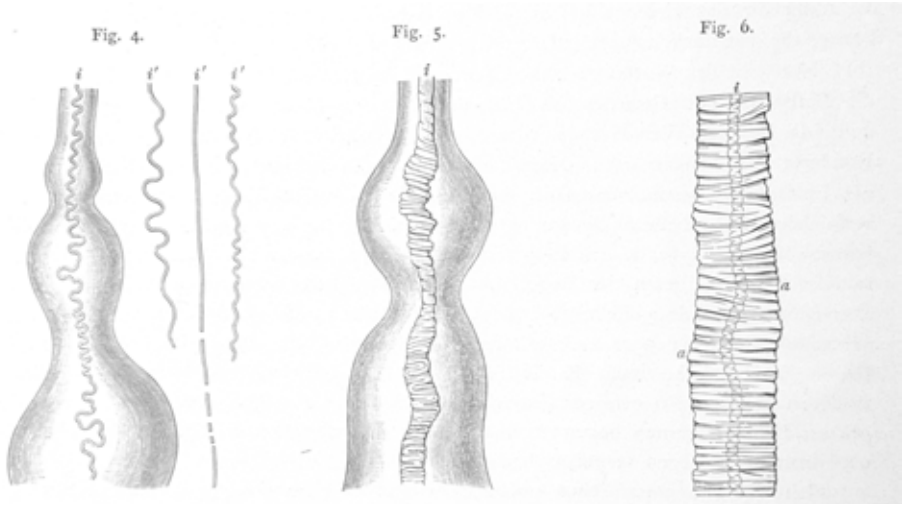
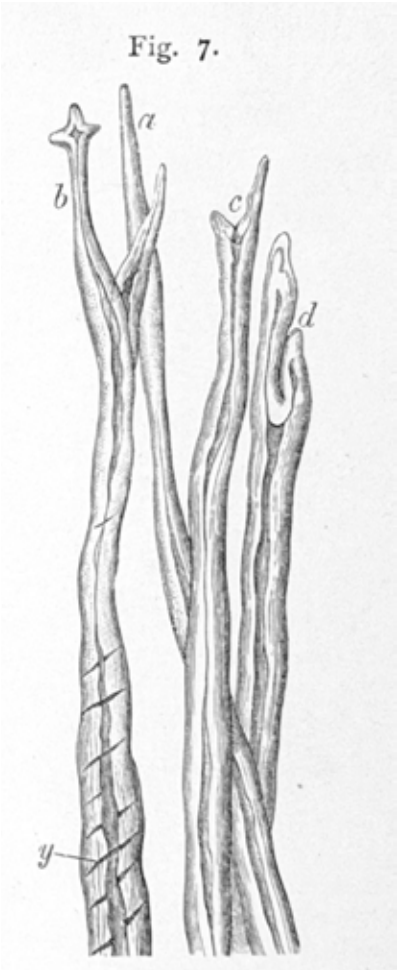


Fig. 6.
Magnification 300.
Hemp fiber fragment from raw, strongly lignified hemp, after treatment with cuprammonium hydroxide.
aa outer lignified cell-wall layer, made wrinkled by the action of the reagent.
i inner membrane.

[1] Wiesner, Technische Mikroskopie, pp. 108–110, and Rohstoffe, p. 376.

In very recent times I have found the following additional distinguishing mark between flax fiber and hemp fiber. The outermost layers of the cell wall of both offer greater resistance to the action of cuprammonium hydroxide than the inner layers adjoining the inner membrane. But while the outer cell-wall layer of the flax bast cell reveals nothing special in this process, the corresponding layers of the hemp bast cell are often richly transversely folded. Evidently these layers underwent the same change under the action of cuprammonium hydroxide as the inner membrane. Neither these layers nor the inner membrane swell as strongly as the rest of the cell-wall mass; above all, however, the outer layer and the inner membrane cannot follow the shortening in the direction of the longitudinal axis that occurs during the swelling of the rest of the cell-wall mass, and they thereby undergo the characteristic changes in form mentioned. Coarse, strongly lignified hemp fibers show this behavior especially clearly. See Fig. 6.

The ends of the flax and hemp bast cells often differ from one another in form, in that those of the former are usually pointed, whereas those of the latter are usually blunt to completely rounded, and also more or less distinctly forked;[1] yet, as I have recently convinced myself, linen fibers with rounded ends also occur, and, as I showed earlier, hemp fibers with pointed ends also occur.[2] If one has unmixed hemp or flax products before one, the difference mentioned can often be used to advantage.



In mixed products, however, all gradual differences — thickness, width of the lumen, form of the inner membrane, and form of the ends — are usually no longer fully reliable. Only when one encounters forked ends, or, after treatment with cuprammonium hydroxide, broad, transversely folded outer and inner membranes, can one conclude with certainty that hemp fibers are present.

Cramer[3] rejects all distinguishing characteristics between linen and hemp fiber derived from the bast cells alone, and considers the decision whether hemp or flax fibers are present possible only when bark constituents of the stem of the mother plant still adhere to the objects to be examined.

Even if Cramer goes too far in declaring the distinction of flax bast cells from hemp bast cells deceptive in all cases, his work nevertheless has the great value of having properly emphasized several criteria that can bring about a decision precisely in the most difficult cases, namely when the determination concerns objects in which

Fig. 7.
Magnification 300.
Ends of hemp bast cells; simple at a, forked at c and d.
v structures taken to be pores.
After Schacht.

[1] Compare Schacht, loc. cit., p. 25; Wiesner, Technische Mikroskopie, p. 110.

[2] Later note: In von Höhnel's work, which appeared long after the completion of this treatise — Mikroskopie der Fasern, Vienna, 1887, p. 38 — the difference mentioned is likewise emphasized, but, in my opinion, stated more sharply than the actual conditions warrant.

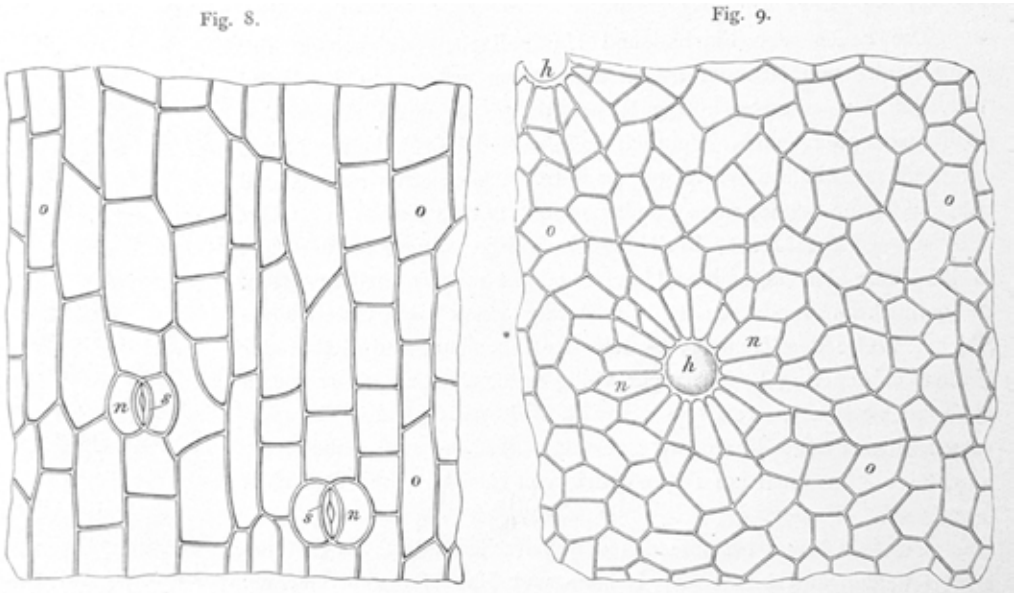
[3] C. Cramer, Drei gerichtliche mikroskopische Expertisen, betreffend Textilfasern. Program of the Swiss Polytechnic for the year 1881–1882.

the fibers composing them are very strongly mechanically attacked.

Cramer's method can be used only for examining coarse textile objects and papers produced from very little cleaned fibers. If one is dealing with textiles consisting of very well-cleaned fibers, or with papers of that kind, the method cannot be used; then only the first method indicated can still be employed. To be sure, cases remain in which neither the one nor the other method leads to the goal: namely, when the fiber is very well cleaned but badly damaged.

Cramer's method has rendered me excellent service in the examination of the Faiyum and other papers, and is altogether irreplaceable in the cases indicated. I therefore wish to sketch it briefly here.[1]

Fig. 8.



Magnification 300.
Epidermis of the flax stem with stomata.
s guard cells; n subsidiary cells of the stoma; o epidermal cells.

Fig. 9.
Magnification 300.
Epidermis of the hemp stem.
oo epidermal cells; h gap left in the epidermis by a fallen hair; n subsidiary cells of the hair.

Cramer bases the distinction between flax and hemp fibers chiefly on the following histological characteristics of the hemp or flax stem:

1. On elongated parenchyma cells occurring between the bast cells of hemp, which are filled with an intensely red-brown content that resists boiling potash lye and concentrated sulfuric acid for a long time. Cells of this kind are completely absent from the flax stem.
2. On the epidermis, which is very poor in stomata on the hemp stem, but rich in stomata on the flax stem. The epidermis of the hemp stem contains on average only 12 stomata per square centimeter, whereas that of the flax stem contains 3,000 stomata per square centimeter. The epidermis of flax is free of hairs, while that of hemp has unicellular, conical, somewhat —

[1] On an earlier attempt to use "accessory constituents" to identify the fiber of mummy-bandage fabric with linen fiber, see above p. 194.

curved hairs covered with warts, which, when they fall off, leave large scars easily recognizable in the epidermis. The cells with red-brown contents are always to be found in hackled hemp, and often also in hemp cloth; according to Cramer, epidermides, by contrast, are always to be observed even in bleached hemp and flax cloths.

I can essentially confirm these statements. I must only note that, according to detailed investigations undertaken by me, in finer linen yarns and linen fabrics often no trace remains of the tissue constituents used for distinction. On the other hand, in coarser sorts of hemp and flax, and in coarser yarns and fabrics prepared from them, the tissue constituents named, especially epidermal fragments, can always be found. Indeed, more than this: in these products I have often also found wood fragments of the flax or hemp stem, which can be used to great advantage for distinction, not only because the vessels of the two differ greatly from one another, but because the vessels occur in a well-preserved state, while the bark constituents — epidermis and cortical parenchyma — are often altered almost beyond recognition.

Of the epidermis of the flax stem, I often find in linen fabrics nothing more than the cuticle, which nevertheless, upon very exact examination, reveals its origin through the remains of stomata. The vessels of the flax stem have an average diameter of 0.02 millimeter; those of the hemp stem, 0.05 millimeter. The outer vessels are pitted in both cases — in flax usually provided with bordered pits arranged in a single row, in hemp usually with bordered pits arranged in several rows; the former have a diameter of about 0.002 millimeter, the latter 0.005 millimeter. The inner vessels, that is, those adjoining the pith, are spirally thickened.

Some bast-fiber products, on the other hand, are easier to recognize. Thus Japanese paper — produced from the bast fibers of the paper mulberry tree, Broussonetia papyrifera — can easily be recognized by the parenchymatous cells occurring alongside the bast cells and filled with crystals of calcium oxalate. One may be completely certain in the determination if one also takes into consideration the form and size relationships of the bast cells, the form and size of the crystal-bearing cells, and finally the form and size of the crystals themselves.[1]

Jute, too, is easy to recognize, namely by the uneven thickening of its walls, which, like its strong lignification, it admittedly shares with several other fibers. But it differs from these by an exceptional homogeneity among textile objects made from bast; for even coarse jute fabrics consist only of bast cells, and are therefore free from medullary-ray cells, bast-parenchyma cells, and other accessory constituents occurring in most spinning fibers.[2]

By its enormous dimensions, the fiber called "China grass" — bast cells of Boehmeria nivea — and ramie fiber — from Boehmeria tenacissima — are distinguished from almost all other vegetable textile raw materials.

Fig. 10.

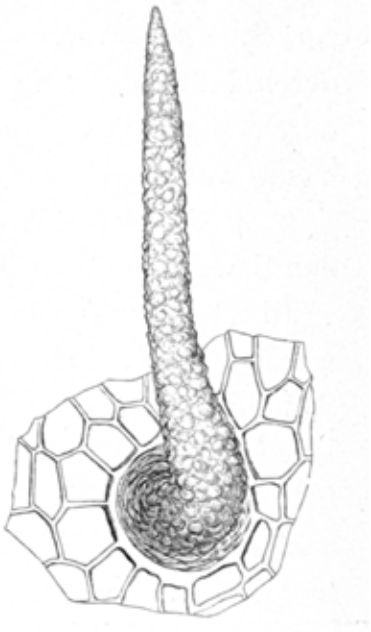


Fig. 10.
Magnification 300.
Hair from the stem of hemp with an epidermal fragment.

[1] For more detail, see Wiesner, Rohstoffe, p. 459.

[2] On the characteristics of jute, see Wiesner in Ausland, 1869, p. 830 ff. On this and similar fibers, see Rohstoffe, p. 393 ff.

The former reaches the unparalleled length of 22 centimeters, and the latter is also several times longer than the bast cells of the other vegetable spinning fibers. The thickness of this bast cell is also exceptional and is, on average, three to four times that of ordinary bast cells. Admittedly, among the East Asian nettles, besides the two Boehmeria species named, there are several other species cultivated for textile purposes whose bast fibers approach those of China grass and ramie. If those fibers, which are at present still wholly insignificant for European industry, should also come into consideration in a microscopic investigation, difficulties in determination would undoubtedly arise; and for lack of the necessary data, it cannot yet be said whether determination would be practicable.

These explanations of mine will have shown sufficiently what difficulties arise when bast cells of dicotyledonous plants are to be referred back to a definite parent plant. These difficulties are often insurmountable unless the question to be decided by microscopic examination has been confined within narrow limits by establishing the provenance of the object or in some other way.

4. Cotton

Cotton is a hair formation. It consists, as is known, of the seed hairs of several species of Gossypium. Since no other vegetable hair formation exists[1] that can be used like cotton for textile purposes and for papermaking, this fiber, especially in an uninjured state, can be detected with complete certainty, and indeed already on the basis of those characteristics that mark it as a hair formation. Just as easily and surely as a bast cell can be recognized as such, a vegetable hair can be recognized as such. But once the observer has recognized a fiber as a bast cell, hundreds of possibilities confront him; here, the class distinction alone already determines the kind of fiber.

One usually contents oneself with declaring a fiber to be cotton if it is twisted like a corkscrew; and on this basis Thomson and Bauer, as I showed above, declared that the mummy garments could not have been woven from cotton. Thin-walledness and strong flattening are also frequently given as characteristics of the cotton fiber.

But I have already shown earlier that these characteristics cannot be regarded as rationally chosen, since they have nothing to do with the nature of cotton as a vegetable hair; that these peculiarities can also occur in bast cells; indeed, more than this, that the cotton fiber can also be quite straight and very thick-walled.[2] I must add, moreover, that in paper the linen fiber too may appear twisted in places.

[1] On other vegetable hairs that are used practically — wool of the silk-cotton trees and vegetable silk — see Wiesner, Rohstoffe, pp. 350–359. I have only to add to the statements there that none of these materials has proved suitable for textile purposes, and that all attempts to use these far too delicate or too brittle fibers for papermaking must be regarded as completely unsuccessful.

[2] Wiesner, Rohstoffe, p. 340.

The most decisive, and therefore the most rational, characteristics of cotton are to be sought in those histological peculiarities through which it is marked as a vegetable hair. As such, every cotton fiber has two unequal ends, just as every cone has one broad end and one tapering end. Essentially, every cotton hair is also a cone strongly elongated lengthwise, whereas the linen fiber resembles a cylinder pointed at both ends. The flat end of the cotton fiber is open; the pointed end is closed. This very conspicuous property, observable in every uninjured cotton fiber, is never taken into consideration in microscopic fiber examinations; and yet there is no simpler or surer means of detecting, or excluding, cotton than this.

Admittedly, to use this property it is necessary that the fiber be preserved along its entire length.

I will note here at once that, on the basis of the characteristics already mentioned, cotton can easily be excluded in the examination of mummy-cloth fibers. In these objects it is easy to show that every fiber uninjured lengthwise — and such fibers occur very frequently — has two pointed ends. In the long-fibered sorts of the Faiyum papers, too, one can show immediately, by demonstrating fibers pointed at both ends, that bast fibers are contained in this writing material, and that the assumption that these papers consist entirely of cotton fibers cannot be correct.

Another no less important characteristic is the cuticle, that fine little membrane which covers the epidermal tissues of plants and can occur only on plant fibers that are epidermal formations. But apart from hairs there are no other fiber-shaped epidermal formations. The cuticle is therefore characteristic of the cotton fiber.

It forms a fine membrane that is granular or irregularly spirally streaked. As I showed some time ago, the cuticle of cotton appears most sharply when the fiber is prepared dry, that is, when it lies between the preparation glasses — slide and cover slip — without any liquid. But even on fibers prepared in water or alcohol it always appears, often very clearly; only on the finest "silky" cotton does it appear indistinct when prepared in liquids. By cuprammonium hydroxide, the cuticle can be separated from the remaining bodies of the hair. Then, while the rest of the cell wall swells strongly and finally dissolves, it is either thrown off partly in the form of shreds, or pushed together in places, where strong blister-like swellings of the fibers arise over those places.[1]

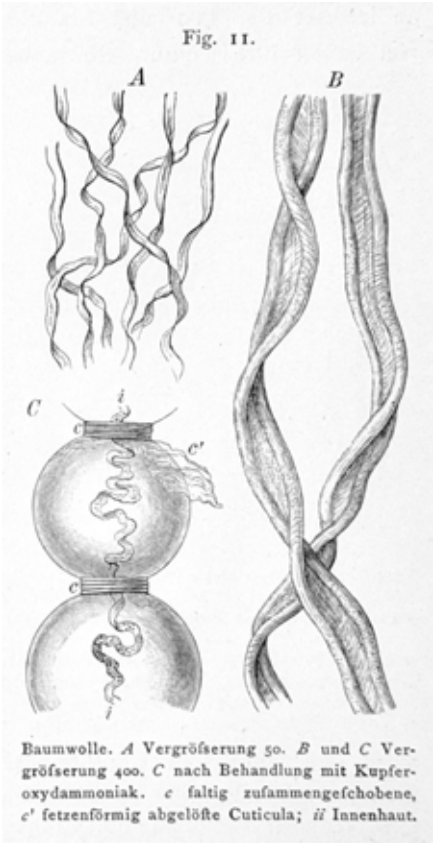


Fig. 11.
Cotton.
A. Magnification 50.
B and C. Magnification 400.
C after treatment with cuprammonium hydroxide.
c cuticle pushed together in folds;
c- cuticle detached in shreds; ii inner membrane.

