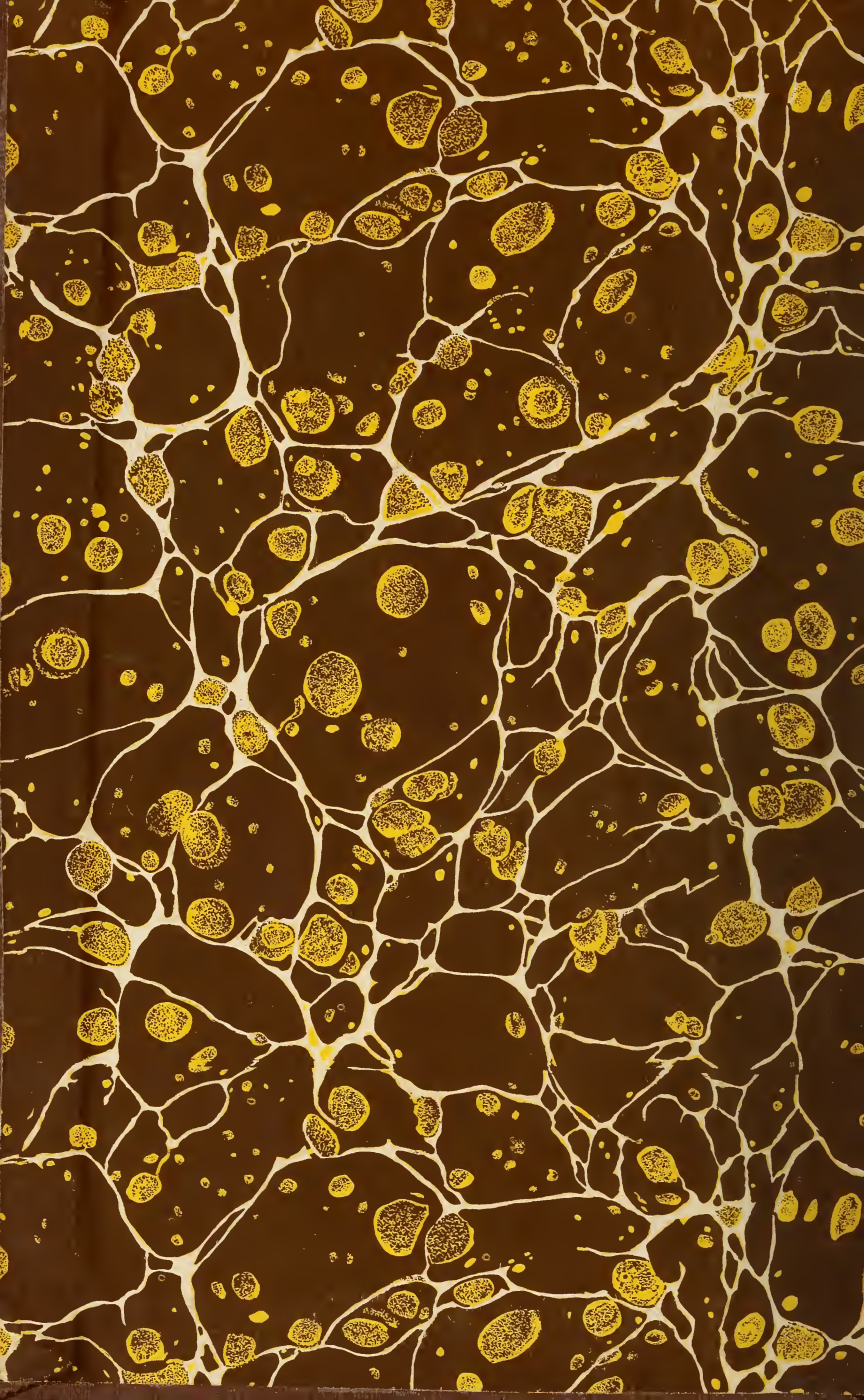
