Appendix Two
The Acidic and Brittle Paper Problem and its Solutions[1]

In 1874, Harvard President Charles W. Eliot wrote, "the Library is the heart of the University." He could not have known that the paper manufacturers of his era, in revolutionizing the way paper was made, were unknowingly igniting the slow fires of paper deterioration. These slow fires would begin to threaten access to the "heart of the University" a mere hundred years later.

The legacy of the acid papermaking process—the acidic and brittle paper problem—is most acute for books printed between 1840 and 1950. When John Harvard bequeathed his books in 1638, paper was made from a pulp of cotton rags, beaten and formed by hand into strong, durable sheets. Although the paper in the books published in John Harvard's day remains strong and flexible, industrial age books and documents are threatened with extinction.

Papermaking Technology and its Effect on Paper Permanence

Paper was invented about 2,000 years ago in China, and spread to Europe during medieval times. Until relatively recently, Western paper was made by hand from a pulp of cotton rags. This type of paper was strong and chemically stable. A master papermaker could produce about 125 sheets of it per day.

The growing need for paper led to the development of mechanized papermaking processes in the nineteenth century. New fiber sources were also needed if supply were to match demand. Wood pulp was introduced during the 1840s as a viable alternative to cotton rags. At the same time, paper mills began to use new chemical additives, especially aluminum sulphate (commonly known as alum), to help give their products a good finish and printability.

Unfortunately, this new paper contained the seeds of its own destruction. The alum sizing combines with humidity in the air to produce sulphuric acid. Over time, this increased acidity destroys the flexibility of cellulose fibers and makes paper brittle. Other chemicals, such as the chlorine used to bleach the paper white, increase the rate of deterioration. Alum-sized acidic paper can become unusable in as little as fifty years' time.

Paper made from ground wood, as opposed to chemically cooked pulp, also contains lignin, a naturally-occurring substance that gives woody plants their

[1] The text of this appendix was adapted from the exhibition "Slow Fires in Harvard's Libraries," prepared by Carolyn Morrow and Elaine Benfatto of the Harvard University Library Preservation Office and on display in various Harvard libraries throughout 1991.

strength. A high percentage of lignin in paper, for example in newsprint, will oxidize and turn the paper brown and brittle within a few years of its manufacture.

Modern developments in papermaking

In the 1880s, the first articles documenting the rapid deterioration of the new machine-made paper appeared in academic journals. However, the true cause of the problem was not fully understood until the mid-twentieth century, with the work of William J. Barrow at the Virginia State Library.

Barrow's work in the 1960s was concurrent with the formulation of new chemical additives to replace alum in the manufacture of paper. A new sizing, Aquapel®, was invented to be used with a new alkaline process of papermaking. This and other technical advances now allow for the manufacture of so-called "permanent" paper on a cost-effective basis.

Alkaline papermaking not only has a positive impact on paper quality, it also reduces the toxicity of many waste products associated with paper manufacture. Unfortunately, not all environmental issues have been solved by alkaline papermaking. Dioxin, a highly carcinogenic chemical, has been discovered in the waste from paper mills. The papermaking industry is working to understand how dioxin is produced and how to adjust the manufacturing process to eliminate it.

Recycled paper

Recycled paper is another significant twentieth-century development, one that has a positive impact on the environment, but, unfortunately, a negative effect on paper permanence. The recyling process degrades the strength of the paper fibers and combines materials that were probably manufactured with acid-producing additives. Even if recycled paper is manufactured using the new alkaline technology, its permanence is questionable. Although it is important that recycled papers be used, it is even more important that they be put to the right use.

The National Response to the "Brittle Book" Crisis

The National Endowment for the Humanities responded to the brittle book crisis in the nation's libraries by establishing the Office of Preservation in 1985. Its activities stimulated widespread attention to the problem, and in 1986 and 1987, several Congressional hearings were held on the threat facing libraries and archives

With urging from Congressman Sidney Yates (D-IL), Chairman of the House Interior Appropriations Subcommittee, NEH came forward at its appropriations hearing on April 21, 1988, to request a dramatic increase in the budget of the Office of Preservation, with the added funds targeted for the microfilming of brittle books. The multi-year plan outlined by NEH increased funding from $4.5 million in FY 1988 to $12.5 million in FY 1989 and provided for steady increases to $20.3 million by 1993. Congress approved the plan in principle and has since increased the budget to recommended levels.