[1] Technische Mikroskopie, p. 63.

The microscopic characteristics communicated here are fully sufficient to distinguish the uninjured cotton fiber from all other spinning and paper fibers.[2]

A strict separation of the bast cells, as we have seen, is generally connected with great difficulties, and these difficulties increase still further when the fibers have been subjected to strong mechanical injuries. Such mechanically badly damaged fibers are not rare in fabrics, and are quite common in paper.

The cotton fiber is, on the whole, more resistant to such attacks. It does indeed tear more easily than hemp and flax fiber, but in stamping, grinding, etc., it retains its texture much longer. Thus it comes about that it is almost always found in fabrics in a well-preserved state, and also appears better preserved in paper than the bast fibers named.

In the examination of paper, particular attention must be paid to the phenomena of mechanical destruction of the fibers. Neglect of this part of paper testing is the chief cause of the uncertain and erroneous results at which many observers have arrived.

I was the first to draw attention to this subject, and in Technical Microscopy, p. 220 ff., I attempted to summarize the most important destruction phenomena of flax, hemp, and cotton fibers. Even then I pointed out that the wall of cotton fibers often retains its texture even after very severe mechanical attacks and, though broken into pieces, still shows the double contour of the cell wall. It is then admittedly traversed by oblique, that is, spirally running clefts and fissures, which, when they occur abundantly, give it a spirally striated appearance.[3] On the other hand, I showed that the linen and hemp bast cells, even under only slight mechanical attacks, are so abundantly split lengthwise that they acquire a parallel-striated appearance and, under further injury, appear frayed. The relatively more brittle character of the hemp bast cell is recognizable in the relative shortness of the split fiber. Yet these differences between the frayed hemp and flax bast cell are only gradual.

Fig. 12.

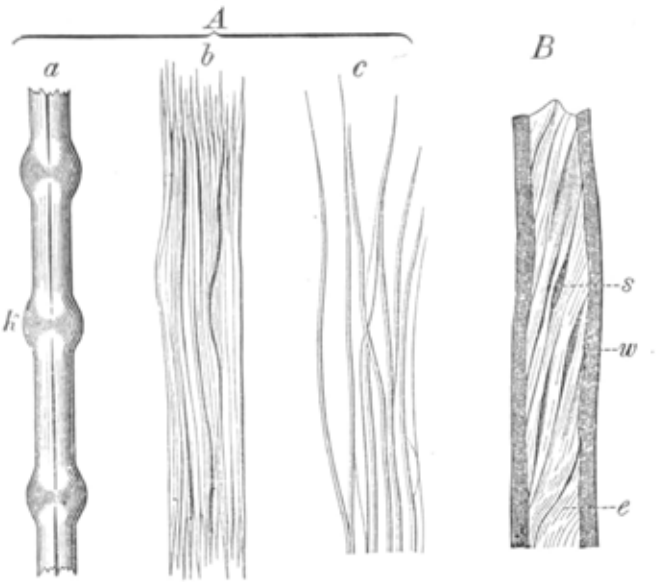


Fig. 12.
Magnification 300.
A. Mechanically attacked linen fiber.
a with node from twisted yarn; b split, c frayed fragment of a linen bast cell from paper.
B. Mechanically attacked cotton fiber, fragment.
w cell wall; s fissures; e cuticle.
From Technical Microscopy, p. 221.

[1] Technische Mikroskopie, p. 63; Rohstoffe, p. 341 ff.

[2] Through which morphological peculiarities the different kinds of cotton can be characterized, I have attempted to set out in Rohstoffe, pp. 335–345. Such a far-reaching distinction does not lie within the plan of this treatise, and I therefore do not go further into this subject here.

[3] See Technische Mikroskopie, Fig. 120B on p. 220.

I had already at that time also drawn attention to the formation of nodes in linen fiber as a result of mechanical attack. The nodes are formed at those places in the fibers where the cohesion of the particles is weakest, and which at first reveal themselves as very narrow, more or less exactly transverse stripes of the cell wall. Schacht and I formerly explained these stripes as pore canals.

The matter, however, is more complicated than it appears at first glance. As narrow transverse bands on the natural bast cell there often appear the remains of cross walls of bast-parenchyma cells adhering to the bast cells. If one presses or twists the fiber, then more or less numerous delicate transverse stripes and lines appear; or, under stronger mechanical attack, the nodes mentioned earlier appear, which arise through transverse folding or buckling of the thickening layers of the cell wall. The nodes are certainly an artificial product; but whether all transverse lines — stripes — first arise artificially, or whether some of these stripes can arise, or all of them arise, already in the living plant as a result of tension conditions, remains undecided.[1]

In no case, then, are the nodes to be regarded as natural peculiarities of the bast cells. Nor do they occur only in linen fiber, but also in hemp fiber and numerous other bast cells. They therefore cannot be regarded as characteristics of linen fiber, as Fr. Bauer believed.

In order to be able to determine the fibers of the Faiyum papers with the greatest possible certainty, I subjected the destruction phenomena of the flax and hemp bast cells, and also of the cotton fiber, to a renewed detailed examination.

I found, first of all, that under mechanical attack that is not too severe the cotton fiber is scarcely altered at all, while the two named kinds of bast cells undergo very considerable alterations under the same conditions. If, for example, cotton fibers gathered together in bundles are twisted — that is, subjected to a procedure such as occurs in spinning and especially in twisting — the fibers appear fairly unchanged, whereas in linen bast cells treated in the same way numerous "stripes" already appear, and here and there nodes as well. The hemp bast cell behaves similarly. Even under moderate pressure, numerous transverse lines — stripes — appear on the flax and hemp bast cell, while cotton under the same conditions shows no noticeable alteration.

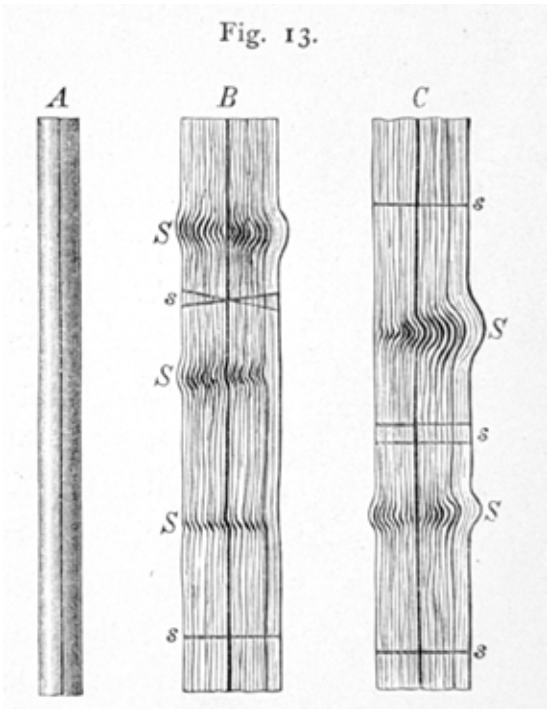


Fig. 13.
A magnified 200 times; B, C magnified 400 times.
Fragments of linen fibers.
A in completely uninjured condition.
B and C mechanically attacked.
ss "stripes"; SS "nodes."

[1] Later note: Von Höhnel, in his above-mentioned work, p. 10, described these stripes as "displacements of the cell wall" and is of the opinion that they always arise already in the living plant through uneven tissue pressure. Von Höhnel also indicated these displacements for other bast cells in Pringsheim's Jahrbücher für wissenschaftliche Botanik, vol. XV, p. 311.

Furthermore, I found that in grinding, cotton fiber often comes so close in external appearance to linen fiber treated in the same way that an observer not exactly familiar with the morphological conditions of the natural and mechanically attacked fiber can thereby be led into serious confusions. Nevertheless, even strongly ground cotton fiber can generally still be securely distinguished from a bast cell of flax or hemp mechanically attacked in the same way. On the other hand, it is only rarely possible to distinguish linen fiber from hemp fiber in the stamped or ground state with complete certainty. This succeeds only when the accessory constituents of hemp and flax fiber mentioned above — epidermides, etc. — are still present, or when the inner membranes are still well preserved and can then be demonstrated by gold chloride, in which reagent these cell-wall parts take on a deep red-violet color after 12 to 24 hours; or finally, when forked fiber ends can be demonstrated, in which case the presence of hemp fibers may be concluded.

If cotton is stamped with water in an iron mortar with a heavy pestle, it is certainly broken into pieces, but otherwise the wall remains well preserved: outer and inner wall of the cell membrane can be seen sharply almost everywhere. The wall appears obliquely striated almost throughout. If it is rubbed — ground — in a mortar after moistening with water, it breaks down into small pieces; but here too the wall otherwise remains well preserved, so that one can usually clearly see the outer and inner contour of the cell membrane. Yet the wall is very strongly loosened, split in many places, mostly obliquely striated, here and there almost parallel to the cell axis, so that in the latter case it gives the impression of a stamped or ground bast cell of flax or hemp. Still, with attentive observation one will be able to determine the fiber securely from the presence of the cuticle, best established by cuprammonium hydroxide, and from the double wall contour — especially if one follows each fiber fragment along its entire length, in which case one will almost always find places that reveal the true nature of the fiber.

The stamped or ground cotton fiber is much broader than the intact fiber. The cotton fiber used for the experiment had a natural maximum width of 0.019 to 0.027 millimeter; in the ground state the maximum fiber width rises to 0.029 to 0.049 millimeter.

If linen or hemp fiber is stamped, it presents, in essence, quite a different image from cotton fiber treated in an analogous way. Very soon after the beginning of stamping, the fiber becomes striated lengthwise, as the thickening layers of the cell wall break apart; and in place of the "stripes" that appear very early in this procedure, nodes come into view. The maximum diameter of the fibers — in the normal state generally not exceeding 0.026 in flax and 0.028 millimeter in hemp — often rises in the stamped fiber to 0.06 millimeter. The inner membrane detaches itself from the neighboring thickening layers as a tube winding back and forth, and is especially easy to make visible after the action of gold chloride solution.

Fig. 14.

Magnification 300.
Fragment of a mechanically — by grinding — strongly attacked linen fiber, appearing cotton-like as a result of spiral twisting. s "nodes"; a outer, denser wall portion.

With continued stamping, more or less long strips detach themselves from the bast cells, especially at the ends produced by fracture; under the microscope these usually appear as fine fibers.

In grinding — rubbing — linen or hemp fiber, the same phenomena also arise, only with the alteration that many fibers appear twisted around their axis. In this way they not only acquire the external appearance of ordinary cotton fibers, but also resemble them in appearing obliquely striated. The diameter of the linen and bast cell rises before disintegration to as much as 0.08 millimeter, which is about five times the average diameter of the natural fiber.

On this occasion I wish to point out another means by which one can easily and quickly distinguish linen and hemp fibers on the one hand and cotton on the other, even in the stamped or ground state, provided only that one proceeds with the necessary attention.

If one allows that reagent which we plant anatomists usually call simply "chromic acid"[1] to act on linen fibers — although it is essentially a mixture of dilute chromic acid and sulfuric acid — then after only a few seconds light pressure or displacement of the cover slip leads to a characteristic disintegration of the fibers into pieces that appear cut off transversely. It gives roughly the impression of a tree trunk cut into logs by a saw. The hemp bast cell behaves in just the same way, and probably many other bast cells as well. By contrast, at the beginning of the chromic-acid action the cotton fiber breaks into irregularly bounded pieces, mostly appearing frayed, and almost immediately thereafter into a mass of small splinters.

In the cases mentioned above, in which the fibers have been strongly split lengthwise by stamping or grinding, this means can be used to advantage. As long as the fibers are still connected into a body, they show the stated behavior, however much they may be split.

Through continued action of chromic acid, every vegetable fiber finally breaks down into small elementary bodies, into the dermatosomes discovered by me.[2] Likewise, after very long continued grinding of the fiber, disintegration into the smallest cell-wall bodies finally occurs.

That an inner connection exists between the transverse "stripes" arising on linen and hemp bast cells through mechanical attack and the transverse cleavage planes produced by the action of chromic acid shall only be briefly indicated here.

5. Briquet's and Caruel's microscopic examination of old papers

As already mentioned above, Briquet, through microscopic examination of papers dating from the eleventh to the fourteenth century, reached the result that cotton papers had not existed, and that the papers examined proved to be composed essentially of linen or hemp fibers.

[1] On this reagent, see Wiesner, Technische Mikroskopie, p. 38.
[2] "Untersuchungen über die Organisation der vegetabilischen Zellwand," in the Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, vol. 93, 1885.

Against this, Paoli, in a work likewise already mentioned, spoke out against Briquet, referring to a microscopic examination of papers from the twelfth to the fourteenth century undertaken by Caruel in collaboration with Mori. This examination is said to have shown that all these papers were prepared from cotton.

The histological arguments used by the named researchers to decide the question agree essentially: these are the cylindrical form and straight extension of the linen fiber, and the flattened and twisted form of the cotton cell — properties which, as I have sufficiently shown, are not adequate for distinguishing paper fibers. The very important cuticle, the behavior of the inner membranes, and the no less important phenomena of destruction of the paper fiber, the so-called accessory constituents, etc., are not considered.

Later note. The present chapter was completed in May 1886. In the following December I received from Mr. Briquet his detailed work, published after the appearance of my communications on the Faiyum papers — June 1886 — Recherches sur les premiers papiers employés en Occident et en Orient du Xe au XIVe siècle.[1]

My results concerning the Faiyum and Ushmunein papers from the eighth and ninth centuries were unknown to Mr. Briquet when he wrote his brochure.

Since Briquet, in this new work, describes the microscopic differences used in examining papers between linen fibers, hemp fibers, and cotton more fully than in his essay La légende paléographique, I insert here a critique of his histological arguments.

To proceed as objectively as possible, I will let my critique follow his own words. What is said in his work concerning microscopic distinction is as follows:

Loc. cit., p. 45 ff.:

"As early as 1828, the studies undertaken by Heilmann had made it possible, with the aid of this instrument — the microscope — to distinguish cotton fibers from those of hemp and flax. Since that time, the progress of micrography, and in particular the use of polarized light, has made known new distinguishing traits among these different fibers.

Cotton fibers, seen under strong magnification, take the form of flattened ribbons whose edges terminate in very narrow, shining ridges; they are usually long and twisted in spirals; their ends are not pointed, but broad and rounded.

Hemp or flax fibers appear in the form of small cylinders, generally grooved, striated, or fissured lengthwise, with frequent swellings or nodosities that give them the appearance of bamboo.

With polarized light and with the aid of a linear magnification of 120 to 150, cotton can be distinguished still more easily from hemp and flax. Cotton appears"

[1] Paris, 1886. Extract from the Mémoires de la Société nationale des Antiquaires de France, vol. XLVI.

[2] See Bulletin de la Société industrielle de Mulhouse, vol. I, p. 5.

"as a narrow folded ribbon and shines with a vivid brilliance. On its surface one sees neither longitudinal striae nor transverse partitions. The fibers of flax or hemp also shine in the visual field of the microscope, but with less brilliance. Their aspect is not ribbon-like and their cylindrical form is ordinarily recognizable, except in papers whose state of preservation leaves much to be desired. Yet even in those, and whatever their age, the fibers always show slight longitudinal striae, unequal and irregularly spaced; then, at intervals, they have straight lines that cross obliquely the whole width of the cylinder. These oblique lines are remains of cellular partitions; they usually cross two by two, in the form of little trestles. These kinds of trestles or crosses are recognizable despite the vivid and varied tints that this mode of illumination gives to the fibers."

Loc. cit., p. 51:

"It is difficult under the microscope to distinguish fibers of flax from those of hemp; they differ scarcely at all except by the smaller dimensions of the former. Therefore we have not attached great importance to this distinction, since it is so likely that linen rags will usually have been mixed, under all climates, in variable proportions, with those of hemp…."

By means of the characteristics given here by Briquet, one will probably be able, on the whole, to distinguish well-preserved cotton from well-preserved linen and hemp fibers. Somewhat broken, straight, and at the same time strongly thickened cotton fibers — see above, p. 32 — would, however, probably be declared bast cells on the basis of these characteristics. But when cotton and linen fibers occur in the ground or stamped state, the criteria given by Briquet no longer suffice. For then, unless attention is paid to the characteristics I have indicated, no decisive differences arise; and polarized light is then of no use either, because the brightness of the glow in the dark field of the polarizing microscope is fairly similar when the fibers are examined in a state of strong mechanical attack — and that is precisely the case in microscopic paper testing.

Briquet's description of linen or hemp fibers is incorrect in several respects. In particular, his assumption of cloisons cellulaires — "cellular partitions" — that are supposed to cross the bast cells shows that the author is not versed in plant histology. The bast cell is, as the name already says, a single cell; it can therefore have no partition walls. What Briquet calls cloisons cellulaires are either the "stripes" named above, or the nodes forming in their place, perhaps also the remains of adhering bast-parenchyma cells. Since Briquet examined his objects at very low magnifications, it is reasonable to assume that what he calls cloisons cellulaires was histologically very heterogeneous.