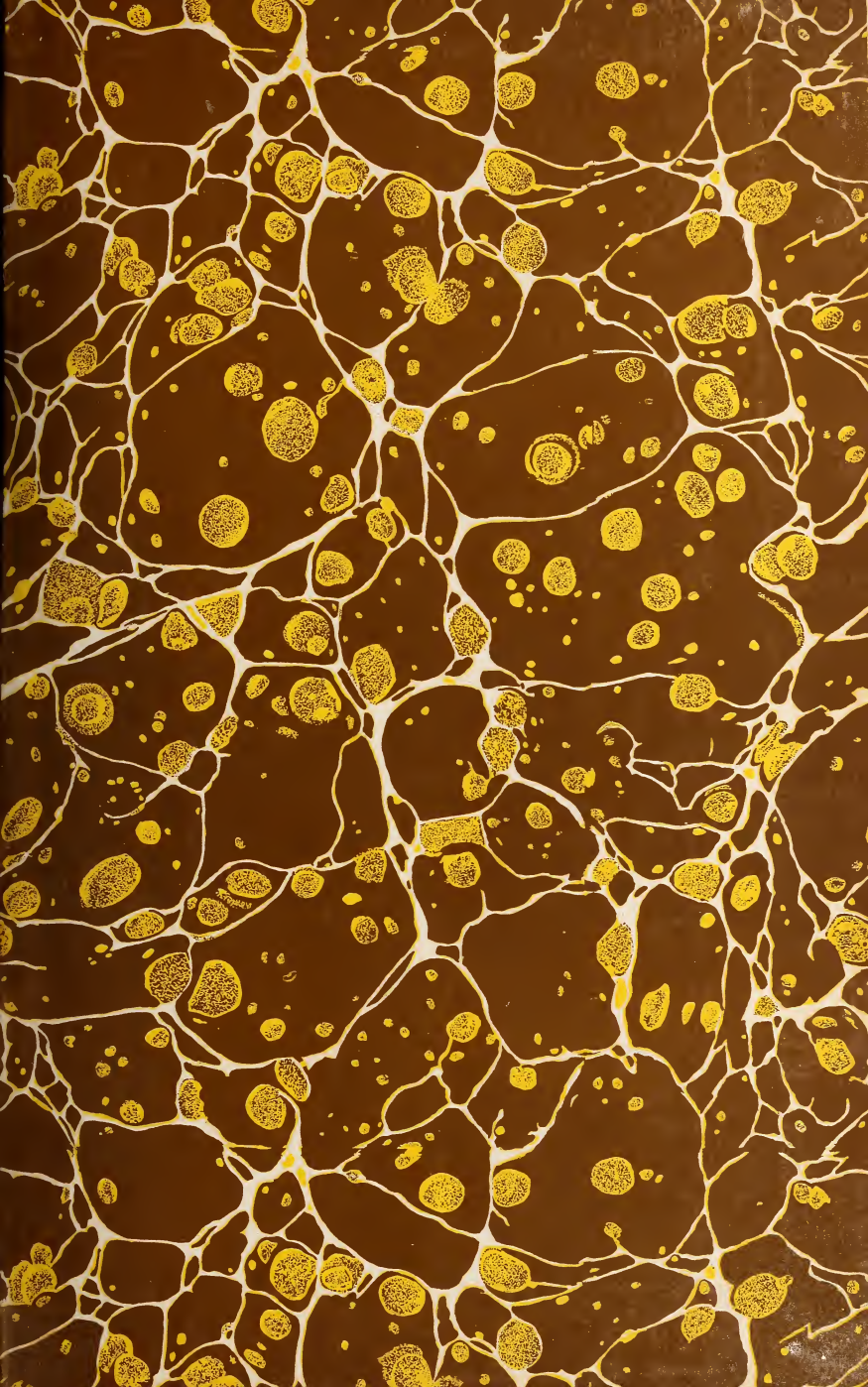