In 1989, the Library of Congress, the National Archives, the National Endowment for the Humanities, and six other national associations and organizations sponsored an invitational conference of officers of state libraries, archives, historical agencies, and universities. Its goal was to encourage the states to develop cooperative, statewide preservation programs.

In 1990, Congress approved a $6 million increase in the 1990 budget of the NEH Office of Preservation, specifically for a "national heritage program" to improve the preservation conditions of the nation's cultural collections held by historical museums. Richard Darman, U.S. Office of Managment and Budget Director, in an essay entitled "Preserving America's Heritage" in The Budget for Fiscal 1991, wrote:

> One might ask what "preserving America's cultural heritage" may have to do with investing in America's future. To many the connection is not obvious. . . . To the extent that investing in the future tends to emphasize technological advances—as it should—there is a need to assure a counterbalancing attention to aesthetic values. To the extent that it implies a race through time, there is a need for a balancing appreciation of history. And to the extent that America's traditional cultural values have helped make America uniquely strong, it is important that these values be preserved.

The Commission on Preservation and Access

The Commission on Preservation and Access was established in 1986 by the Council on Library Resources as a private, non-profit organization to encourage collaborative strategies for preserving and making available the deteriorating published and documentary record. The first initiative of the Commission was to help establish a nationwide "brittle books" program, which they envisioned as a coordinated, large-scale twenty-year plan to reformat on microfilm one-third of the estimated 10 million books in the nation's libraries that were becoming unusable due to paper deterioration.

Commission President Patricia Battin wrote in a 1989 editorial:

> Americans call the problem brittle books. To the Norwegians, it's sour books—*sur bøker*—and to the Germans—*Bröselbuch*—or the book of crumbs. But the French use the subtlety of their language to project the true horror of the scholarly world's potential loss—*livres incommunicables*—or silent books. If the books are silent, our history is lost to us. The great voices of nineteenth-century scholarship will be stilled far more effectively and finally than by war, flood, censorship, or fire."[2]

Other initiatives of the Commission on Preservation and Access include:

- exploring image digitization and electronic storage as a preservation and access medium
- improving the longevity of all recording mediums in cooperation with authors, legislators, publishers, and manufacturers
- working internationally to create a compatible, machine-readable international database of preserved titles to insure that preservation efforts can be shared across national boundaries
- expanding the public's access to preserved materials by stimulating new thinking about the use of emerging technologies and new delivery systems to ensure equitable access.

[2] Patricia Battin, "Crumbling Books: A Call for Strategies to Preserve Our Cultural Memory," *Change* (September/October 1989).

Solutions to the Acidic and Brittle Paper Problem

Making the Most of Good Fortune: Alkaline Papermaking

The development in the 1960s of a synthetic sizing agent compatible with alkaline papermaking was not in itself sufficient to change paper manufacturing, but other factors fortunately conspired to increase the number of mills "going alkaline." Inexpensive calcium carbonate was available to use as a high-quality "filler" to increase opacity and printability. Strict EPA regulations concerning waste treatment and effluent levels at paper mills encouraged the industry to switch to the cleaner, less-polluting alkaline process. Libraries and enlightened citizens have mounted an impressive public relations and educational effort to encourage manufacturers to produce alkaline paper and publishers to choose it. Although printing and writing paper accounts for less than two percent of the paper produced in the United States, the trend toward conversion of mills continues.