A serious distinction between linen and hemp fibers is not attempted by Briquet. He merely states that it is difficult and rests only on the difference in the size of the cross-sections. But I have shown that this distinguishing feature fails completely in the examination of papers, and indeed whenever mechanically badly damaged bast fibers are to be distinguished; and that quite different morphological peculiarities must be used to establish the quality of the fibers — though even these are applicable only up to a certain limit.

Mitteilungen aus der Sammlung der Papyrus Erzherzog Rainer, 1887, vols. II and III.

Thus enough cases still remain in which it cannot be decided whether linen fiber or hemp fiber is present.

Despite this wholly insufficient distinction between the fibers named, the tables of Briquet's treatise, which contain the results of the paper examination in detail, state without reservation whether the particular sample contained linen or hemp fiber. That, moreover, many papers are said to be mixtures of linen and hemp fibers makes — to put it mildly — the reliability of his microscopic findings appear very doubtful.

That Briquet believes he has found linen or hemp fibers with such great certainty in all old papers, and that, given the inadequacy of the criteria he applied, scarcely any doubt arose in him as to whether the fibers he saw might not after all have been cotton, evidently has its reason in the fact that he must always have used intact cotton for comparison. This does in fact shine more intensely between the crossed Nicols of the polarizing microscope than intact hemp or linen fibers. But if Briquet had chosen stamped or ground cotton for comparison, as seems necessary for the purposes of paper examination, he would certainly have felt the need to find new and sharper criteria than those he selected.

May Mr. Briquet forgive me if I meet his histological investigations with such sharp criticism, which perhaps, in view of the circumstance that we agree in one of the most important final results, may not appear justified. But in proceeding critically, I by no means diminish the value of the results contained in the historical part of his investigations; and in essence I proceed as he does. He too has challenged what appeared to him incorrect in the results of historical research, and has removed much with full justification. Just as Briquet, from his certainly deep historical researches, derives the right to criticize historical investigations concerning old papers, so I, as a natural scientist, feel equally entitled and obliged to apply the critical probe to defective publications concerning the material examination of paper.

It is indispensable to exercise criticism here as there; otherwise a final solution cannot be brought about to the so complicated and so long-protracted question concerning the nature of old papers.

Third Chapter

Examination of the Sizing of Paper

The importance that knowledge of sizing possesses for judging paper has already been set out above, p. 2.

From the technical side, due weight has always been attached to this subject. By contrast, palaeographers have not appreciated the significance of the conclusions to be drawn from the sizing of —

paper that arise from sizing sufficiently; only Mr. Briquet struck the right path in this respect as well. He showed, namely, that those old papers that had previously been mistakenly regarded as cotton papers differ from later ones not by the quality of the fiber, but chiefly by the sizing.[1]

The methods used by technologists for determining the sizing material consist in the ordinary qualitative and quantitative determination of the substances used for sizing. Apart from starch, which is so easily recognized by iodine solution, they can of course be applied only when larger quantities of paper are available. But this is usually not the case in the examination of old papers. Here one must make do with pieces of a few square centimeters in area, often with still smaller fragments. It is therefore necessary to find a way to reach a secure decision even with so little material.

Obviously Briquet must have used such methods, for from the old archives only small paper samples were certainly available to him. Unfortunately, he did not touch, even in a word, on the important question of how he detected tragacanth, resin, and glue.[2]

I shall now show how, by means of several reagents, one is able to call forth color reactions in every small piece of paper that, as a rule, permit a secure conclusion about the sizing material — naturally assuming that it is still present in sufficient quantity and in an undecomposed state. I shall indicate exactly in which cases the reactions I give do not prove reliable, and I hope to show that the results obtained on the basis of my method completely resolve the question of the sizing materials of old papers. As for those of modern papers, we are in any case sufficiently informed.

For detecting animal glue in paper, I have for years[3] used the well-known reagent for albuminous bodies, namely Millon's reagent — mercuric nitrate.

It is necessary, however, to use this reagent with particular caution, so as not to be misled by it. Since nothing is known about the detection of glue in paper except my brief note in Technical Microscopy and in the Communications from the Collection Papyrus Archduke Rainer, and since the subject nevertheless has great importance in the examination of papers, I will communicate my experiences here.

[1] Recherches sur les prem. pap., Paris, 1886, p. 41.

[2] Briquet, loc. cit., p. 41 ff., provides numerous data on the sizing of old papers. The oldest of the papers he tested in this respect come from the eleventh century; they are said to have been sized partly with tragacanth and partly with resin. Papers from the twelfth century he found sized partly with resin, partly with gelatin — glue; papers from the thirteenth century, in addition, with glue and a mixture of glue and tragacanth. In the fourteenth century, according to his statement, resin, glue, and a mixture of resin and glue appear; in the fifteenth century, resin and glue; and in the sixteenth century only gelatin as sizing material. How far these statements are correct will be shown later.

[3] See Wiesner, Technische Mikroskopie, 1867, p. 232.

If I moisten any sample of commercial glue — for example, common carpenter's glue or the finest, completely colorless gelatin — with Millon's reagent, a rose to brick-red coloration appears even in the cold; more quickly and intensely if I warm it gently. Chemically pure glue substance, which, however, does not occur commercially and of course could not occur at all in earlier times, does not indeed show this reaction; but this is of no practical importance.

The red coloration by Millon's reagent is usually regarded as a reaction for albuminous bodies, but this is only conditionally correct. Millon's reagent indicates only simply hydroxylated aromatic groups, which are never absent in albumen, which pass from albuminous substances into commercial glue, but which may also occur independently of albuminous bodies.

Thus, if one is to infer glue from the occurrence of Millon's reaction, it is necessary to show that neither albuminous substances nor simply hydroxylated aromatic bodies are present. Albumen, apart from the so-called albumen papers of photographers, will never be found as an addition in papers. Albuminous substances, however, do occur in the form of small protoplasmic remains inside the paper fiber, while the glue added in papermaking will be found on and between the paper fibers.

Of simply hydroxylated aromatic bodies, only one needs to be considered in paper examination: namely vanillin, which forms an essential constituent of all lignified membranes, and therefore will be encountered chiefly in papers made from wood. Compare above, p. 22. The lignified membranes consequently also give Millon's reaction, but they also show the reaction with aniline sulfate and phloroglucin that is absent from albuminous bodies and glue. See above, p. 22. In this respect, therefore, every doubt can easily be excluded.

If Millon's reaction appears in paper and arises from substances occurring outside the paper fibers, then one will have to conclude that the paper was sized with animal glue.[1]

Millon's reaction presupposes a properly prepared reagent; otherwise it usually fails. It may therefore be appropriate here to give the proper preparation of Millon's reagent. A weighed quantity of mercury is treated with the same weight of fuming nitric acid, left to stand for several hours, then the liquid is mixed with the same volume of distilled water and left to stand for twelve hours, and finally filtered. The reagent prepared in this way retains its effectiveness for two to four weeks.

Detection of tragacanth as a sizing substance

Tragacanth is, as is known, a kind of gum that swells strongly in water but dissolves only slightly. When small quantities of paper are available, the most practical way to proceed in detecting this substance is as follows.

[1] Only when large quantities of starch paste are present in the paper is it not impossible that albuminous bodies occur alongside it, and indeed outside the cells, in the form of gluten, which accompanies the starch granules in small quantity in poor grades of starch. An attentive observer will immediately recognize that Millon's reaction in this case does not indicate glue.

The paper to be tested is placed in a test tube with a few drops of a concentrated orcin solution — or a small crystal of orcin — after which hydrochloric acid is added in excess and the mixture is boiled. If any kind of gum — tragacanth, gum arabic, etc. — is present, the liquid is colored violet and then an indigo-blue precipitate separates out.[1] The sensitivity of the test is extraordinarily great, so that a piece of paper one square millimeter in size, intentionally sized with tragacanth, still shows the test very beautifully. If the sizing material can be removed only by long continued action of water, one would infer tragacanth, which, because of the frequent inclusion of starch, is often also blued by iodine solution. But one need not go so far, since in testing old papers the orcin test never gives a reaction, and thus the statement that old papers were sized with tragacanth or with another kind of gum is incorrect. I shall substantiate this further below.

The detection of starch sizing is carried out, as is known, with an aqueous iodine solution, which produces a violet to blue coloration. When old papers are tested, certain precautions must be observed; I shall discuss these only in the characterization of the Faiyum papers, where I shall also draw attention to those peculiarities of some old papers that make detection by aqueous iodine solution more difficult.

Detection of resin sizing

The method I use is entirely new and should, when quantitative determinations are not specifically at issue, also render very good service in testing modern papers.

I was led to the method to be described by my assistant, Dr. Molisch, who assisted me in carrying out the investigations communicated in the final chapter in a manner deserving thanks.

Dr. Molisch recalled an older statement by Raspail, according to which resins and fats, like albuminous bodies, take on an intense red-violet color when treated with sugar solution and sulfuric acid — Raspail's reaction. In fact, resins, for example common resin, colophonium, sandarac, benzoin, and others, are colored red-violet by sugar solution and sulfuric acid. Modern papers sized with resin — aluminum resinate — give the named characteristic coloration with sugar solution and sulfuric acid.

Thus Raspail's reaction can be used to test the sizing of paper, provided that albuminous bodies and fats are excluded.[2]

In studying this resin reaction I convinced myself that the resins named above take on the stated coloration even with sulfuric acid alone. If I grind a piece of colophonium, or take several crystals of abietic acid, or sandarac or benzoin in a reduced state, and treat each of these substances with concentrated sulfuric acid, I obtain in every case, especially sharply in the presence of cellulose,

[1] On this reaction, see Wiesner, "Über das Gummiferment," Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, mathematical-natural science class, vol. 92, 1885.

[2] Ground-wood paper is colored so intensely dirty green by sulfuric acid that the resin reaction occurring alongside it is completely covered. For rag papers, however, and in general for all papers consisting of non-lignified fibers, the reaction named is quite usable.

which is converted into sugar by sulfuric acid, a red-violet coloration. By this observation I am in a position to simplify my method greatly. Namely, I need only drip one drop of sulfuric acid onto the paper to be tested in order to find whether resin was used for sizing or not. If the paper — rag paper, or another paper consisting of non-lignified fibers — does not turn red-violet, then certainly no resin sizing is to be assumed. If the coloration does occur, however, one must make sure that albuminous bodies or fats are not present, which, when sulfuric acid is used, would necessarily give Raspail's reaction, since sugar is produced by the action of this acid on cellulose; thus all the conditions for the occurrence of Raspail's albumen reaction would be present.

In the final chapter I shall show, contrary to Briquet's statement, that neither the old Oriental nor the old European papers were sized with resin; rather, resin sizing came into use only in our century.

Fourth Chapter

Examination of the Faiyum Papers

1. Characterization of the Faiyum Papers

The number of paper leaves and paper-leaf fragments contained in the collection "Papyrus Archduke Rainer" already amounts, although not all pieces of the great Faiyum treasure have yet been sorted, to many thousands. I had the opportunity to examine all the characteristic pieces of the collection, and those especially important with respect to age. I found that all these papers agree with one another in their essential properties; above all, that they were produced from the same material — rags — and that the kind of sizing also seems to have been the same, since in all paper sorts in which the sizing mass could still be established with certainty, starch paste or its decomposition products could be detected as such.

In this section I shall first characterize the appearance of these papers, then the "sizing" and "filling" of these writing materials, and finally gather together all those observations that seem important to me and that relate to the "fiber" of these objects.

As for the thickness of these papers, it mostly corresponds roughly to that of ordinary handmade felted papers and, according to measurements obtained microscopically, varies between 0.17 and 0.56 millimeter. The thinnest, for example no. 39 — fourth century H., tenth century A.D. — I found dense and fairly smooth; the others rough to felt-like. No. 38 — fourth century H., tenth century A.D. — for example, has medium thickness.

[1] Outside the parentheses are the numbers under which the object in question was entered in the archducal collection. Inside the parentheses is the century or year in which the paper was written on, according to the Hijra — H. — and according to the birth of Christ — Chr.

Among the thickest belongs no. 476 — fifth century H., eleventh century A.D. The felt-like character is probably not grounded in the original nature of the paper and may perhaps be only the result of later external influences. Yet this view may also be mistaken, since on many such papers one can still write even with ordinary ink, though not without difficulty because of their great roughness.

Color. All the papers possess a peculiar color. I would describe it as Isabella-yellow to the brown of tinder fungus. The individual pieces naturally do not agree in shade. Some pieces are very light in color — no. 1311, fourth century H.; others are darker — for example, no. 981, fourth century H.[1] Poorly preserved, worm-eaten leaves — no. 351, fifth century H.[2] — are brown and very uneven in color. In general, those pieces on which the writing, undoubtedly black at first — see the later section on the inks with which the Faiyum papers are written — has become dirty brown show stronger coloration than the others. From this it may probably be inferred that the coloration of the papers was not an original property, but rather should be regarded as a consequence of later influences.

The fibers of the Faiyum papers can easily be freed from the yellow or brown pigments by chromic acid. After such treatment, only cellulose remains.

The question arises what kind these coloring substances are. The amount of paper available for examination was too small to allow a detailed investigation of the pigments. What could be established under the given conditions is the following.

Only a small part of the pigment dissolves in cold water, somewhat more in boiling water. It goes almost completely into solution if one boils the paper for a longer time in a solution of sodium carbonate. If the solution thus obtained is concentrated on the water bath, it takes on a honey-brown color. Hydrochloric acid precipitates from this solution an organic substance in the form of brownish flakes, which dissolves in sodium carbonate. Deep-brown papers do not give up their pigment completely to water and sodium carbonate, but are freed from it completely only by boiling in potash lye. From the alkaline solution a flocculent precipitate can again be separated by hydrochloric acid. All these facts, and also the circumstance that plant fibers exposed for a long time to the action of air and moisture are partially transformed into humin substances, permit one to assume with great certainty that the coloration of the Faiyum papers is to be traced to a humification process, in which three kinds of humin bodies were formed: those soluble in water — crenic and apocrenic acid; those that go into solution only in an aqueous solution of sodium carbonate — humic acid or geic acid, or both; and finally those that are dissolved only by solutions of caustic alkalis — humin or gein, or both.

[1] In order to characterize the color as precisely and objectively as possible, I compared the leaves in question with Radde's large international color scale, Hamburg, 1877, which contains 42 gamuts in 900 constant color tones. Paper no. 1311 corresponds to gamut no. 33 — brown — letter s. Paper no. 981 corresponds to gamut no. 33, letter L.

[2] Gamut no. 33, letters s to o.

What the original color of the Faiyum papers was can no longer be determined with certainty. Yet for the following reasons I consider it probable that these papers were white or nearly white after their completion.

The papers consist of fine fibers, for the most part isolated bast cells. When a bast tissue is broken down into its elementary constituents — cells — whether by atmospheric influences or by artificial means, the latter usually already appear fairly colorless, since in the breakdown the substances contained in the cell walls alongside cellulose, including the pigments, are destroyed. If this process is carried very far, as in bleaching, nothing finally remains but cellulose, in a pure white color. This far, however, one did not go in producing the papers, as is already shown by the circumstance that some bast cells are still wholly or partly connected with others, and here and there even other tissue remains still adhere to the fibers. The paper pulp thus reduced may have had a grayish or gray-white color. But it was then, as I shall show more precisely later, sized with starch paste. By this starch sizing alone the papers gain in whiteness. But I shall show that ungelatinized starch was also added to the papers, by which a further very considerable increase in whiteness must have been brought about. There is therefore scarcely any doubt that at least the better sorts of the Faiyum papers originally had a white or nearly white color.

2. The sizing of the Faiyum papers

It has already been mentioned in the introduction that the Faiyum papers were sized and, for the most part, are still writable now; they are therefore in a condition that permits the search for the sizing substance.

According to technologists, the sizing of paper was at first carried out with glue; hence the expression "sizing" — literally, "gluing" — is used for the procedure of making paper writable. Only at the beginning of our century, they say, did resin sizing — vegetable-mineral sizing — replace "animal sizing."[1] The use of starch in this procedure — as an addition to resin sizing — is described from this side as an invention belonging to the new period of machine-paper manufacture.

The statements of the palaeographers do not agree with this. According to Briquet, resin and tragacanth are said to have preceded glue as means of sizing. See above, p. 41.

I first convinced myself that resin could not have served for sizing the Faiyum papers. Even the sulfuric-acid test given above, p. 43, gave a negative result. But I did not content myself with this; instead, I collected enough material to test directly for resin. The paper cuttings I collected were extracted directly with ether, benzene, and absolute alcohol, and then after pretreatment with hydrochloric acid; but in no case did I obtain a resin extract.

[1] On the invention of paper sizing by means of aluminum resinate by Illig, see Ersch and Gruber, loc. cit., p. 112, where it is also stated that this important invention became known only in 1827.

The Faiyum papers do not give Millon's reaction, from which it follows that they were not sized with animal glue. In a few papers, a reddening did indeed appear microscopically in places, but this came from small quantities of gluten, whose presence in our papers will later be fully explained.

Since tragacanth is said to have been used in the Orient for sizing paper, and since it often takes on a violet color with iodine solution as a result of the frequent occurrence of starch granules within this kind of gum, I studied the behavior of the Faiyum papers toward iodine solution. All better-preserved Faiyum papers did in fact become violet with aqueous iodine solution. But this proves only the presence of starch — or starch paste — in the paper, and it remained to decide whether tragacanth or starch paste was present as the sizing mass. By means of the orcin test named above, p. 43, one is able to establish the presence of tragacanth. In applying this fine reaction I obtained entirely negative results, from which it follows that tragacanth could not have been used for sizing the Faiyum papers.