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A STUDY
OF THE DETERIORATION OF BOOK PAPERS
IN LIBRARIES

By

ARTHUR E. KIMBERLY

ADELAIDE L. EMLEY

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A STUDY OF THE DETERIORATION OF BOOK PAPERS IN LIBRARIES ¹

By Arthur E. Kimberly ² and Adelaide L. Emley ²

ABSTRACT

The examination of paper from identical books submitted by city and country or suburban libraries disclosed that paper from books stored in urban institutions is uniformly more deteriorated than that from identical volumes kept in country libraries. The poorer condition of the city books is shown by their higher acidity, lower alpha cellulose content, higher copper number, and lower folding endurance. Since the papers from books stored in urban localities had high acid contents and showed the type of chemical deterioration of fiber that occurs when papers are exposed to air containing small amounts of sulphur dioxide gas, it was concluded that their greater deterioration was mainly due to this fuel combustion product.

Papers containing chemically refined rag and wood fibers were found invariably to be in better condition than papers containing appreciable quantities of ground wood fibers. This serves to emphasize the importance of the chemical purity of the fibers themselves as a factor in paper permanence.

Data are given on the kinds of fibers found in the book papers as related to the dates of the publications. Since the dates cover the transition from use of rag fibers alone to use of straw and wood fibers also, these data are of historical interest in the use of fibers for book papers. They also define a period, 1875-1910, during which crude fibers were frequently used in book papers, and thus serve as a warning that the papers in books published in this period may be quite impermanent.

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I. INTRODUCTION

The deterioration of the paper contained in books has been a source of worry to librarians and archivists for over a century. As early as 1823, in an article in the *Gentleman's Magazine* of London, John Murray deplored the disintegration of paper produced prior to that time and in a later publication suggested means of improving the lasting qualities of paper. Since then the problem

¹ This is one of a series of investigations concerning the preservation of written and printed records which is being made at the Bureau of Standards with the assistance of a fund granted for the purpose by the Carnegie Corporation to the National Research Council.

² Research associate representing the National Research Council.

of paper preservation has become increasingly important until today it is a matter of great concern to all those interested in the permanence of records.

A recent survey of storage conditions in libraries³ showed that books and manuscripts stored in the average library are not well protected against the effects of such "external" agencies of deterioration as air polluted by acid gases,^{4,5} and changing temperature and humidity.^{6,7} Moreover, consultation with librarians in different localities indicated a belief that books stored in city institutions deteriorated more rapidly than similar volumes kept in country or suburban localities, even though the wear and tear incident to use was approximately the same for each depository. It, therefore, appeared to be of value to compare the effect of city storage versus county storage upon similar books and also to ascertain the relative state of preservation of different kinds of book papers. In view of data on air pollution⁸ previously considered it would not be surprising if a book which had been exposed to an urban atmosphere, contaminated by acid gases, deteriorated to a greater extent than a similar book stored in a country or suburban locality relatively free from air pollution. In order to study these problems the cooperation of representative libraries throughout the United States was invited.

II. METHOD OF COLLECTING SPECIMENS

Through the courtesy of the New York Public Library a group of 34 deteriorated books was obtained for complete examination. A list of these books was then sent to libraries throughout the United States with the request that they forward duplicates for examination, whether deteriorated or not. They were further requested to send any other books which showed a definitely good or bad state of preservation and which could be spared for examination. By this means, 229 books published during the period 1720-1930, as well as 85 duplicates of 31 different titles were collected from 23 libraries in widely separated localities.

III. INSPECTION AND TESTING OF SPECIMENS

The similar books were carefully inspected to insure uniformity of edition and date of printing, and the records of the contributing institutions were checked so as to include for examination only these books which had been subjected to approximately the same degree of use while in circulation. This final process of selection yielded a group of 11 titles, each represented by 2 or more volumes. The paper of these was carefully inspected for state of preservation and then subjected to thorough chemical and physical analyses, the same portion of each different book being tested to insure absolute similarity of samples.

³ Kimberly, Arthur E., and Hicks, J. F. G. jr., B. S. Misc. Pub. No. 128.

⁴ Richter, George A., Ind. and Eng. Chem., vol. 23, No. 4, p. 371, 1931.

⁵ Kimberly, Arthur E., B. S. Jour. Research, vol. 8, p. 159, 1932.

⁶ Norris, J., Library J., vol. 38, p. 16, 1913.

⁷ Brauns, O., Pulp Paper Mag. Can., vol. 26, pp. 11, 165, 1928.

⁸ See footnote 3.