In October 1988, the Technical Association of the Pulp and Paper Industry (TAPPI) held an international conference on the topic of permanent paper and launched an era of greater understanding and communication among librarians, publishers, and papermakers. That same year, Senator Claiborne Pell (D-RI) introduced a Senate joint resolution to establish a "national policy on permanent paper." The House Appropriations Committee in July 1989 directed the Government Printing Office to "aggressively pursue the use of alkaline paper for inhouse and commercially procured printing" and develop a plan and a strategy to identify those government publications of enduring value that should be printed on alkaline paper. Similar initiatives have been forthcoming from the private sector as authors and publishers recognize their common stake in preventing the crumbling of our cultural and documentary heritage.

Retarding Deterioration Through Cool Storage

Although libraries and archives can expect that greater and greater portions of the new materials they acquire will be printed on alkaline paper, there remains a substantial problem in the form of millions of books and documents already printed or written on acidic paper. Whether these last indefinitely or only briefly depends on more than the materials and methods used in manufacture. It depends as well on the conditions under which they are stored.

Acids in paper catalyze hydrolytic degradation of the polymeric cellulose molecules, reducing their chain length. Even a few chain scissions per molecule cause a substantial loss of physical properties.[3] The inevitable chemical reactions that turn acidic paper into brittle, unusable paper can be substantially retarded, however, by storage in cool, dry environments.[4]

J. A. Chapman was probably the first to demonstrate the importance of environmental conditions. In "An Inquiry into Perishing Paper" (*Calcutta Review*, 1911), he showed that books stored in tropical areas of India deteriorated more

[3] An overview of the chemical principles behind paper deterioration was published by Chandru J. Shahani and William K. Wilson in the May-June 1987 issue of *American Scientist*.

[4] Donald K. Sebera, "A Graphical Representation of the Relationship of Environmental Conditions to the Permanence of Hygroscopic Materials and Composites," in *Proceedings of Conservation in Archives*, an international symposium, Ottawa, Canada, May 10-12, 1988 (Ottawa Canada), pp. 51-75.

rapidly than the same books stored in cooler areas of northern India or in England. Since then, a considerable body of data has been developed, using accelerated aging techniques, to demonstrate that higher temperature and relative humidity facilitate the degradation of cellulose and that cool, dry environments significantly extend the life of paper.

The role of air pollution in the degradation of paper has also been studied by comparing books in heavily-polluted cities with the same books stored in rural areas. Laboratory studies have shown that paper exposed to small amounts of sulfur dioxide, nitrogen oxide, and ozone undergo substantial degradation.

Treating Acidity and Embrittlement at the Source

The technology now exists on a commercial scale to chemically stabilize acidic paper, thereby preventing embrittlement. Depending on the original strength and composition of the paper, deacidification will extend the useful life of an acidic book three to five times. Approximately two-thirds of Harvard's library collections would benefit from this treatment.

Studies conducted at the Library of Congress, Yale, and Stanford have confirmed that 25 to 35 percent of the collections of large, old research libraries are already brittle. While it is likely that most brittle materials will be reformatted onto microfilm, the Harvard collections contain many items with graphics, illustrations, and plates for which microfilm is not a suitable option. These materials should be preserved by methods that strengthen or provide support for the weakened paper. Unlike deacidification, however, low-cost paper strengthening technology is still in the research and development stage.

Deacidification: Forty-Five Years of Research and Development

Research to develop chemical methods to stabilize acidic paper and prevent deterioration and embrittlement has been undertaken steadily since the mid-1940s. A technique of aqueous deacidification was first developed by William J. Barrow, and a variation is still used by paper conservators in libraries and museums to treat individual paper artifacts.

Since the 1960s, libraries have sponsored research to find a mass solution to the problem of acidic paper—one that could be applied to whole books—and to encourage activity by the private sector. There are currently three different processes under commercial development with existing pilot plants. During mass deacidfication, whole books or groups of paper documents are treated under vacuum pressure in a chamber to neutralize the acid in the paper and leave and alkaline reserve to buffer against future acid attack from polluted environments.