But I shall now provide direct proof that the violet and blue coloration taken on by the papers moistened with aqueous iodine solution comes from intentionally added starch.

When those Faiyum papers that give a distinct blue or violet coloration with aqueous iodine solution are examined under the microscope, one finds in many of them numerous starch granules in such an uninjured condition that one can actually determine them and recognize them as cereal-starch granules. I shall return to these starch granules in the part of this treatise devoted to the "filling" of the papers. Here the presence of these starch granules is cited only as proof that the sizing was carried out with starch paste and not with tragacanth.

I tested all Faiyum papers accessible to me with iodine solution and found that among them some show the most pronounced blue coloration and others show no trace of blue or violet coloration. From one extreme to the other I saw all possible transitions, and this circumstance alone makes it highly probable that all Faiyum papers were sized with starch, but that the sizing mass was preserved in varying degrees.

This assumption is confirmed by the following observations.

The iodine reaction for starch fails under certain conditions. It does not occur when the starch or starch paste is in an alkaline-reacting liquid; it also fails in the presence of ferments, both organized ferments — for example yeast, many, perhaps all bacteria — and unorganized ferments, the so-called enzymes, such as diastase, etc.[1] In both cases, the presence of starch can be demonstrated with iodine if the sample is first treated with hydrochloric acid. In fact, all those Faiyum papers that are already colored more or

[1] Compare, on the suppression of the iodine blueing of starch, my above-cited treatise on the gum ferment, p. 46 — offprint p. 7.

less distinctly blue or violet directly by iodine solution are colored intensely blue or blue-violet by iodine solution after previous treatment with hydrochloric acid. But numerous papers that did not react directly to iodine also give the starch reaction after previous treatment with hydrochloric acid.

The circumstance that prevents the iodine-starch reaction in the Faiyum papers could be decided easily and securely. None of the papers shows the slightest trace of alkaline reaction. But on the fibers of most papers — especially abundantly on those that are colored neither blue nor violet by iodine — there is a mass of small ferment organisms — micrococci and small yeast-like formations — and these are undoubtedly what prevent the iodine reaction for starch in our papers.

Some of the papers take on neither a blue nor a violet color even after pretreatment with hydrochloric acid; in these there is certainly no trace of starch or starch paste.

Of these papers, some are colored more or less distinctly reddish — wine-red — by iodine; others are not colored at all. The wine-red color, and several other peculiarities that I pass over here, indicate that adhering to the paper fiber is that form of dextrin which, because of its iodine reaction, is called erythrodextrin. The papers that remain uncolored by iodine often contain achroodextrin.

Thus dextrin is contained in some of these papers. One can easily convince oneself that blotting paper can be brought into the "sized," that is, writable condition by a dextrin solution. This circumstance suggests the conjecture that some of the Faiyum papers may have been sized with dextrin.

This conjecture, however, is rendered irrelevant by paper no. 2176 — fourth century H. Microscopic examination demonstrates between and on the fibers of this paper all possible transitions from dried paste to achroodextrin. It must therefore be assumed that the starch paste adhering to the papers, under the influences to which these papers were exposed, was transformed more or less abundantly into dextrin. It is, after all, surprising that on so many papers the starch or dried paste has remained unchanged for many centuries.

On the basis of these observations I believe myself justified in stating that the Faiyum papers were sized with starch paste. This remained completely preserved in many papers; in others it passed wholly or partly into dextrin. I should not omit to mention that in some papers even the presence of sugar — glucose — could be demonstrated, which evidently arose from the dextrin through more advanced influences. The sugar could not be detected in the extracts of the papers by the copper test, but it could be detected by that fine reaction — with α-naphthol — recently discovered by Dr. Molisch in my laboratory.[1]

For more precise indication of what has been communicated, I cite the following data:

a) The following papers were directly colored distinctly blue or violet by aqueous iodine solution: no. 8156 — seventh century H., thirteenth century A.D.; no. 8157 — seventh century H., thirteenth century A.D.; no. 7086

[1] "Zwei neue Zuckerreactionen," Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, vol. 93.

— sixth century H., twelfth century A.D.; no. 301 — year 306 H., 918 to 919 A.D.; no. 859 — year 412 H., 1026 A.D.; etc.

A weak reaction after addition of aqueous iodine solution, more distinct after pretreatment with hydrochloric acid: no. 734 — fourth century H., tenth century A.D.; no. 1500 — fifth century H., eleventh century A.D.; no. 39 — fourth century H., tenth century A.D.; no. 1072 — year 490 H., 1097 A.D.; etc.

No starch reaction, but an erythrodextrin reaction, was given by: no. 3412 — fourth century H., tenth century A.D.; no. 3671 — fourth century H., tenth century A.D.; and no. 4885 — fifth century H., eleventh century A.D. No starch reaction, but achroodextrin and sugar reaction, in no. 1417 — fourth century H., tenth century A.D.

No reaction at all for starch and its derivatives: no. 5062 — fifth century H., eleventh century A.D.; no. 167 — year 375, Rabi I; July–August 985 A.D.; no. 384 — year 356 H., 967 A.D.; etc.
If only very well-preserved papers are taken for examination, a fairly clear relationship emerges between the sizing and the age of the paper.

I find, namely, that abundant, though not exactly strong, sizing belongs to the papers from the beginning to the middle of the tenth century A.D., and that only from then on was strong starch sizing carried out.

The papers from the ninth century are very uneven with respect to sizing; some are distinctly sized with starch paste, others more or less recognizably so. It seems as though starch sizing became established only gradually. But that strong starch sizing first arose later I should, on the basis of my observations, regard as established. As supporting pieces for this opinion I cite the following papers:

No. 974 — year 351 H., 962 A.D.; no. 165 — year 355 H., 966 A.D.; no. 162 — year 400 H., 1009 A.D.; no. 841 — year 400 H., 1010 A.D.; no. 842 — year 402 H., 1012 A.D.; no. 859 — year 417 H., 1026 A.D.; no. 936 — year 464 H., 1071 to 1072 A.D.; no. 4455 — fifth century H., eleventh century A.D.; no. 7086 — sixth century H., twelfth century A.D.; no. 8156 — seventh century H., thirteenth century A.D.; no. 8157 — seventh century H., thirteenth century A.D.; no. 5487 — year 500 H., 1006–1007 A.D.

All these papers are strongly sized with starch paste and give a very conspicuous iodine reaction.

3. The filling of the Faiyum papers

I have already mentioned above the presence of unchanged starch granules in the paper mass of our objects of investigation. This fact seems very noteworthy to me. Since starch suspended in water, during paste formation, is altered in such a way that the individual starch granules can no longer be distinguished — rather, all granules swell greatly to the point of unrecognizability and finally flow together into a gelatinous mass — the occurrence of unchanged starch granules can be explained only under the assumption that starch was added to the paste.

With what intention was the unchanged starch added to the starch paste? I will try to answer this question.

Since the introduction of machine-paper manufacture, the operation of "filling" papers has been practiced. It consists in bringing finely divided mineral substances, especially

kaolin, gypsum, barytes, and zinc white, between the fibers, in order to make the paper more substantial, and especially to make it heavier.

I believe that in the addition of starch to the paste serving as sizing mass we may see a technical procedure corresponding to "filling." Only, I think, the filling of paper with starch had less the purpose of making the paper more substantial than of making it whiter.

The starch filling of papers is in any case to be regarded as a further advance. I find it most clearly developed in papers from the twelfth to thirteenth century. As examples I cite: no. 4983 — sixth century H., twelfth century A.D.; no. 7086 — sixth century H., twelfth century A.D.; no. 8156 — seventh century H., thirteenth century A.D.

The question also seems justified to me whether the Faiyum papers were not also filled with mineral substances. For between and on the fibers of these papers there are always numerous fine granules that do not react to iodine and are for the most part incombustible. If such granules occurred in modern papers, one would unhesitatingly explain them as "filling material."

But the question posed must be answered most decidedly in the negative, for, as I shall show further below, these granules are nothing other than dust particles, which penetrated in great quantity and in a state of extraordinarily fine distribution into the interior of the paper mass and fixed themselves between and on the fibers.

It seems worth mentioning to me that in many sorts of modern Japanese papers produced from paper-mulberry bast, starch occurs as filling material; and also those fine papers known as "Chinese silk paper," used for printing the finest woodcuts and engravings, contain unchanged wheat starch, as I pointed out years ago.[1]

The detection of the "filling" of the Faiyum papers is interesting not only because it shows us that the Arabs invented this technical procedure, which one is inclined to regard as an achievement of the most recent period, but also because the discovery of uninjured starch granules in the paper mass puts us in a position to establish from which plants the Arabs prepared the starch used for sizing the papers.

The uninjured starch granules of the Faiyum papers agree completely with those of our common cereals — wheat, rye, barley. Namely, as in these, one can easily distinguish in many of our papers two kinds of granules: large lenticular ones, which on average measure about 0.03 millimeter, and small, spherical, partly flattened ones, whose diameter is about 0.006 millimeter. The cereal starch granules named can easily be distinguished from others, for example those of oats, rice, maize, potato, etc. Only by a large number of exact measurements of the starch granules can one show that a particular kind of cereal starch comes from wheat, rye, or barley. If two kinds are mixed, distinction is often impracticable.

On the basis of the micrometric investigations I carried out, I would attribute the starch granules occurring in the Faiyum papers to wheat.

[1] Technische Mikroskopie, p. 237.

The number of measurements was nevertheless too small, because of the limited material, for me to present this statement as proven. Still, in further support of my statements, I may add that the Arabs and Egyptians did not know rye;[1] consequently only the one possibility remains that the starch used for sizing and filling the papers came from barley. But the microscopic values agree only slightly with this assumption. Modern experience also shows that the preparation of starch from barley, in comparison with that from wheat, appears so little rational that it is practiced nowhere. It may therefore be assumed that the Arabs, who in Egypt had both wheat and barley available to them,[2] used the former for obtaining starch.

It is therefore, I believe, to be regarded as almost certain that the Faiyum papers were sized with wheat-starch paste.

The starch used for filling the papers was still a fairly crude product, containing gluten remains and other flour constituents, derived from the common fruit and seed coat. Such bran constituents are not rarely found in the papers, though usually not in a well-preserved state.

The presence of small quantities of gluten reveals itself in individual papers by a weak Millon's reaction of the corresponding formed constituents. Compare p. 42.

For filling and sizing the Faiyum papers, ordinary cereal starch — most probably wheat starch — was generally used, as explained above. In two kinds of paper, however — no. 476 from the eleventh century A.D. and no. 39 from the tenth century A.D. — I found a kind of starch that differs most decisively from cereal starch. It consists of granules that, in size, form, and composition, agree very exactly with those of the starch of buckwheat — Fagopyrum esculentum. Compare on this kind of amylum: Wiesner, Technische Mikroskopie, p. 206, and Rohstoffe, p. 280. I can state most definitely that these granules are identical neither with the small starch granules of wheat — or rye or barley — nor with those of oats, rice, and maize, the latter of which is, moreover, completely excluded for other reasons. Apart from buckwheat starch, I would not know how to refer the starch named to any of the known flour-yielding plants.

It would be all the more tempting to use this observation of mine to establish a hypothesis concerning the age and extent of buckwheat cultivation in earlier times, since the reports concerning the origin and earlier cultivation of this flour crop are very uncertain and have so far not been traced back farther than the middle of the fifteenth century. The names that arose in Europe after the introduction of this cereal —

[1] Compare Unger, "Botanische Streifzüge auf dem Gebiete der Culturgeschichte. I. Nahrungspflanzen des Menschen," p. 9 of the offprint, Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, mathematical-natural science class, vol. XXIII, p. 159 etc.; and IV. "Die Pflanzen des alten Aegyptens," pp. 31–33 of the offprint, loc. cit., vol. XXVIII, p. 69 etc.

[2] Compare Unger, loc. cit.

[3] Compare Hehn, Culturpflanzen, etc., 2nd ed., p. 439; and also Alph. de Candolle, Origine des plantes cultivées, Paris, 1883, p. 281 ff.

sarasin — Saracen grain — Heidenkorn, Tatarkorn — frumentum Tatarorum; Finnish tatari; Hungarian tatarka, etc. — Greek grain — German Grücken; Russian greca, grecucha, etc.; Polish gryka, etc. — have given rise to very different theories about the origin of this now so widespread cultivated plant.

I confine myself to deriving from my observation that the cultivation of buckwheat may possibly already have been introduced in the tenth century of our era.

4. Examination of the dust adhering to the papers

When one takes under the microscope any preparation made from the Faiyum papers, one sees between the fibers a greater or lesser quantity of granules of the most varied form and size. Whether these particles are to be regarded as "filling" of the paper cannot be decided by immediate inspection; indeed, it cannot at once be stated to what extent these manifold little bodies belong to the paper as such.

But a cursory comparison of this granular mass with the dust adhering to the papers suggests at least a partial agreement between the two.

In order to distinguish everything that came onto the papers from outside as "dust" and, in the course of the centuries, penetrated into the interior of the paper mass, from the true paper constituents, an exact microscopic examination of the dust is necessary. The need for such a careful examination will seem all the more urgent when one considers that in certain cases conclusions about the fibers are drawn from certain tissue constituents not identical with the fibers themselves — for example, from the occurrence of isolated, specifically formed epidermal cells and other organized companions of bast cells, whose nature is then derived as "straw fiber," as I have already stated above, p. 25.

The dust used for examination was obtained from the paper partly by shaking it off and partly by dry brushing.

Both the organized organic and the inorganic constituents of the dust document its character as "local dust": that is, as a fine-grained mass that arose at the place where the papers were kept, or not far from it, and settled on them from the atmosphere.

The organized constituents are not very different from the analogous structures of ordinary dust. The following were found: vessel fragments, epidermal cells of grasses, thick-walled isodiametric or elongated cells with contents appearing opaque, probably constituents of seed or fruit coats — buckwheat? — coarser fragments of plant hairs, and bast-like cells no longer determinable. All these structures occur in the dust only in relatively small quantity; in the interior of the paper mass, however, they are not to be found at all, so that they have nothing to do with the material from which the papers were prepared. Between these coarser parts lie numerous splinters of plant cells that can no longer be determined, and in general small indeterminable combustible particles. Such splinters are also found among the paper remnants.

Dr. Max Schuster, privatdozent of mineralogy at the University of Vienna, kindly subjected the mineral portions of the dust to a more detailed microscopic examination, and most kindly placed the following notes at my disposal:

"Between green, rose-red to brown-colored or uncolored fabric fibers — and other vegetable constituents — lie mostly angular and shapeless mineral elements, almost all of which likewise appear somewhat contaminated by coloring substances. Especially in the ashed samples this secondary coloration appears more clearly. In the ashed samples, the clay particles show the beginning of fritting and are in places somewhat baked together; some of the silicate particles show a trace of melting, while most have retained their outlines.

In the samples the following may be distinguished and determined with some probability: angular and rounded quartz particles, sometimes more strongly, sometimes more weakly polarizing, presenting a uniaxial interference image, characterized by lack of cleavage and sometimes by fluid inclusions, sometimes in a union reminiscent of granitic aggregate quartz or of chalcedony. In addition, in the dust there can certainly be established relatively numerous feldspar shards, quite a lot of orthoclase extinguishing straight, little plagioclase with twin lamellae, both with distinct cleavage cracks and in places with rectilinear boundaries. All the constituents just named are colored wholly — clay particles — or only in places — quartz, feldspar — by iron hydroxide.

Pale-yellowish to yellow-green and dark-brown little flakes, remaining dark in polarized light between crossed Nicols, mostly rounded but also jagged, are to be regarded as more or less bleached magnesia mica. Alongside this, however, some lighter potash mica may also occur. Here and there are found weakly greenish-colored rhombohedra of calcium carbonate,[1] furthermore mostly lighter yellow-green, but also dark-green flat splinters and rounded columns with cleavage, smaller extinction angle, somewhat dichroic — probably hornblende fragments — then pale-yellowish little crystals with strong refraction, somewhat rounded outlines, possibly zircon, and quite isolated ore particles, probably magnetite.

The behavior when treating the sample with acids seems to confirm the stated conjectures, insofar as most particles were only little attacked; iron hydroxide went into solution; some jelly — probably silicic acid — separated out; the rhombohedra disappeared throughout, and, when sulfuric acid was used, gypsum crystals appeared in their place."

Through comparative microscopic examination it was established that the mineral parts of the dust penetrate into the interior of the paper mass in the form of small, partly extremely fine particles. What I shall immediately describe as the "incrustation" of the paper fibers comes about for the most part through the accumulation of exceedingly fine dust on the surface of the fibers.

5. Incrustation of the fibers

The fibers of the Faiyum papers are distinguished by a peculiar incrustation, which I have not yet encountered in any kind of paper.

[1] In the dust of some papers, calcium carbonate occurs in great quantity.

This incrustation is developed in different degrees in the individual papers; but even the fibers of one and the same kind of paper show various differences according to the manner of formation of the enveloping layer.

On cursory inspection one would be inclined to take the crusts lying on the fibers for a strongly developed cuticle and, on the basis of this characteristic, to declare the paper fibers to be cotton. This would be a serious error, for if one adds a drop of hydrochloric acid to the fibers prepared in water, the crusts disappear either completely or at least for the most part. See Fig. 15.

The crusts named either cover the fibers in a continuous course, or they visibly consist of variously fine and variously shaped particles that lie more or less close to one another and often leave spaces between them so broad that certain structures of the fibers — for example transverse stripes — can be recognized.

It is very natural to assume that these incrustations derive from the sizing of the paper. But this assumption too is not correct, as papers nos. 2 and 3 teach.