The alpha cellulose content and copper number of these books were determined by modified procedures developed by the bureau specifically for testing paper.⁹ The alpha cellulose content of any paper is that part of the cellulosic material which is insoluble in a sodium hydroxide solution of mercerizing strength (17.5 per cent NaOH) under certain specified conditions, and is regarded as a measure of the amount of unmodified cellulose which the material contains. A high alpha cellulose content is considered an indication of superior condition in paper. The copper number, on the other hand, is a measure of the amount of modified or deteriorated cellulose present and, when high, is regarded as an indication of poor condition in paper. The procedure for determining the acidity of these specimens was the one selected for use in the investigation of the effect of sulphur dioxide on paper.¹⁰ The M. I. T. folding endurance tester, a device by means of which a strip of paper under tension is repeatedly folded upon itself until broken, was used throughout this work, as a significant number of double folds could be obtained on many of the deteriorated specimens only by the use of a very low tension, which is easily obtained in this tester. The tension used was 300 g.

All of the books, whether in the selected group of titles or not, were subjected to a determination of fiber composition according to the official methods of the Technical Association of the Pulp, and Paper Industry.¹¹ The papers were then jointly graded by three persons into three classes with consideration of color and strength. The specimens were said to be in good condition if there was no apparent weakening of the fibers and no discoloration. They were graded in intermediate condition if somewhat discolored and embrittled, and rated in bad condition if they broke after creasing once with the fingers and were highly discolored. In the case of identical volumes, care was taken to examine paper from the same portion of each book.

IV. RESULTS

Table 1 contains test data for 11 different titles, copies of which were contributed by two or more libraries. The table also contains a statement as to whether the atmosphere in the vicinity of any given library is polluted or relatively free from acid pollution, based upon a careful survey of the surroundings in person or by correspondence, when a personal survey was impracticable and upon what little data on air pollution that is now available. For example, the New York Public Library is situated in the heart of New York City surrounded by high buildings, a condition under which one might expect to encounter a marked degree of atmospheric pollution. Analyses of air in this vicinity show 0.8 to 1.2 parts sulphur dioxide per million parts of air.¹² Similarly the University of Pennsylvania Library is located in down-town Philadelphia, bounded on one side by main-line railroad tracks and in close proximity to an oil refinery

⁹ Burton, J. O., and Rasch, R. H., *B. S. Jour. Research*, vol. 6, p. 603, 1931.

¹⁰ See footnote 5, p. 2.

¹¹ Copies of the official paper testing methods of the Technical Association of the Pulp and Paper Industry may be obtained from the secretary at 370 Lexington Avenue, New York, N. Y.

¹² Communication from the Bell Telephone Laboratories.

TABLE 1.—Test data for paper from identical books stored in different libraries

| Title | Source | Atmosphere | | Date of issue | Fiber composition | | | | Average folding endurance ¹ | Acidity as sulphuric anhydride (fiber suspension) | Copper No. | Alpha cellulose content |
|--|---------------------------------|------------|-----------------------|---------------|-------------------|---------------|-------------|---------|--|---|------------|-------------------------|
| | | Polluted | Relatively unpolluted | | Rag | Chemical wood | Ground wood | Esparto | | | | |
| United States Geological Survey. | University of Pennsylvania | x | | 1892 | 15 | 55 | 30 | 16 | 0.80 | 4.90 | 54.3 | |
| | New York Public Library | x | | 1892 | 15 | 65 | 20 | 46 | .85 | 4.84 | 58.8 | |
| | University of Utah | | x | 1892 | 20 | 65 | 15 | 99 | .42 | 4.53 | 70.2 | |
| Democracy and Social Ethics. | St. Louis Public Library | x | | 1902 | 30 | 70 | | 3 | .75 | 5.16 | 55.1 | |
| | New York Public Library | x | | 1902 | 50 | 50 | | 3 | .73 | 5.30 | 65.9 | |
| | Iowa State College | | x | 1902 | 50 | 50 | | 6 | .47 | 4.71 | 71.2 | |
| | Chattanooga University | | x | 1902 | 40 | 60 | | 6 | .40 | 4.15 | 63.5 | |
| World Almanac. | New York Public Library | x | | 1923 | 45 | 55 | 55 | 280 | .89 | 8.63 | 64.0 | |
| | St. Louis Public Library | x | | 1923 | 40 | 60 | 60 | 680 | .73 | 6.85 | 76.0 | |
| | University of Chicago | x | | 1923 | 35 | 65 | 65 | 790 | .64 | 6.72 | 77.4 | |
| | University of Washington | | x | 1923 | 40 | 60 | 60 | 1,000 | .46 | 5.98 | 84.1 | |
| History of Higher Education in Michigan. | New York Public Library | x | | 1891 | 10 | 65 | 25 | 60 | .71 | 7.13 | 53.5 | |
| | University of Michigan, general | | x | 1891 | 10 | 65 | 25 | 110 | .57 | 6.50 | 59.6 | |
| | University of Michigan | | x | 1891 | 10 | 65 | 25 | 164 | .57 | 5.17 | 69.6 | |
| | Oakland Free Library | | x | 1891 | 10 | 80 | 10 | 500 | .48 | 6.37 | 61.5 | |
| Modern Italian Poets. | St. Louis Public Library | x | | 1887 | 40 | 60 | | 4 | .56 | 6.16 | 49.5 | |
| | New York Public Library | x | | 1887 | 45 | 55 | 55 | 48 | .51 | 3.95 | 55.1 | |
| | Oakland Free Library | | x | 1887 | 45 | 55 | | 300 | .46 | 2.72 | 70.4 | |
| Selective Service Regulations. | University of Pennsylvania | x | | 1918 | 30 | 70 | 70 | 126 | .60 | 7.10 | 76.1 | |
| | Library of Congress | x | | 1918 | 25 | 75 | 75 | 588 | .50 | 4.89 | 82.3 | |
| | New York Public Library | x | | 1918 | 25 | 75 | 75 | 699 | .32 | 7.41 | 74.0 | |
| | Oakland Free Library | | x | 1918 | 40 | 60 | 60 | 1,448 | .33 | 5.77 | 88.2 | |
| Tristram of Lyonesse. | Princeton University | x | | 1882 | | | | 1 | .82 | 7.20 | 54.1 | |
| | Columbia University | x | | 1882 | | | | 100 | .89 | 6.91 | 56.3 | |
| Labor Movement in America. | New York Public Library | x | | 1886 | 55 | 45 | 45 | 3 | .66 | 6.06 | 51.9 | |
| | Library of Congress | x | | 1886 | 50 | 50 | 50 | 5 | .32 | 5.96 | 52.2 | |
| | Iowa State College | | x | 1886 | 45 | 55 | 55 | 8 | .31 | 5.68 | 54.6 | |
| War of the Rebellion. | New York Public Library | x | | 1892 | 15 | 75 | 10 | 25 | 1.06 | 9.25 | 51.4 | |
| | University of Michigan | | x | 1892 | 10 | 80 | 10 | 24 | .87 | 8.95 | 56.5 | |
| | Oakland Free Library | | x | 1892 | 5 | 85 | 10 | 74 | .46 | 5.15 | 68.2 | |
| Weather, Crops, and Markets. | New York Public Library | x | | 1923 | 25 | 75 | 75 | 510 | .76 | 8.96 | 78.7 | |
| | Oakland Free Library | | x | 1923 | 35 | 65 | 65 | 740 | .34 | 4.90 | 88.2 | |
| To-day on the Nile. | New York Public Library | x | | 1905 | 50 | 50 | | 18 | .54 | 5.12 | 69.7 | |
| | Oakland Free Library | | x | 1905 | 45 | 55 | | 25 | .39 | 4.45 | 71.7 | |

¹M. I. T. folding endurance tester. Tension 300 g. A average of machine and cross direction folding endurance.

and numerous chemical plants. The sulphur dioxide content of air in this vicinity was found to vary from 0.1 to 1.8 parts sulphur dioxide per 1,000,000 parts of air ¹³ and damage by sulphur dioxide to the foliage of elm trees in the university botanical gardens has been observed by members of the university staff. With these highly polluted localities may be contrasted that of Iowa State College situated several miles from the down-town section of Ames, Iowa, in an area relatively free from industrial pollution.