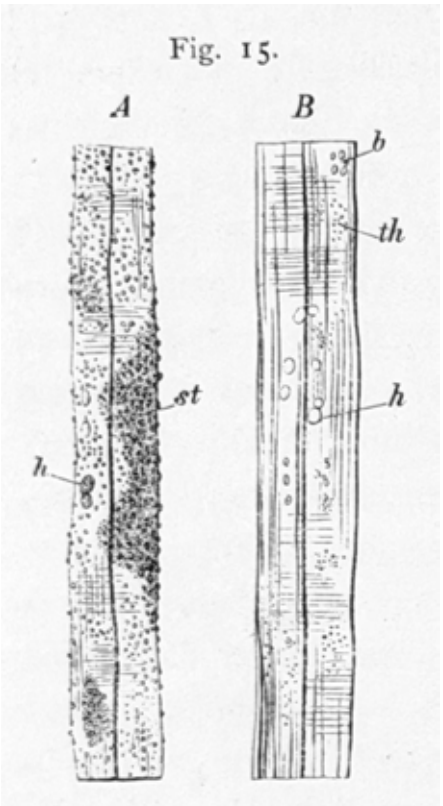
These two numbers consist, namely, of paper and an underlying silk fabric. Between the two, as a kind of filling, there occurs a tow-like mass, which, judging by fiber and accessory constituents, is undoubtedly linen fiber. But the fibers of this tow mass are incrusted just like the paper fibers, from which it follows that the incrustation named cannot be identical with the sizing.

Since, however, the principal mass of the incrustation is composed of particles that agree with the constituents of the dust accompanying the papers, there can be no doubt that at least the principal mass of it consists of exceedingly fine dust particles that penetrated between the paper fibers and fixed themselves on their surface.

Part of the incrustation dissolves in hydrochloric acid with gas evolution, and likewise in sulfuric acid. Since gypsum crystallizes out when the latter is used, it follows that the dissolved mass was calcium carbonate. The residue consists partly of exceedingly fine mineral particles — especially clay — and partly of ferment organisms — bacteria and micrococci, and small yeast-like organisms. I shall not go into these organisms more closely here, and merely note that the behavior of the starch paste used for sizing the Faiyum papers toward iodine solution — namely, that it becomes blue or violet only after previous treatment with hydrochloric acid — is most probably to be traced back to these organisms. See above, p. 48.

This fine incrustation must not be confused with the coarser one that does in fact derive from the sizing. The paste used for sizing lies partly in more or less coarse lumps between the fibers, and partly adheres to the fibers in the form of coarser crusts — Fig. 15, st. These crusts color themselves

Fig. 15.



Magnification 300.
Fragments of linen fiber from Faiyum paper. A incrusted and in places provided with starch-paste crusts — st.
B after treatment with hydrochloric acid; of the incrusting mass there remained only: b bacterium-like organisms, h yeast-like organisms, and fine clay particles — th.

through iodine, usually directly, or at least after pretreatment with hydrochloric acid, blue or violet, and are therefore easily distinguished from the dust incrustation.

If the incrustation is removed by means of hydrochloric acid, the structural relations of the fibers emerge much more sharply, or indeed become recognizable for the first time; in any case, after this pretreatment the fibers have become more suitable for microscopic determination.

6. Length of the Fibers

If one compares the Faiyum papers with our modern handmade and machine-made papers used for writing, printing, and drawing, a very considerable difference appears with respect to the length of the fibers: the former are long-fibered, the latter short-fibered.[1]

This difference appears most clearly when the paper to be tested is moistened with water and, after the latter has been absorbed, is torn with the least possible force. At the tear one recognizes the length of the fibers.

Other old papers behave similarly to the Faiyum papers, namely those that one is accustomed to call cotton paper. But already in the fifteenth century very short-fibered papers appeared.
If one disregards modern wood, straw, and esparto papers, which are almost always short-fibered — see the note — one recognizes that the difference in the length of the fiber is entirely independent of the raw material. In every case, linen, cotton, and hemp fibers already used in woven fabric constitute the paper. The difference in the length of the fibers is undoubtedly grounded in the different preparation of the papers, and I hold the opinion that the old long-fibered papers were produced by stamping, and the short-fibered ones by grinding the rags.

I have made detailed studies of the length of paper fibers and, in what follows, select several series from my observations in order to make clear the differences that exist in this respect. The papers were carefully separated into fibers; then, after adjustment under the microscope, 30 fibers lying side by side were measured from one point in the field of view.

Faiyum paper no. 8432 — 2nd century H. = 8th century A.D. — very long-fibered.

Length: 10—20 mm.	5—10 mm.		1—5 mm.	0.1—1 mm.
15.1	9.4	5.0	0.9	
12.3	8.3	4.8	0.8	
10.5	8.0	4.8	0.6	
10.0	7.4	4.5	0.5	
-------	6.5	2.9	0.2	
13.3%	6.0	2.8	0.1	
	6.0	1.5	0.08	
	5.8	-------	0.05	
	5.8	23.3%	0.05	
	5.2		-------	
	-------		30.1%	
	33.3%			

[1] Exceptions to this are, first, the well-known modern Japanese papers distinguished by the extraordinary length of their fibers; and second, certain very modern kinds of wood paper whose fibers were obtained by chemical means and often appear very long-fibered at the tear.

Faiyum paper no. 3671 — 4th century H. = 10th century A.D. — ordinary length

Length: 10—20 mm.	5—10 mm.	1—5 mm.	0.1—1 mm.
12.5	10.0	4.5	0.8
10.6	6.5	4.5	0.7
-------	6.0	4.5	0.6
6.6%	5.1	4.5	0.4
	-------	4.5	0.3
	13.3%	4.2	0.2
		4.2	0.2
		4.1	0.15
		4.0	-------
		4.0	26.8%
		4.0	
		3.8	
		3.5	
		3.0	
		2.5	
		1.5	

		53.3%	

Faiyum paper no. 4455 — 5th century H. = 11th century A.D. — short-fibered sort.

Length: 10—20 mm.	5—10 mm.	1—5 mm.	Under 1 mm.
0%	9.8	4.8	0.9
	9.1	4.6	0.6
	8.3	4.1	0.4
	6.5	4.0	0.3
	-------	4.0	0.2
	13.3%	3.8	0.1
		3.6	0.09
		3.5	0.06
		3.5	-------
		3.4	26.7%
		3.4	
		3.0	
		2.8	
		2.6	
		2.5	
		1.5	
		1.3	
		1.0	

		60%	

Paper from the Royal Library of Turin from the year 1442:[1] copy of a document of Louis, Duke of Savoy, from the year 1442.

Length:	10—20 mm.	5—10 mm.	1—5 mm.	Under 1 mm.
	0%	0%	27%	73%

Printing paper from the year 1567: P. Terentii comoediae sex elegantissime, etc. Basel, apud haeredes Nicolai Brylingeri.

Length:	10—20 mm.	5—10 mm.	1—5 mm.	Under 1 mm.
	0%	3.3%	66.6%	30.1%

Modern writing paper from the year 1884 — letter paper, produced from linen and cotton rags.

Length:	10—20 mm.	5—10 mm.	1—5 mm.	Under 1 mm.
	0%	0%	30%	70%

Modern printing paper from the year 1875 — Wattenbach, The Writing System of the Middle Ages, second edition, Leipzig, 1875; printed on a paper produced from rye straw and rags.

Length:	10—20 mm.	5—10 mm.	1—5 mm.	0.1—1 mm.	Under 0.1 mm.
	0%	0%	28%	64%	8%

7. Determination of the Kind of Fiber

After removal of the incrustations described above — pp. 53 ff. — the fiber of the Faiyum papers is suitable for microscopic analysis.

That these papers are not, as would have to be assumed according to the prevailing doctrine, pure cotton papers is evident first of all from a fact very easily established in these very long-fibered products: many of the fibers are provided at both ends with natural pointed ends — or somewhat rounded, but always tapering ends. This form cannot occur at all in cotton; rather, it points to a bast fiber.

By comparing the broken fibers with those pointed at both ends, it further appears that the former are wholly, or at least for the most part, fragments of the latter. In many papers there also occur cells united into bundles — bast bundles — which otherwise agree with the other fibers and undoubtedly derive from a dicotyledonous plant. See above, p. 26.

As certainly as the fiber of the Faiyum papers could be determined as a dicotyledonous bast cell, the form-relations of these fibers alone can give little guidance concerning the parent plant, or indeed concerning the production material of the papers named. For there are extraordinarily many dicotyledonous plants whose bast cells are shaped like the fibers —

[1] Numerous so-called cotton papers examined by me agree approximately with papers nos. 3671 and 4455 in regard to fiber length. I shall, however, discuss these papers more closely only in the next chapter.

The Papers from Fayyum

The solution to our question would not have been possible at all had the condition of the fibers not clearly identified them as "textile fibers," and had the paper not contained additional components that made it possible to determine with certainty the textile plant from which the fiber originated.

Circumstances that I shall be able to discuss more fully only in the following paragraph leave no doubt that the Fayyum papers were made from woven fabrics. We are sufficiently informed about the textile plants of the Arabs and Egyptians to restrict the plants under consideration to a very small group.

As we have seen, the fibers in our papers are bast cells from dicotyledonous plants. Cotton, therefore, as well as fibers from monocotyledonous plants, can be excluded. This leaves only flax, hemp, and jute—the bast fibers of Corchorus species. Hemp was not cultivated in Egypt, although it was grown in Arabia. The jute plant was known both to the ancient Egyptians and to the Arabs; however, only the species C. olitorius was cultivated, and it is mentioned only as having been used as a vegetable.[1] By contrast, there can be no doubt about the extensive use of flax as a textile plant in Egypt and Arabia. If one assumes that the raw material of the Fayyum papers came from Egypt, only flax would need to be considered. It cannot, however, be ruled out that the papermaking raw materials were of Arabian or, more generally, Eastern origin. In that case, hemp would also have to be included in the inquiry.

Jute fiber can be disregarded entirely. Even supposing that the jute plant had been used for textile purposes in Egypt or Arabia—although there is no evidence for this—the fiber does not occur in the Fayyum papers. It differs so conspicuously from hemp and flax both in form and chemical character; see above, page 31.

The investigation therefore needed to concern itself only with flax and hemp. When the well-preserved paper fibers are selected for closer examination, the findings point much more strongly to flax than to hemp. For the reasons given above, however—pages 27–31—the properties of the bast cells alone do not permit the origin of the fibers to be determined with certainty, at least through microscopic examination of the paper.

I was fortunate, through investigations that were admittedly extremely laborious and time-consuming, to discover enough tissue components from the original plants to identify the fiber with absolute certainty in at least some of the papers. Of approximately seventy varieties of paper examined, I was able to demonstrate components of the linen stalk—the flax stalk, or stem of Linum usitatissimum—in fourteen.

For example, in papers no. 5277, sixth century AH, equivalent to the twelfth century CE; no. 351, fifth century AH, equivalent to the eleventh century CE; no. 163, dated 305 AH, or 917–918 CE; and no. 233, dated 356 AH, or 967 CE, I found fragments of the epidermis of the flax stalk and detached masses of its cuticle.

I also found woody portions of the vascular bundles of the flax stalk, containing tracheids, pitted vessels, and spiral vessels, in papers no. 4776, fourth century AH, equivalent to the tenth century CE; no. 38, fourth century AH, equivalent to the tenth century CE; no. 936, dated 464 AH, or 1071–1072 CE; and no. 974, dated 351 AH, or 962 CE.

The ends of the bast fibers in all these papers likewise indicate flax, as do those in most of the other papers.

[1] Woenig, Die Pflanzen im alten Aegypten [The Plants of Ancient Egypt], Leipzig, 1886, p. 222. The relevant sources are also given there.

Stem constituents of hemp — epidermis, hairs, and woody parts from the stem of Cannabis sativa — I was unable to find in any of the Faiyum papers. On the other hand, the ends of the bast cells from papers no. 165 — year 355 H. = 966 A.D. — and no. 860 — year 427 H. = 1036 A.D. — speak for the presence of hemp fibers, as does the weak lignification of the fibers so formed.

In most papers, however, it remains uncertain, because of excessive mechanical destruction, whether the material is linen or hemp fiber.[1] But the observations cited allow one to assume that linen rags furnished a far greater share in the preparation of the Faiyum papers than hemp rags.

Apart from the incrustations and colorations already mentioned, caused by humification, the Faiyum papers show several other peculiarities that can easily mislead anyone not fully familiar with microscopic examination: namely, the destruction phenomena of paper fibers described exactly above — pp. 34 and 35 — which are to be traced partly to the separation of the raw materials from the stem, partly to the processes of weaving and spinning, and finally also to the mechanical procedures that the fiber has to endure during papermaking itself.

In examining these papers, one must pay particular attention to the spirally twisted fibers — see Fig. 14 on p. 214 — which one is so often accustomed to interpret immediately as cotton fibers. But most of these fibers are nevertheless linen or hemp fibers, which have assumed the form named only through mechanical attack. It has been shown sufficiently above how one may guard against error in such a case.

By means of the behavior of linen and hemp fibers toward chromic acid, described above — p. 36 — it can likewise be shown in the Faiyum papers that they do not consist of pure cotton. This can also be shown by the morphological differences that result when these papers, and also cotton and linen fibers, are "pulverized" or "carbonized," which is done with one-percent hydrochloric acid and, after removal of the adhering liquid, by heating the substance to 50–60° C. In this process these fibers fall apart into an exceedingly fine mass and present characteristic structures.[2] I cannot go into this subject more closely here and content myself with referring to the original work cited below.

8. Evidence for the assertion that the Faiyum papers were produced from rags

In the preceding paragraph it was shown that the principal mass of the Faiyum papers is composed of linen and hemp fibers, mechanically attacked to a greater or lesser degree.

Many of these papers consist in fact only of these fibers; others, however, contain a small quantity of cotton fibers, for example papers no. 254 — year 322 H. = 934 A.D. — no. 485, 1336, 1498, 2155, 5019 — all fourth century H. = tenth century A.D. — no. 344

[1] I shall disregard cotton in this paragraph, since it forms, so to speak, only a secondary constituent of the Faiyum papers.

[2] See Wiesner, "Untersuchungen über die Organisation der vegetabilischen Zellhaut," Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, vol. XCIII, January 1886.

and 5019 — both fifth century H. = eleventh century A.D. Relatively much cotton was found in no. 164 — year 336 H. = 947/8 A.D. In some papers — no. 485, 4776, and 4885 — I also found here and there sheep's-wool fibers. The detection of the latter is, as is known, extraordinarily easy. By contrast, as already noted, the distinction between linen and hemp fibers and cotton in paper is accompanied by some difficulties. Nevertheless, by means of the characteristics given above, the presence of cotton in the Faiyum papers could be demonstrated with complete certainty.

Since fragments of spinning fibers are not rare in atmospheric dust, naturally including cotton and sheep's-wool threads, and since, as explained more fully above — p. 52 — large quantities of dust accumulated on the Faiyum papers over the centuries, it had to be carefully examined whether the cotton and sheep's-wool fibers demonstrated in the latter might not derive from wind-borne dust. For this purpose, before microscopic examination, the papers in question were most carefully freed of all adhering parts, and the fibers were prepared out from the interior of the papers. But even when these precautions were applied, the detection of cotton and animal fibers succeeded in the papers named above.

The overwhelmingly principal mass of the paper consists of colorless fibers, or fibers colored yellowish or light brown as a result of humification, and also of more or less divided fiber bundles. Alongside these, and also in the interior of the papers, there occur here and there fibers distinguished by very vivid colors: sulfur-yellow cotton and sheep's-wool fibers; blue-green, green, and blue cotton fibers; and finally also deeply brown and rose-red textile fibers, including silk. Which coloring materials occur in these fibers could be determined only for the blue fibers: the behavior of the coloring matter toward sulfuric acid, potash lye, and nitric acid proved the identity of the blue pigment with indigo.

Both the occurrence of cotton and sheep's-wool fibers and the presence of definitely artificially colored textile fibers in the midst of the other paper mass consisting of linen and hemp fibers allow no other interpretation than this: worn fabrics — rags, scraps, strazze — were used for papermaking; these consisted chiefly of linen, but among them were also white and colored — or incompletely decolorized — cotton rags, and, in very small quantity, even sheep's-wool and silk rags.

Should the evidence just given for my assertion that the Faiyum papers were produced from rags not be considered sufficient, every doubt must nevertheless disappear when I cite the following facts.

In numerous examples of these papers, well-preserved yarn threads were found, including in the oldest paper in the collection datable by its writing: no. 679 — about 180 H. = 796 A.D., therefore from the end of the eighth century. Very beautiful yarn threads, mostly already visible to the naked eye, were found in no. 166, 167, 2155, 3671, 5019 — all from the tenth century A.D. — and also in 351 and 2634, from the eleventh century A.D. In no. 7827 — year 355 H. = 946/7 A.D. — there are very beautiful yarn threads whose twist is already visible with the loupe.

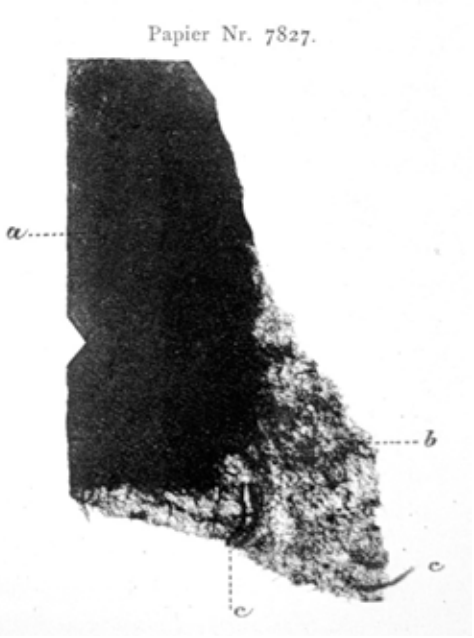
See the adjoining illustration at c. In numerous other papers, after making them transparent, more or less well-preserved yarn fragments were found by means of the microscope. In the previously mentioned no. 3671, I was even able to expose a place that still contained crossed yarn threads — that is, a remnant of a fabric with warp and weft!