Table 2 shows the results of the visual examination of 129 books published before 1911. This date was chosen in order to examine only papers which had been in existence long enough for differences in relative stability to become apparent. The papers are divided into nine groups according to kinds of fibers. Data as to the oldest and the most recent specimens of the various papers and the average age of the specimens in each group are included in Table 2.

TABLE 2.—Relation of state of preservation to kind of fiber

| Fibers | Date of oldest specimen | Date of most recent specimen | Average age | Good condition ¹ | | Intermediate condition ² | | Bad condition ³ | |
|---|-------------------------|------------------------------|-------------|-----------------------------|-------------------|-------------------------------------|-------------------|----------------------------|-------------------|
| | | | | Number of papers | Per cent of total | Number of papers | Per cent of total | Number of papers | Per cent of total |
| Rag..... | 1804 | 1874 | 80 | 16 | 73 | 6 | 27 | ----- | ----- |
| Rag and straw ⁴ | 1867 | 1878 | 61 | 2 | 29 | 4 | 57 | 1 | 14 |
| Rag and chemical wood..... | 1870 | 1908 | 39 | 14 | 33 | 27 | 64 | 1 | 3 |
| Rag, chemical wood and straw ⁴ | 1876 | 1910 | 37 | 2 | 40 | 3 | 60 | ----- | ----- |
| Chemical wood..... | 1889 | 1909 | 32 | 5 | 38 | 8 | 62 | ----- | ----- |
| Chemical wood and straw ⁴ | 1903 | 1910 | 26 | 1 | 50 | 1 | 50 | ----- | ----- |
| Straw ⁴ | 1877 | 1882 | 52 | ----- | ----- | 1 | 25 | 3 | 75 |
| Mixture containing 10 per cent or less ground wood..... | 1869 | 1896 | 45 | 6 | 67 | 3 | 33 | ----- | ----- |
| Mixture containing more than 10 per cent ground wood..... | 1875 | 1904 | 50 | 3 | 12 | 14 | 56 | 8 | 32 |

¹ No indication of weakening—color usually excellent.

² Somewhat embrittled, giving indications of breaking when creased.

³ Very brittle, highly discolored.

⁴ Some or all of the fibers reported as straw may be esparto due to the difficulty of distinguishing between these fibers.

V. DISCUSSION OF RESULTS

The data in Table 1 show that books stored in libraries where the atmosphere is characteristically urban (for example, New York Public Library) contain more acid than other copies of the same books stored in libraries where the atmosphere is less likely to be contaminated (for example, Iowa State College). The data also show that this increase in acidity is invariably accompanied by a decrease in the strength of the paper and characterized in most cases by an increase in copper number and a decrease in alpha cellulose content, all of which are indications of poor condition in paper.

The principal difference between storage conditions in cities and elsewhere, as shown by the survey of library storage conditions previously mentioned, ¹⁴ is the presence in urban air of measurable quantities of sulphur dioxide. This gas, a product of the combustion of fuel and of certain industrial processes, combines with moisture and

¹³ Information from University of Pennsylvania Botany Department.

¹⁴ See footnote 3, p. 2.

oxygen in the air to form sulphuric acid, which is known to be very destructive to paper.¹⁵ The outstanding characteristic of paper which has been exposed to an atmosphere containing sulphur dioxide is an abnormally high acidity. This is illustrated in Table 3 which shows the change in acid content of 3 different papers after natural aging for 4 years in an atmosphere relatively free from sulphur dioxide, and after 240 hours exposure to the action of 2 to 9 parts sulphur dioxide per 1,000,000 parts of air at 65 per cent relative humidity and 30° C. In each case the acidity of the specimen exposed to the action of sulphur dioxide is markedly higher than that of the naturally aged sample. Since it has already been shown that the acidity of books stored in large cities, such as New York and Philadelphia, is usually considerably higher than that of similar books stored in country or suburban libraries and that sulphur dioxide, which in the process of acting on paper produces high acidity in the paper, is present in the air of such cities, it seems reasonable to ascribe the major portion of the greater deterioration noted in the books from city institutions to the action of sulphur dioxide.