The yarn pieces named consist, like the rest of the paper mass, of bast cells, which are, understandably, on the whole better preserved than the completely isolated fibers. In the papers, all transitions could be demonstrated from twisted yarn to isolated fiber; therefore there is no doubt that these, like those, come from the same raw material.

9. Examination of the ink with which the Faiyum papers are written

By ink I understand the black substance, undoubtedly applied in the liquid state, with which the Arabs wrote on their paper.

A careful inspection of the Faiyum papers must immediately lead to the assumption of two different inks. On all well-preserved papers the strokes of writing are indeed deep black; but on the browned, generally less well-preserved papers, one finds either all written characters deep black or dirty brown. One of the inks withstands all influences harmful to the paper; the other, under such influences, undergoes a change of color from black to rust-brown.



Paper no. 7827. From the year 946/947 A.D. a double-layered, opaque; b after detachment of one layer, photographed as a transparent light image; c yarn threads.

Let us first subject the writing strokes that have become brown to chemical examination.

If one passes over these written characters with a finely drawn-out glass rod dipped in hydrochloric acid, they change their color: formerly dirty and dull brown, they have now become rust-red. If one dips a finely drawn-out glass rod into a solution of yellow prussiate of potash — potassium ferrocyanide — and then passes it over the written characters already exposed to the action of hydrochloric acid, they are instantly colored intense blue. This blue color comes from iron ferrocyanide — Prussian blue — and proves that the ink with which these written characters were produced contained iron. The paper itself is not colored blue, or only very weakly blue, by hydrochloric acid and prussiate of potash; not more strongly than substances that contain only traces of iron. Such substances are, as is known, quite common.

A completely different behavior is presented by those papers whose writing strokes have retained their deep-black color even when the paper itself has been strongly altered. These strokes are not altered by hydrochloric acid; indeed, they are attacked by no reagent. Even nitric and chromic acid remain without effect. If one cuts a —

piece of paper provided with such a written character, places it on a glass plate, and adds a chromic-acid solution, then after some time one finds the substance of the paper dissolved, while the written character remains unchanged and lies sharply outlined on the glass plate. This behavior, and also the circumstance that this substance burns on platinum foil, suggests that it is finely divided carbon, probably soot; this is also supported by the extraordinary fineness of the particles into which the color of the writing can be divided.

Each of the inks examined proved to contain either iron or carbon. I observed no third kind. Thus two kinds of ink are to be assumed in the Faiyum papers.

As regards first the iron-containing ink, there can be little doubt that it contains iron tannate as the blackening constituent, and therefore agrees essentially with our gall-nut ink. The tanning of leather had long been known at the time when the Faiyum papers were written on, and certainly also the property of tannins to form black — deep blue or deep green — compounds with iron salts.

By contrast, it is unlikely that any other black iron compound suitable for ink making was known at that time. The well-preserved written characters produced by iron ink also presented me with a peculiar image under the microscope: one part appears brown, another deep blue-violet. I take the latter to be iron tannate, the former to be iron oxide hydrate formed from the tannic-acid compound.

The carbon-containing ink was undoubtedly a product similar to India ink, or to a color prepared from pine soot, whose more precise nature can now hardly be clarified. What was contained in the ink besides the black-coloring substance could no longer be determined from the minute quantities available.

Many papers are written on both sides.

Finally, I give an overview of the results concerning the quality of the inks, noting, however, that in order to spare the precious material as much as possible, I tested only part of the papers made available to me in this respect.

Written only with gall-nut ink:
No. 661 — fourth century H. = tenth century A.D.; no. 936 — fifth century H. = eleventh century A.D.

Written only with soot ink:
No. 2078 — turn of the eighth century A.D.; no. 163, 167, 254, 1309, 1311, 2716, 3412, 7827 — all fourth century H. = tenth century A.D.; further no. 205, 345, 476, 841 — fifth century H. = eleventh century A.D.

Written on both sides with gall-nut ink:
No. 2080 — third century H. = ninth century A.D.; no. 485 and 919 — fourth century H. = tenth century A.D.; no. 860 — fifth century H. = eleventh century A.D.

d) Written on both sides with soot ink:
No. 301 — beginning of the tenth century A.D.; no. 39, 164, 165, 223, 384, 731, 981, 1498, 3671, 3781, 4776 — all fourth century H. = tenth century A.D.; no. 161, 344, 1500, 2634, 5062, 8092 — fifth century H. = eleventh century A.D.; 4983, 5487, 7086 — sixth century H. = twelfth century A.D.; 8200 — seventh century H. = thirteenth century A.D.

e) On one side with soot ink, on the other with gall-nut ink:
No. 671, 2155 — fourth century H. = tenth century A.D.; 8156 and 8179 — seventh century H. = thirteenth century A.D.

Fifth Chapter

Examination of Oriental and European Papers from the Ninth to the Nineteenth Century

In this chapter, the changes undergone by the fiber and sizing materials of paper are to be described from the time when paper began to be produced on European soil, insofar as this is possible through direct material examination.

The principal questions at issue here are: 1. Has there ever been a so-called cotton paper? 2. Which sizing materials were used in succession for papermaking?

In one of the preceding chapters, the methods by which the sizing material can be ascertained have been sufficiently set out. As regards, however, the decision of whether a paper was produced from rags or not, it seems necessary to me to preface my observational results with several remarks.

Formerly a paper was declared to be rag or scrap paper if yarn threads could be demonstrated in it. Nothing could be more obvious. But it is easy to see that this characteristic will prove valid only in very crudely prepared papers; a well-worked paper stock no longer contains yarn threads. Briquet declared those papers that contain linen or hemp fibers to be rag paper, even when no yarn threads occur in them. This conclusion, however, does not seem to me justified without further qualification. For it is not impossible that the old paper millers knew a maceration process by which they were able to transform raw hemp or raw flax, or waste from flax and hemp processing — for example tow — into a finely fibrous mass.

Already in discussing the Faiyum papers I have given several important characteristics of rag papers that can be applied to all other papers.

Accordingly, I declare a paper to be a product made from rags only when the following peculiarities are observable:

Fibers of different kinds, for example cotton alongside linen fibers, etc.; or when, besides colorless fibers, others occur that clearly come from colored fabrics; or when I can demonstrate yarn threads in it. But one must not rely here on macroscopic observation. I have found that in many papers which, when viewed with the naked eye, show no trace of yarn threads, such threads can not rarely be demonstrated by the microscope after the paper has been made transparent with water — or better, with alcohol.

But I must point to a fourth, very important criterion of rag papers, which I have not yet had occasion to mention.

In rags from laundry and other fabrics there are always more or less distinct remains of starch paste, which served for starching or finishing these materials. This starch paste remains in the paper mass, though in very small quantities, and in hundreds of papers I have established its presence by the microscope by means of iodine solution — and pretreatment with hydrochloric acid; see above, p. 48.

In the following compilation I call these paste remains "starch traces." It is self-evident that this characteristic cannot be used if starch paste served as the sizing. Confusion of the "starch traces" with starch paste as sizing mass cannot occur, because in the former case the quantity of starch is very small. Under the microscope, after treatment with hydrochloric acid and aqueous iodine solution, one recognizes only here and there small blue-colored places, often only after long searching. When the paper is sized with paste, by contrast, the iodine solution at once — or, in papers that have suffered greatly over time, after pretreatment with hydrochloric acid — produces a violet to blue color already visible to the naked eye, usually very saturated and often deep.

In what follows, I give the results of the examination of more than 500 papers from the ninth to the nineteenth century. In each individual case, the arguments on the basis of which the paper was declared to be rag paper are named.

In carrying out this extraordinarily laborious and time-consuming work, I was assisted, in the most praiseworthy manner, by my assistant, Privatdozent Dr. H. Molisch. Many sizing tests were carried out by Dr. Fridolin Krasser, student of the Institute of Plant Physiology.

Ninth century

1. Cod. 298. Leiden. Dhu al-Qa'dah. 252 H. = Dec. 886 A.D.
Rag paper: yarn threads, mostly in a poorly preserved state, to be found under the microscope. Linen fibers.[1]
Sizing: not detectable; probably not present at all.

Tenth century

2. Cod. Refaya, 33. Leipzig. 380 H. = 990 A.D.
Rag paper: mixture of much linen and little cotton fiber.
Sizing: not detectable; probably not present at all.

Eleventh century

3. Cod. graec. theol. CXCIII. Vienna Imperial-Royal Court Library.
Rag paper: distinct trace of yarn threads detectable under the microscope; principal mass linen fibers, some cotton.
Sizing: with starch paste, directly detectable by iodine solution.

Millon's reaction occurred weakly. Here, however, it certainly does not indicate animal glue, but, as microscopic examination shows, gluten and mold filaments. The presence of gluten suggests that the starch used for sizing was obtained by washing and not by fermentation, and was in general of very poor quality.

[1] When, in what follows, "linen fibers" or "hemp fibers" are mentioned without one of the absolutely decisive characteristics being specifically indicated, the determination is to be regarded only as probable. In these cases it could not be established with absolute certainty whether one or the other was present.

4. Cod. 597. Leiden. From Baghdad. 489 H. = 1096 A.D.
Rag paper: here and there colored threads. Principal mass linen fibers with a trace of cotton.
Sizing: with starch paste, directly detectable by iodine.

5. Cod. Wetzst. II. 1958. Berlin. Beginning of the fifth century H. = eleventh century A.D.
Rag paper: linen fibers, hemp fibers — forked cell ends — some cotton.
Sizing: starch paste.

6. Cod. Refaya 354. Leipzig. 484 to 492 H. = 1091 to 1099 A.D.
Rag paper: linen fibers and a trace of cotton.
Sizing: not detectable, probably destroyed.

Twelfth century

7. A paper from the collection of the Institute for Austrian Historical Research at the University of Vienna, with the signature "Arab. Pap. M. S. v. 1100."
Rag paper: linen fibers with a trace of cotton.
Sizing: starch paste.

8. Another paper from the same collection, with the signature "Arab. Pap. mit Fäden, 1100."
Rag paper: linen fibers with a trace of cotton.
Sizing: starch paste.

9. Cod. CCLXI. Copenhagen. 523 H. = 1129 A.D.
Rag paper: only linen fibers. Since no absolutely certain argument for the rag nature of this paper could be found, in this case one can infer rags as the raw material only indirectly.
Sizing: starch paste.

10. Cod. CXXXV. Copenhagen. 580 H. = 1184 to 1185 A.D.
Rag paper: principal mass linen fibers, some cotton.
Sizing: starch paste, indistinct and detectable only by hydrochloric acid and iodine solution.

11. Cod. 212. Leiden. Latin-Arabic lexicon with mixed parchment and paper leaves. Twelfth century A.D. Compare Dozy, Supplément aux Dictionnaires arabes, I, Préface VIII.
Rag paper: yarn threads of linen fibers.
Sizing: not detectable.

Thirteenth century

A. Oriental papers

12. Cod. CLXVIII. Copenhagen. 616 H. = 1219 to 1220 A.D.
Rag paper: linen fibers and some cotton.
Sizing: starch paste.

13. Cod. CCLVI. Copenhagen. 648 H. = 1250 to 1251 A.D.
Rag paper: linen fibers and some cotton.
Sizing: starch paste.

14. Cod. CLIV. Copenhagen. 676 H. = 1277 to 1278 A.D.
Rag paper: linen fiber and some cotton.
Sizing: starch paste.

B. European papers

15. The Schwandner document of Emperor Frederick II from the year 1228, from the Imperial-Royal Court and State Archive in Vienna.
Rag paper: yarn threads of linen fiber. Trace of silk threads.
Sizing: starch paste, directly detectable from aqueous iodine solution.

16. A paper from the collection of the Institute for Austrian Historical Research with the signature "From Aquileia 1288, cotton-rag paper."
Rag paper: linen fibers and some cotton. Yarn threads to be found microscopically.
Sizing: starch paste.

17. Liber plegiorum comm. 1223. State Archive in Venice.

Rag paper: yarn thread, linen fiber and some cotton. According to Briquet, loc. cit., p. 61, this paper is said to consist of hemp fiber.
Sizing: with starch paste, already very beautifully detected directly by aqueous iodine solution. Briquet, loc. cit., p. 61, gives tragacanth and much resin as sizing material. Not even a trace of either could be found.

18 to 24. Volume degli atti del Podestà a Murano. Seven samples from 1279 to 1291, State Archive in Venice.
Rag paper: yarn threads; almost throughout linen fiber mixed with some cotton. In one piece the epidermis was demonstrated; in two, bast bundles; in two, the wood of the linen stem.
Sizing: starch paste.

25. Registro di un Consiglio dei X precedente al Consiglio dei X… 1289 to 1291. State Archive in Venice.
Rag paper: linen and some cotton, starch traces from fabric finishing. Individual blue and bluish fibers.
Sizing: weakly with glue.

26. Volume degli atti del Podestà a Torcello 1289 to 1299. State Archive in Venice.
Rag paper: yarn threads. Linen fiber with trace of cotton. Starch traces.
Sizing: probably glue — doubtful Millon's reaction.

27 to 38. Consiglio generale. State Archive in Siena. Through Professor Paoli in Florence. Vol. II — 1248; Vol. III — 1251; Vol. IV — 1254 to 1255; Vol. VII — 1256 to 1257; Vol. VIII — 1258 to 1259; Vol. X — 1262; Vol. XI — 1266; Vol. XVII — 1273; Vol. XXVI — 1282; Vol. XIX — 1284; Vol. XXXII — 1286.

The objects marked with * were obtained through the kind mediation of my highly honored colleague Court Councillor Professor von Sickel. The relevant samples, with exact signatures and notes on the results of my investigations, were incorporated into the collection of the Institute for Austrian Historical Research.

Rag paper: almost all interspersed with yarn threads; principal mass linen fiber with some cotton, or entirely linen fiber.

Sizing: throughout abundantly with starch paste, easily detectable directly by means of iodine solution.

39 to 41. Misture di Biccherna 1277, 1281, 1298. State Archive in Siena. Through Professor Paoli.
Rag paper: yarn threads. Linen fiber alone or with a trace of cotton.
Sizing: throughout abundantly with starch paste.

42 to 43. Misture di Bicherna 1298, 1299. State Archive in Siena. Through Professor Paoli.
Rag paper: linen and some cotton, starch trace.
Sizing: with glue, abundantly — Millon's reaction excellent.

44 and 45. Sangimignano, Deliberazione del Comune 1223 and 1279. From the State Archive of Florence.
Rag paper: yarn thread; much linen fiber, some cotton.
Sizing: with starch paste.

46. Consulte del Comune di Firenze 1293. State Archive in Florence.
Rag paper: yarn threads; much linen fiber, little cotton fiber.
Sizing: with starch paste.

47. Documento di Pistoia 1296. State Archive in Florence.
Rag paper: yarn threads of linen fibers and yarn threads of cotton fibers. Relatively much cotton. Starch traces microscopically detectable.
Sizing: strongly with animal glue.

48. Miscellaneae patriae. No. 163. Royal Library in Turin. From the second half of the thirteenth century, around 1270.
Rag paper: linen and some cotton.
Sizing: with starch paste.

49. Carte Miscellanee dei Fascicoli Angiovini — 1282 to 1283. State Archive in Naples.
Rag paper: yarn threads; much linen fiber, some cotton fibers.
Sizing: starch paste.

Fourteenth century

A. Oriental and Egyptian papers

50. Cod. CXCVI of Copenhagen. Year 702 H. = 1302 to 1303 A.D.
Rag paper: linen fiber and relatively much cotton. Bast bundles from linen.
Sizing: with starch paste.

51. Cod. CLVI of Copenhagen. Year 728 H. = 1328 A.D. Consists of two paper leaves pasted together.
Rag paper: only linen fibers found. Determination as rag paper only by comparison, therefore indirect.
Sizing: with starch paste.

52. Hariri's Maqamat. From the Imperial-Royal Court Library in Vienna. Year 734 H. = 1334 A.D.
Rag paper: linen fiber, with isolated green and yellow threads among it.
Sizing: with starch paste.

53. Cod. CCXXXVII of Copenhagen. Damascus, year 738 H. = 1337–1338 A.D. Consists of two paper leaves pasted together.
Rag paper: probably hemp and linen fibers. It could not be determined exactly, since the fibers are too strongly mechanically attacked.
Sizing: strong, with starch paste.

54. Iraqi. Year 786 H. = 1384 A.D.
Rag paper: hemp and linen fiber. Cotton not present.
Sizing: with starch paste.

55. Syrian. Eighth century H. = fourteenth century A.D.
Rag paper: hemp fiber, linen fiber, and cotton.
Sizing: with starch paste.

56. Egyptian paper from a Coptic codex of the Princely Czartoryski Museum in Kraków. Year 791 H. = 1389 A.D.
Rag paper: yarn threads, linen and cotton fiber.
Sizing: with starch paste.

57. Cod. LIV of Copenhagen. Year 798 H. = 1395–1396 A.D.
Rag paper: linen fiber predominant, alongside some silk and cotton fiber.
Sizing: with starch paste.

B. European papers

58 to 76. Volume degli atti del Podestà a Torcello. From the State Archive in Venice. 1304 to 1390.
Rag paper: mostly with yarn threads; usually much linen fiber and some cotton. Everywhere one recognizes microscopically the rag nature by the starch traces. In one number — from 1304 — isolated blue and cinnabar-red fibers. In one number from the year 1321 also hemp fibers; in another, from the year 1369, hemp fiber seems to predominate.
Sizing: weak to strong with glue.

77. A paper from the State Archive of Venice, designated only with the signature "Secolo XIV," is a pronounced linen-rag paper, in which remains of the epidermis of the flax stem could be demonstrated. It is sized with starch.