TABLE 3.—Increase in acidity of papers

| Sample No. | Fiber composition | | Acidity as sulphuric anhydride | Increase in acidity |
|--|-------------------|-----------------|--------------------------------|---------------------|
| | Rag | Sulphite | | |
| 94011..... | <i>Per cent</i> | <i>Per cent</i> | <i>Per cent</i> | <i>Per cent</i> |
| 94011; 4 years ¹ | 100 | | 0.09 | |
| 94011; SO ₂ -240 ² | 100 | | .10 | 11.1 |
| 94011; SO ₂ -240 ² | 100 | | .18 | 100 |
| 94008..... | 60 | 40 | .08 | |
| 94008; 4 years ¹ | 60 | 40 | .10 | 25 |
| 94008; SO ₂ -240 ² | 60 | 40 | .16 | 100 |
| 94010..... | | 100 | .08 | |
| 94010; 4 years ¹ | | 100 | .12 | 50 |
| 94010; SO ₂ -240 ² | | 100 | .20 | 150 |

¹ Naturally aged four years in an atmosphere relatively free from sulphur dioxide.

² Treated for 240 hours with 2 to 9 parts sulphur dioxide per 1,000,000 parts of air, at 65 per cent relative humidity and 30° C.

The results of this work emphasize further the necessity of eliminating sulphur dioxide from library air, either by washing the incoming air with an alkaline solution as suggested in a previous report,¹⁶ or by some other means. Work now in progress indicates that sulphur dioxide is completely removed by the alkaline wash method.

The results of the examination of 129 books printed before 1911 are shown in Table 2 and indicate that the presence of more than 10 per cent ground wood fibers causes a marked decrease in the resistance of paper to natural aging. This finding is in accord with work on present-day book papers¹⁷ and adds to other evidence secured by the bureau of the importance of fiber purity for the stability of such papers relative to internal sources of deterioration.

The average age of the various groups of papers and the earliest

¹⁵ See footnotes 4 and 5, p. 2.

¹⁶ See footnote 3, p. 2.

¹⁷ Burton, J. O., *E. S. Jour. Research*, vol. 7, p. 429, 1931.

date for each group, given in Table 2, are of historical interest as they show the approximate time of initial use of the different types of fibers in book papers. This information also serves as a warning that many valuable books printed later than 1875 may contain impermanent papers made from crude fibers. Such fibers are rarely found in important publications after 1910. A peculiarity observed in some of the old books was the use of good and poor papers. In several instances the best grades of paper were mixed with the poorest grades, which is one cause of the uneven deterioration of different pages often observed in old books.

VI. SUMMARY

1. The paper of books printed at the same time on the same paper does not deteriorate at the same rate, even though subjected to approximately the same degree of use.

2. The paper of books stored in libraries where the atmosphere is characteristically urban was invariably found to be less well preserved than the paper of similar books stored in a less contaminated atmosphere.

3. The greater deterioration of books stored in large cities is probably due to the harmful effect of contact with air polluted by sulphur dioxide.

4. Papers containing appreciable quantities of crude fibers such as ground wood, were invariably in poorer condition than those containing chemically refined rag and chemical wood fibers. Papers containing crude fibers were most frequently found in books printed during the period 1875 to 1910, even valuable records being printed on papers of this type.

5. The uneven deterioration of different pages sometimes observed in old books is often due to the use of good and poor grades of paper in the same book.

VII. ACKNOWLEDGMENT

The assistance of W. L. Holt¹⁸ and of the staff of the New York Public Library, Coker College, Library of Congress, Princeton University Library, Columbia University Library, University of Utah Library, University of Nevada Library, Seattle Public Library, Portland (Oreg.) Public Library, University of Chattanooga Library, University of Michigan Library, St. Louis Public Library, Library of Iowa State College, University of Pennsylvania Library, Oakland Free Library, University of Chicago Library, Library of Louisiana State University, and of Yale University Library is hereby gratefully acknowledged.

WASHINGTON, February 25, 1933.

¹⁸ Assistant research associate representing the National Research Council.