78 to 85. Documenti patri sec. XIV. No. 8 — 1306; no. 120 — 1329; no. 121 — 1333; no. 135 — 1334; no. 136 — 1335; no. 175 — 1347; no. 194 — 1353; no. 252 — 1369. From the Royal Library in Turin.
All rag paper, partly with yarn threads — no. 166, 120 — made from linen fibers, or with much linen and little cotton — no. 120, 121.

No. 8 is sized with starch paste; all the others with glue. Remarkable is no. 175 — testament of Humbertus dalphinus Viennensis — which seems to be sized with a mixture of starch paste and glue.

85 to 98. Fourteen documents from the Chapter Archive of Verona from 1305 to 1396, namely: Processus monast. S. Leonardi — near Verona, 1305; a legal case written in Venice — 1325; protocol of the notary Oliverius de Nuptis — 1326; accounting register — 1327; protocol of the notary Gardesanis — 1330; register — 1346; protocol of the notary Stephanus de Gardesanis — 1347, 1350, 1354, 1360; Locationes of the convent S. Caterina in Verona — 1353; protocol of Leon. de Codelupis — 1374; protocol of the notary Bart. de Broilo — 1391, 1396.

Throughout rag paper. Mostly much linen and some cotton fibers, further yarn threads. Yarn threads of cotton and yarn threads of linen fibers in the piece from the year 1325. Linen bast bundles and epidermal pieces of the linen stem in the piece from the year 1326.

In all these papers, the starch traces deriving from fabric finishing were to be found microscopically, which likewise speaks for the preparation of these papers from rags.

All more or less strongly sized, and throughout with glue.

99 to 105. Seven monastery registers from 1305 to 1390. Antichi archivi di Verona — Biblioteca comunale — namely: Abatia S. Zenonis — 1305; Monast. S. Mariae de Virginibus, Verona — 1338; S. Maria ad Organum — 1368; Commenda di Malta — 1370; S. Zeno, Ver. — 1379; S. Maria de Virg. Verona — 1377; S. Maria ad Organum — 1390.
Throughout rag paper, mostly from linen, but also linen and cotton. In the piece from the year 1338, hemp fibers; in that from 1379, linen epidermis; here and there also yarn threads — 1305.

The youngest of these papers is already short-fibered, while all the well-preserved papers named so far were throughout long-fibered.
All more or less strongly sized, but throughout with glue.

106. Notarial document copied in Pistoia, 1308. From the State Archive in Florence.
Rag paper: predominantly linen fibers, also some cotton. Under the microscope, starch traces deriving from fabric finishing are detectable.
Sizing: with glue.

107 to 114. Document books from the Archivio Camerale in Turin. From Savoy — 1308, 1315, 1323; Monferrato — 1328; Trana near Turin — 1346; Abbey of Saint Justus in Susa — 1365; Aosta — 1376; Crussilie near Geneva — 1386.
Throughout rag papers, chiefly of linen with traces of cotton.
Sizing: the papers from 1308, 1315, and 1323 with starch paste; the later ones all with glue.

115. Protocol of the notary Antonius Crottus from the Archivio Camerale in Turin, 1332.
Rag paper: linen fibers with some cotton.
Sizing: with glue.

116 to 119. Antichi registri di Rogiti notar. from the years 1307, 1330, 1364, and 1370, from the State Archive of Milan.
Rag paper: linen and cotton fibers.
Sizing: with glue.

120 to 123. Trattati from the years 1324, 1369, 1396, 1422, from the State Archive in Milan.
Rag paper: linen fibers alone or mixed with some cotton fibers, mostly with starch trace.
Sizing: with glue.

124 to 126. Potenze Sovrane. Galeazzo II° Visconti. Milan State Archive, 1371, 1374, 1397.
Rag paper: linen fibers and some cotton.
Sizing: with glue.

127, 128. "Dal Registro Ducale A. Pace e Feudi," 1375, 1380. Milan State Archive.
As before.

129. Cod. S. Pantaleo no. 16: Trattato delle virtù… — second text. Rome, Biblioteca Vittorio Emanuele. Fourteenth century.
Rag paper: linen fibers, starch traces very distinct.
Sizing: weakly with glue.

130. Cod. Farfensis 14: Sermones varii. Rome, Biblioteca Vittorio Emanuele. End of the fourteenth, beginning of the fifteenth century.
Rag paper: linen fibers, some cotton. Starch traces.
Sizing: weakly with glue.

130a. Salzburg Chronicle. From the collection of the Institute for Austrian Historical Research, as are the two following. Circa 1300.
Rag paper: yarn threads, partly visible to the naked eye; only linen fibers.
Sizing: with starch paste.

131. Manuscript from Murau. 1377.
Rag paper: linen fibers. Starch traces.
Sizing: with glue.

132. Manuscript from Eger. 1379.
As no. 131, only the sizing is stronger.

Fifteenth century

A. Oriental papers

133 and 134. Cod. CXCII, year 828 H. = 1424–1425 A.D. Cod. CXXIV, Copenhagen. Year 833 H. = 1429–1430 A.D.
Rag paper: yarn threads, linen and some cotton fibers.
Sizing: with starch paste.

135. Cod. CCLXIII, Copenhagen. Year 831 H. = 1427–1428 A.D.
Rag paper: hemp, linen, and cotton fiber.
Sizing: with starch paste.

136. Cod. CCLXIII, Copenhagen. Year 840 H. = 1436–1437 A.D.
Rag paper: much linen fiber, little cotton fiber.
Sizing: with starch paste.

137. Cod. CXXXIX, Copenhagen. Year 851 H. = 1447–1448 A.D.
Rag paper: linen fibers with trace of cotton, yarn threads.
Sizing: with starch paste.

138. Cod. CCLXXVIII, Copenhagen. Year 892 H. = 1487 A.D.
Rag paper: linen, hemp, and cotton fiber.
Sizing: with starch paste.

139 and 140. Two different papers, signed "Syrian," eighth to ninth century H. = fourteenth to fifteenth century A.D.
Rag paper: linen, hemp, and cotton fiber.
Sizing: with starch paste.

B. European papers

141 to 151. Volume degli atti del Podestà a Torcello, from the years 1400, 1410, 1420, 1430, 1440, 1450, 1460, 1470, 1480, 1490, 1499. From the State Archive of Venice.

Throughout rag paper, consisting of linen fibers or of these with some cotton. In individual examples, for instance those from the years 1460 and 1490, yarn threads are present. Microscopic starch trace from fabric finishing. Constituents of the linen stem occur in the papers from the years 1400, 1410, 1420, 1450, and 1460.
All more or less strongly sized with glue.

152. Inventarium scripturarum of the House of Savoy. Beginning of the fifteenth century. From the State Archive in Turin.
Rag paper: linen fiber. Starch traces under the microscope by iodine and hydrochloric acid.
Sizing: weakly, with glue.

153. Acta generalium audientiarum Aug. Praetorie (Aosta). Original manuscript from the year 1430. State Archive in Turin.
Rag paper: linen fiber, starch trace.
Sizing: with glue.

154. Original manuscript of the Chronicle of Pierre du Pin, written about the year 1460, from the State Archive in Turin.
Rag paper: linen fiber, starch trace.
Sizing: weakly, with glue.

155. Manuscript of the fifteenth century. Vegetius, French translation, from the State Archive in Turin.
As no. 154.
156. Summa Rolandina, manuscript from the year 1401 — Savoy.
157. Protocol of an unknown notary from Grenoble from the year 1405.
158. Letter of the Count of Savoy. Ambronai, August 24, 1411.
159. Protocol of the notary Andr. Hugon, Bourg, 1439.
160. Cartulary of the fiefs of the Abbey of Saint Justus in Susa, 1435.
161. Protocol of an unknown notary from Savoy, 1456.
162. Letter of Duke Louis of Savoy. Rumilly, November 26, 1457.
163. Letter of the Duchess of Savoy, Yolande of France. Vercelli, March 3, 1472.
164. Protocol of the notary Gaspardus Faber, Bourg, 1482.
165. Accounts of the Castellania Biella, 1480.
166. As no. 160, but from the year 1485.
167. Protocol of the notary Johannes Ferrandus. Nice, 1485.

168. Protocol of the notary Bernardus Lanlongus. Rivara near Turin, 1487.
169. Cartulary for the Margraviate of Saluzzo, written in Piedmont, 1487.
170. Letter of Charles I, Duke of Savoy. Turin, February 8, 1489.

All from the Archivio Camerale in Turin.

Throughout rag papers, most made from linen fiber, frequently with starch trace. Individual examples also contain some cotton, namely nos. 159, 162, 164, and 169.

All more or less well sized with glue.

171. Protocol of the notary ….. Faber from Cerdon in Bugey, 1477. Likewise from the Archivio Camerale in Turin.
Rag paper: linen fiber and traces of cotton fiber. Isolated blue threads. Starch trace.
Sizing: not detectable.

172 to 177. Docum. patri. Fifteenth century, from the Royal Library in Turin. No. 5 — 1402 to 1404; no. 58 — 1425; no. 67 — 1435; no. 197 — 1467; no. 240 — 1470; no. 356 — 1483.

Throughout rag papers, mostly already very short-fibered. Prepared partly from linen, partly from a mixture of linen and cotton rags — no. 58; all with starch trace.
All more or less strongly sized with glue.

178. Storia patria no. 965, from the Royal Library in Turin — 1407.
Rag paper: linen and cotton fibers, blue and bluish fibers. Starch trace.
Sizing: with glue.

179. Storia d'Italia no. 101, 1425. Royal Library in Turin.
Rag paper: linen fiber, isolated silk threads. Vessels of the linen stem. Starch trace.
Sizing: with glue.

180. Contemporary copy of a document of Duke Louis of Savoy, from the year 1442, from the Royal Library in Turin.
Rag paper: already fairly short-fibered; certainly contains hemp fibers, since fragments of the hemp-stem epidermis are present, and alongside these also linen and cotton fibers. Starch trace.
Sizing: with glue.

181 to 196. Sixteen pieces from the Antichi Archivi, Verona. Registrum, now in the archive "Esposti" — 1403; Registrum liter. officii datiorum — Archive of the commune of Verona, 1404; Estimo of the city of Verona — 1409, 1425; Abbatia S. Zenonis — 1430; register of the monastery S. Antonio del Corso — Verona, 1437; register of S. Michele in Campagna — 1443; Acta Consilii communis Veronae, vol. E — 1443 to 1450; a letter written in Venice in 1447 from the Archivio del Comune; register of the monastery Fidenzio — 1448; account register of the monastery S. Antonio del Corso — 1454; Liber affictualium of the monastery S. Martino di Avesa — 1468; Officii Veneti — 1477; Acta consilii Communis Veronae, vol. K — 1483 to 1491; a letter written in Venice in 1489 from the Archivio del Comune, Verona; a letter written in Venice in 1496 from the Archivio del Comune, Verona.

Partly already very short-fibered rag papers, mostly made from linen fibers with adhering starch trace. Cotton fibers occur in the papers from the years 1404, "1443 to 1450" — there also epidermis of linen stem — and "1483 to 1491."

All more or less strongly sized with glue.

197 to 201. Protocols and registers from the Chapter Archive in Verona, from the years 1418, 1424, 1434, 1438, 1493.
Rag paper: made from linen fiber, or from this and some cotton; in some examples yarn threads can still be found microscopically — 1493. Some — 1418 — already very short-fibered.
Sizing: insofar as detectable, glue.

202. Cod. S. Pantaleo 16. Rome. Biblioteca Vittorio Emanuele.
Rag paper: linen fiber, starch trace.
Sizing: with glue.

203. Cod. Sessorianus 290. Rome. Biblioteca Vittorio Emanuele.
Rag paper: linen and some cotton fiber.
Sizing: with glue.

204 to 239. Thirty-six papers from the State Archive in Milan. Fondo di Religione — 1433; Potenze Estere-Borgogna — 1432, 1460, 1473, 1496; Potenze Estere-Austria — 1458, 1461, 1477; Potenze Estere-Bologna — 1457, 1486, 1483; Potenze Estere-Firenze — 1451, 1461, 1474, 1485, 1497, 1499; Potenze Estere-Genova — 1450, 1461, 1472, 1481, 1492, 1499; Potenze Estere-Modena — 1452, 1464, 1480, 1496; Dai registri delle Missive — 1450, 1460, 1464, 1470, 1480, 1490, 1493, 1499.

Throughout rag paper made from much linen and little cotton fiber, or from the former alone, often with starch trace. In one — 1480, Modena — yarn threads still occur.

All more or less strongly sized with glue.[1]

Sixteenth century

240. Year 1509, April 19. Letter of dispatch from A. Chr. Steinpeckh, Imperial-Royal Court and State Archive in Vienna.
Rag paper: linen fiber with starch trace.
Sizing: with glue.

241. 1516, September 6. Bond of Archduke Ferdinand of Austria for the city of Freistadt, Imperial-Royal Court and State Archive.
Rag paper: yarn threads. Linen fiber with starch trace.
Sizing: strongly with glue.

[1] After the completion of my manuscript, I received from Court Councillor von Sickel a collection consisting of no fewer than 229 paper samples. This rich collection was assembled by Professor Dr. Carlo Conte Cipolla in Turin and contains papers from the Archivio Gonzaga in Mantua from the thirteenth and fourteenth centuries, from Bologna, Ferrara, Florence, Genoa, Milan, Naples, Rome, Venice, etc. I no longer had time to test each piece of this collection; nor did this seem necessary, given the completely consistent results already obtained from material that was probably more than ample. I restricted myself to ten spot checks, all of which confirmed the observations communicated in the text.

242. Nomocanon Barb. Compare Miklosich, Lexicon palaeoslovenico-graeco-latinum, Vienna, 1862 to 1865, p. XV. 1566 A.D., Imperial-Royal University Library in Vienna. Manuscript.
Rag paper: linen fiber with traces of cotton fiber and starch traces.
Sizing: with glue.[1]

Seventeenth century

243. 1605, August 6. Copy of H. Khevenhüller's testament. Imperial-Royal Court and State Archive in Vienna.
Rag paper: linen and traces of cotton fiber. Isolated bluish fibers also occur.
Sizing: with glue.

244. 1648, October 8. Archbishop P. Lodron, deed of transfer concerning several farms, Imperial-Royal Court and State Archive.
Rag paper: linen fiber, starch trace.
Sizing: with glue.

245. 1675, December 12. Letter of Elector Ferdinand Maria of Bavaria to Archbishop Max Gandolf in Salzburg, Imperial-Royal Court and State Archive.
Rag paper: linen fiber, starch trace.
Sizing: with glue.

255. 1696, March 30. Archbishop Ernst establishes a benefice in Salzburg, Imperial-Royal Court and State Archive in Vienna.
Rag paper: linen fiber, starch trace.
Sizing: with glue.

Eighteenth century

About 80 works, duplicates from Viennese libraries, were examined, both the printing paper and the white leaf situated between cover and title, which was always a writing paper.

Both the printing and writing papers revealed their rag nature most sharply. Either only linen fiber, or a mixture of much linen and little cotton fiber, was found. Hemp fiber is rarer than linen fiber.

Most of the printing papers are unsized. The sized papers all contain only glue.

Nineteenth century

About 50 samples of writing and printing papers from the first third of the nineteenth century gave essentially the same results as the 80 works from the eighteenth century, with the sole difference that in some, somewhat larger quantities of cotton were already to be found.

[1] Since the other paper sorts dating from the sixteenth century always gave the same result, I content myself with citing the above examples. The same applies also to the seventeenth and eighteenth centuries. From both centuries, 50 papers were tested.

From then on cotton begins to become more frequent, and the combined starch-resin sizing appears sporadically, and later more and more often. The composition of papers since the introduction of the so-called substitutes is known, and therefore was not further entered into.

From the data communicated, the following conclusions result:

1. Like the Arabic papers, the European papers too, from the beginning of their production until far into our century, were prepared from rags. A paper produced from raw cotton has never existed. Among about 500 Oriental and European papers examined by me, there is not a single one composed only of cotton fibers; rather, all bear the stamp of rag paper. Apart from two linen-fiber papers — nos. 9 and 51; see pp. 65 and 67 — direct proof could everywhere be furnished that they were prepared from rags.
2. The oldest European papers, like the Arabic ones, are strongly sized with starch paste, which may well be regarded as new proof of the connection between European and Arabic papermaking art.

All Oriental papers that I examined are sized with starch paste. The youngest date from the end of the fifteenth century of our era.

In Europe, starch sizing disappeared much earlier. The boundary between sizing with starch paste and animal glue — glue — falls at the end of the thirteenth or the beginning of the fourteenth century. In the series of papers from Siena, starch sizing disappears with the year 1298, and with this year sizing with animal glue also begins. In the series of papers from Venice, the boundary falls in the year 1291; in the series from Florence, between 1293 and 1296; in the Veronese series, in the year 1305; and in the Turin series, in the year 1323.

Later investigations may perhaps allow the boundary to be drawn still more exactly, since it would be possible that the document from the year 1323 was written on paper from an earlier time. Nevertheless, it will be permissible to conclude from the blue and violet coloration of a non-modern European paper by aqueous iodine solution that its upper age limit does not go beyond the end of the thirteenth or the beginning of the fourteenth century.[1]

3. In the old Arabic — that is, Islamic-Oriental — and European papers, linen fiber probably plays the chief role. Already at the beginning of papermaking, cotton fiber appears in paper, but always only in small quantity, often only in traces. But even in papers from the first third of our century, cotton is still usually present in small quantity. This fact agrees better with the actual development of the cotton industry than the existence of cotton paper asserted until very recently. Only in this century did cotton gain importance in Europe,

[1] According to Briquet, paper was already sized with glue in the Orient in the twelfth century. Briquet, loc. cit., pp. 66 and 67.

and only since the end of the previous century was it brought to Europe in its raw state as an article of commerce — at first as a competitor, later as the conqueror of linen.

4. Linen fibers were demonstrated in the papers I examined much more frequently than hemp fibers.

Judging by those determinations that could be made with absolute certainty, the ratio of cases of linen papers to those of hemp papers is about 3:1.[1]

5. According to my investigations, paper was sized with starch paste until the end of the thirteenth, or beginning of the fourteenth century. After this came glue. Only in our century did resin sizing begin, combined with starch sizing. The tragacanth, resin, and combined tragacanth-resin sizing asserted by Briquet, which is supposed to have preceded sizing with animal glue,[2] could not be observed by me in any case, although I found and used very sensitive reactions for the two substances named.

In the question of sizing, the Liber plegiorum listed above under no. 17 — 1223, from the State Archive of Venice — already examined by several palaeographers, is of special importance. Briquet states that it is sized with tragacanth and much resin. But no sizing material other than starch paste was found in it.

6. Until the fourteenth century, European papers are very long-fibered; gradually short-fibered papers take their place, which points to a deep-reaching transformation of the papermaking process.

The long-fibered papers were, I believe, produced by hand stamping, or in general by a very primitive process that did not attack the fibers so strongly, while the short-fibered papers were obtained by grinding and similar operations.

Since the introduction of rag substitutes and their chemical processing, very long-fibered papers appear again, including even wood papers.

Appendix

After the printing of the present treatise had been completed — Easter 1887 — I received, through the kind mediation of Court Councillor Professor von Sickel, a collection of papers from the Paris National Library. These claim particular interest because the papers in question — 26 in number, from the tenth to the thirteenth century, partly of Oriental, partly of European origin — were all also examined by Mr. Briquet.

[1] By contrast, the ratio of linen paper — in which linen fiber allegedly predominates — to hemp paper — in which hemp allegedly predominates — is calculated by Briquet as 1:6. Compare above, p. 40.

[2] See above, p. 41.

[3] These long-fibered papers were what led to the assumption of "cotton papers." See above, p. 8.

This collection is owed to Mr. L. Delisle, Director of the Manuscript Department of the Paris National Library. After the investigation was completed, the paper sorts in question were handed over to the Institute for Austrian Historical Research.

The investigation of the named papers again confirmed my earlier observational results concerning both the "fiber" of paper and its "sizing." By means of the objects also examined by Mr. Briquet, it could be shown that his statements about the sizing of old papers cannot be maintained; in particular, proof was furnished that in the periods at issue there was neither tragacanth nor resin sizing of paper.

In what follows, Mr. Briquet's results are set opposite those obtained by me. Since Mr. Briquet did not furnish direct proof of the rag nature of the papers he examined, I give everywhere the arguments on the basis of which I declare the papers to be rag papers.

The most exact possible determination of the fiber sorts contained in the papers caused much laborious investigation. A large part of it was carried out, using the characteristics established by me, by my assistant, Dr. Molisch, Privatdozent at the Imperial-Royal University, with the care, reliability, and expertise that distinguish all his work.

I. "Fonds des nouvelles acquisitions latines no. 12964."[1] Spain, eleventh or twelfth century.

Briquet, Recherches sur les premiers papiers, etc., Paris, 1886, pp. 66 and 67, no. 61: "Linen; absence of gelatin; sizing with resin, part of which has been altered by time."
Rag paper, in which the presence of remains of yarn threads could be established by the microscope. Linen, judging by the form of the fiber ends. Resin not present. By contrast, even aqueous iodine solution gives the starch reaction clearly. The color varies in tone and lies between blue and violet. Thus this paper is not sized with resin, but with starch paste.

II. "Fonds grec no. 154" — formerly no. 2436 — Orient, twelfth century.

Briquet, loc. cit., pp. 66 and 67, no. 62: "Hemp; sizing with gelatin."
The form of the fiber ends and the presence of fragments belonging to the woody parts of the vascular bundles of the flax stem provide proof that this paper contains linen fiber. Hemp fiber may possibly also occur in it; according to the characteristics of this fiber known so far, its presence in the present paper could not be proven. Undoubtedly rag paper, although this could not be established directly. Millon's test gave a negative result; therefore no animal glue is present in this paper. Aqueous iodine solution does not indeed produce a reaction directly in this paper, but does so after addition of hydrochloric acid. Thus this paper is sized not with animal glue, but with starch paste.

III. "Fonds grec no. 194 A." Written at? Dated 1255.

Briquet, loc. cit., pp. 66 and 67, no. 63: "Hemp; sizing with gelatin."

[1] After the consecutive Roman numerals follow, in quotation marks, the designations under which the objects in question appear in the Paris National Library.

In this paper, yarn threads can already be demonstrated with the naked eye, and more abundantly with the loupe and the microscope. This furnishes direct proof that this paper was produced from rags.

The ends of the fibers and the behavior of the still relatively well-preserved bast cells speak for the presence of hemp and linen. Iodine solution directly gives blue coloration. Millon's test gives a negative result. This paper is therefore sized not with animal glue, but with starch paste.

IV. "Fonds hébreu no. 1225." Written at? Earlier than 1291.

Briquet, loc. cit., pp. 66 and 57, no. 64: "Hemp."
Linen and cotton — the latter in smaller quantity — could be established in this paper with complete certainty. The presence of remnants of both fibers speaks for the rag nature of this paper.
Iodine reaction distinct: therefore starch-paste sizing.

V. "Fonds hébreu no. 175." Written at? Dated 1271.

Briquet, loc. cit., pp. 66 and 67, no. 65: "Hemp mixed with linen; sizing with gelatin."
Linen and hemp fiber. Iodine solution gives no starch reaction; iodine solution and hydrochloric acid make blue points appear microscopically — "starch trace" — which speaks for the rag nature of this paper.
Millon's reagent indicates sizing with animal glue.

This paper seems important to me because — assuming the correctness of the dating — it is the oldest known paper sized with animal glue. In my treatise I have shown that in the paper series examined by me, starch sizing in Europe ceased between 1298 — Siena — and 1323 — Verona — and that sizing with animal glue immediately followed. Since the Oriental papers I examined, even from the fifteenth century, are all sized with starch paste, one may probably assume that the present paper is of European and not Oriental origin.

VI. "Fonds hébreu no. 79." Written at? Thirteenth century.

Briquet, loc. cit., pp. 68 and 69, no. 66: "Hemp mixed with linen; sizing with resin."
It is a rag paper, as shown by the "starch trace" demonstrable with iodine solution and hydrochloric acid. The principal mass, perhaps the entire paper mass, consists of linen and not hemp, as follows from the form of the ends and the traces of the inner membrane.
This paper is not sized with resin, but, as can be shown by Millon's test, with animal glue.

VII. "Fonds arabe, supplément no. 952 bis" — catalogue of 1883. Written at Shiraz in Persia. Dated 969.

Briquet, loc. cit., pp. 68 and 69, no. 67: "Pure hemp."
Linen fibers, to judge by the form of the cell ends. Millon's reagent produces no effect. Through aqueous iodine solution only a "starch trace" appears. The paper runs strongly and was probably not sized at all. That this paper was produced from rags follows, despite the homogeneity of the fibers, from the "starch trace."

VIII. "Fonds arabe no. 1097" — catalogue of 1883. Written in? Dated 1025.

Briquet, loc. cit., pp. 68 and 69, no. 68: "Hemp; sizing with resin."
Contains yarn threads, which mostly become visible only under the microscope. It is therefore rag paper, something also expressed by the fact that, alongside linen, some cotton fiber occurs. Starch reaction only after addition of hydrochloric acid. The starch-paste sizing is therefore beyond doubt.

IX. "Fonds arabe no. 882 a" — catalogue of 1883. Written in? Earlier than 1027.

Briquet, loc. cit., pp. 68 and 69, no. 69: "Pure hemp."
Contains linen and cotton. The latter occurs in this paper even in the form of yarn threads. Iodine solution gives a very weak starch reaction; iodine and hydrochloric acid give a very distinct one.
This paper is therefore sized with starch paste.

X. "Fonds arabe no. 736" — catalogue of 1739. Written at? Dated 1167.

Briquet, loc. cit., pp. 68 and 69, no. 70: "Hemp."
Hemp could not be demonstrated in this paper; but from the form of the ends and from the behavior of some well-preserved fibers toward cuprammonium hydroxide, the presence of linen could be inferred. A small quantity of cotton could be established in it with certainty. The starch-paste sizing was already very beautifully demonstrable by aqueous iodine solution.

XI. "Fonds arabe no. 1028" — catalogue of 1739. Written at? Dated 1166.

Briquet, loc. cit., pp. 68 and 69, no. 71: "Hemp."
Yarn threads are already perceptible macroscopically. Linen fiber, to judge by the form of the ends. Even aqueous iodine solution indicates the presence of starch paste as sizing material.

XII. "Fonds arabe no. 1405" — catalogue of 1739. Written at? Dated 1162.

Briquet, loc. cit., pp. 68, 69, no. 72: "Hemp mixed with linen."
This paper required special attention, since Millon's reagent and aqueous iodine solution both gave positive results. If one relies on the results of this test, one must assume that this paper was sized both with glue and with starch paste. But microscopic examination teaches that Millon's reaction, in itself only very weak, comes from gluten remains.[1] The presence of gluten — in the form of protoplasmic remains and even small pieces of bran, which contain it abundantly but enclosed by cell walls — suggests that either very poorly cleaned starch, or actual flour, was used for sizing this paper.
The ends of the fibers point to hemp.
The rag nature of this paper, likewise sized with starch paste, is probably beyond question, but could not be directly proven.

XIII. "Fonds arabe no. 1294" — catalogue of 1739. Written at? Dated 1157.

Note on this by Briquet, loc. cit., pp. 68, 69: "This manuscript is indicated as being from the year 551 after Christ. We think that one must read 551 of the Hijra, that is, 1157."

Briquet, loc. cit., pp. 68 and 69, no. 73: "Hemp, mixed with some cotton fibers."

[1] Concerning the interpretation of microscopic findings with Millon's reagent, see above, p. 42.

Contains linen and cotton, and is therefore a rag paper. The cotton occurs in smaller quantities than the linen fiber. The starch-paste sizing could already be made visible directly by aqueous iodine solution.

XIV. "Fonds arabe no. 1104" — catalogue of 1739. Written at? Dated 1155.

Briquet, loc. cit., pp. 68, 69, no. 74: "Hemp, mixed with some cotton fibers."
This paper gave the same results as the preceding one. The only difference was that yarn threads, and indeed already macroscopically, could be recognized; this was not possible in the preceding case.

XV. "Fonds arabe no. 1295" — catalogue of 1793. Written at? Dated 1109.

Briquet, loc. cit., pp. 68, 69, no. 75: "Hemp mixed with little linen."
Yarn threads already recognizable with the naked eye. Fibers: much linen and some cotton. By aqueous iodine solution the starch reaction was only indicated; it appeared very beautifully, however, after addition of hydrochloric acid. This paper is therefore undoubtedly sized with starch paste.

XVI. "Fonds arabe no. 79" — catalogue of 1739. Written at? Dated 1016.

Briquet, loc. cit., pp. 68, 69, no. 76: "Hemp; sizing with gum tragacanth."
Both the presence of small quantities of hemp wood — that is, of the woody parts of the vascular bundle of the hemp plant — and the ends of the fibers speak for hemp fiber.
The test for tragacanth was carried out with all care, yet not a trace of this kind of gum could be demonstrated in the paper.
By contrast, the starch sizing of this paper could already be established by aqueous iodine solution.

XVII. "Fonds arabe no. 35" — catalogue of 1739. Written at? Dated 980.

[The source text here appears corrupted in the OCR.] Without doubt a rag paper. The presence of linen fibers was established beyond doubt. The starch sizing could already be demonstrated by aqueous iodine solution.

XVIII. "Fonds syriaque no. 10" — catalogue Zotenberg. Written at? Dated thirteenth century.

Briquet, loc. cit., pp. 68, 69, no. 78: "Hemp."
Between linen fibers there occur isolated blue-colored cotton fibers and yellow-colored sheep's-wool fibers. The occurrence side by side of colored and uncolored fibers, especially of different kinds, forms, as I explained above, a very compelling argument for the rag nature of this paper.
Iodine solution already directly produces blue coloration; this paper is therefore sized with starch paste.

XIX. "Fonds syriaque no. 155" — catalogue Zotenberg. Written at Nicosia, Cyprus. Dated 1280.

Briquet, loc. cit., pp. 68, 69, no. 79: "Hemp."
Contains linen fiber, yarn threads partly demonstrable microscopically, and also some hemp fiber. The presence of linen fiber follows from the presence of linen-stem wood; that of hemp fiber from the form of the fiber ends.
Iodine solution gives the starch reaction directly. Alongside the starch there also occurs, as in paper no. XII, some gluten.

XX. “Fonds syriaque no. 56” — catalogue Zotenberg. Written at the Convent of the Mother of God in the Desert of Scété. Dated 1264.

Briquet, loc. cit., pp. 68, 69, no. 80: “Hemp mixed with linen.”
Direct proof that this paper was produced from rags could not be furnished.
With complete certainty, however, it could be established — both on the basis of the form of the fiber ends and on the presence of linen-stem wood — that this paper contains linen fiber. It probably consists entirely of this fiber.
Aqueous iodine solution directly produces blue coloration; this paper is therefore sized with starch paste.

XXI. “Fonds syriaque no. 134” — catalogue Zotenberg. Written at the Convent of Nahr Khepton in Syria. Dated 1256.

Briquet, loc. cit., pp. 70, 71, no. 81: “Hemp, mixed with a little linen.”
That this paper was prepared from rags could be inferred from the yarn threads present in it, some of them already visible to the naked eye. From the shape of the fiber ends, the behavior of the fibers toward cuprammonium hydroxide, and finally from the detection of woody parts of the vascular bundle of the hemp stem, it could be shown that the fiber of this paper contains hemp fiber. Whether linen fiber is also present alongside it could not be decided.
This paper too is already colored blue by aqueous iodine solution; it is therefore sized with starch paste.

XXII. “Fonds syriaque no. 112” — catalogue Zotenberg. Written in Syria. Dated 1239.

Briquet, loc. cit., pp. 70, 71, no. 82: “Hemp, pure and beautiful fiber.”
The rag nature of this paper could not be proven directly, but is of course beyond doubt. It contains linen fiber, as the ends of the well-preserved fibers and the traceable wood of the linen stem prove.
The starch sizing could be established directly by aqueous iodine solution.

XXIII. “Fonds syriaque no. 42” — catalogue Zotenberg. Written in Cairo. Dated 1226.

Briquet, loc. cit., pp. 70, 71, no. 83: “Hemp mixed with a small quantity of foreign substance that is not cotton.” That this paper was prepared from rags is shown by the fact that it contains linen fibers and cotton. The latter is present only in relatively small quantity. As for the foreign fiber found in this paper by Mr. Briquet, I tried in vain to find such a fiber. The only thing that may appear conspicuous are fibers having a thickness up to 0.042 millimeter. These, however, are nothing other than strong, mechanically attacked flax bast cells, possibly hemp bast cells, whose diameter, as I showed above — p. 36 — can rise to 0.06 millimeter.

XXIV. “Fonds syriaque no. 234” — catalogue Zotenberg. Written at Antioch. Dated twelfth or thirteenth century.

Briquet, loc. cit., pp. 70, 71, no. 84: “Hemp mixed with linen, fiber altered by a strong alkali.”
Contains yarn threads, which are in part already perceptible to the naked eye.

So far as the fiber of this paper is still determinable, it has proved to be the bast cell of linen.
Iodine solution gives only a trace of starch reaction; with the addition of hydrochloric acid, however, it gives a very distinct blue coloration. Here too, therefore, the starch-paste sizing is beyond question.

XXV. "Fonds syriaque no. 236" — catalogue Zotenberg. Written at? Dated 1194.

Briquet, loc. cit., pp. 70, 71, no. 86: "Hemp mixed with linen."
Two arguments speak for the rag nature of this paper: first, yarn-thread fragments, which could be demonstrated by the microscope; second, the presence of two kinds of fibers, namely bast cells of linen and cotton fibers. The latter are present only in traces.
The starch-paste sizing could be found directly by aqueous iodine solution.

XXVI. "Fonds syriaque no. 50" — catalogue Zotenberg. Written at? Dated 1187.

Briquet, loc. cit., pp. 70, 71, no. 85: "Hemp mixed with linen."
No direct proof could be furnished for the rag nature of this paper. The still determinable fibers of this paper are bast cells of linen.
Sizing with impure starch paste or with flour paste — as in no. XII.

I cannot close this treatise without first gratefully remembering those gentlemen, archive directors and professors, who so abundantly supplied me with precious material for investigation.

My thanks are due to His Excellency Privy Councillor Dr. Alfred Ritter von Arneth, Director of the Imperial-Royal Court and State Archive; to Court Councillor von Fiedler, Vice-Director of the same archive; to Court Councillor Dr. E. von Birk, Director of the Imperial-Royal Court Library; to Dr. Grassauer, Director of the Vienna Imperial-Royal University Library; to Court Councillor Professor Dr. R. von Sickel, through whose kind mediation I received from Italy several hundred paper samples from the thirteenth to the fifteenth century for examination; and to Professor Dr. Mühlbacher, who acquainted me with the relevant palaeographical sources.

The directors of archives and libraries in Italy who sent paper samples to Court Councillor R. von Sickel for the purposes of the present investigations are Messrs. Pellegrini — Belluno; C. Paoli — Florence; Davari — Mantua; Capasso — Naples; Gnoli — Rome; Banchi — Siena; Promis and Cipolla — Turin; Cecchetti and Bertoldi — Venice.

But I am most deeply indebted to my esteemed colleague Professor Karabacek, so highly deserving for the acquisition and scholarly treatment of the Faiyum treasure. He not only most willingly fulfilled all my wishes concerning the Faiyum and Ushmunein papers, but also supplied me with precious ancient Oriental material from the libraries of Leiden, Copenhagen, Leipzig, Berlin, and from private collections, and in general gave my work the most active support.

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