Pioneer research undertaken by Richard D. Smith at the University of Chicago led to the development of a non-aqueous deacidification method—the first step towards a mass process. Smith called his process Wei T'o, after an ancient Chinese god thought to protect art against destruction from fire, worms, insects, and robbers (big or small). The process uses methoxy magnesium methyl carbonate dissolved in chlorofluorocarbon and methanol solvents. Smith went on to devise a system to deposit the deacidification agent into whole books. The first mass deacidification pilot plant was installed in the Public Archives of Canada in 1981.

In 1987, Texas Alkyls (an affiliate of Akzo Chemical, Inc.) designed and built a pilot mass deacidification facility in Deer Park, Texas, for the Library of Congress—

to perfect treatment parameters for LC's patented DEZ process, under development by LC since 1973. Under their contract, Akzo and Texas Alkyls retained ownership of the pilot plant, and in 1989, Akzo acquired an exclusive license from the U.S. Department of Commerce. Akzo is committed to making the DEZ process available to libraries worldwide.

A third process was developed by the FMC Lithium Corporation starting in 1988. The Lithco process is a non-aqueous liquid process using hydrocarbon and halocarbon soluble magnesium butoxytriglycolate to neutralize the paper and add a magnesium carbonate buffer. Lithco's pilot plant, built in 1990, is located in Bessemer City, North Carolina.

Projected at $6-$10 per book, mass deacidification is comparable to the cost of binding and thus a cost-effective preventive preservation option, and Harvard, like a number of libraries and library consortia, has established a task force to review mass deacidficiation technologies and recommend action.

Paper Strengthening: Promise for the Future

Research into paper strengthening methods has followed a parallel course to that of deacidification—from techniques developed for individual sheets to mass production methods involving treatment on a molecular level.

William J. Barrow invented a mechanized system in the 1930s to laminate brittle sheets of paper between tissue and cellulose acetate film. This method replaced the earlier hand method of "silking"—applying transparent silk to a weak document with a starch paste. Paper conservators now prefer a reversible technique of encapsulating brittle paper between thin, inert sheets of polyester film. The film is sealed on the edges by means of ultrasonic vibration.

"Leaf-casting" is a mechanized method of paper strengthening used by conservators to strengthen valuable paper artifacts. Using vacuum pressure, a slurry of paper pulp is pulled through the areas of loss in a document to fill in lacunae or strengthen an entire leaf.

In the late 1970s, Nova Tran, a subsidiary of Union Carbide, developed parylene technology, a system that deposits a clear polymer conformal coating on the surface of brittle paper. Its major use, however, has been by the electronics industry to protect delicate microcircuitry from hostile environments. Studies are underway at the J. Paul Getty Conservation Institute to qualify the use of parylene for ethnographic collections.

Under contract to the British Library, the University of Surrey has been developing a paper strengthening method using graft polymerization. Books are placed in a small chamber, doused with a chemical mix of monomers, and irradiated with gamma rays to change the monomers to polymers. The British Library is seeking financing for a pilot plant.

When paper strengthening becomes a viable commercial option, Harvard's libraries will want to take advantage of this technology for selected brittle materials, particularly those with illustrations.

Preservation and Access: Brittle Book Replacement and Reformatting

Research libraries and archival repositories began using microphotography in earnest in the mid-1930s to make rare and scarce materials—and frequently whole collections on a particular subject—more widely available. As paper deterioration

became an urgent problem, microfilming became an accepted method of preserving the intellectual content of a deteriorated item.

In 1968, twenty years before Congressman Yates held the hearing on increasing the funding for a national brittle books program, the Library of Congress launched a Brittle Book Project with funding from the Council on Library Resources and began publication of the *National Register of Microfilm Masters.* The *Register* is now being converted to machine-readable form through a project sponsored by NEH and the Andrew W. Mellon Foundation. In the 1990s, the concept of a decentralized "national" collection of master negative microforms is widely accepted. At $60-$90 per volume, preservation microfilming is best operated as a coordinated national program in which libraries share the information that an intellectual work has been preserved and make low-cost copies available to other libraries.

Microfilm to Image Technology

In 1983, the National Micrographics Association changed its name to the Association for Information and Image Management (AIIM). The name change reflected a revolution in the development of electronic imaging technology and new applications in all areas of information storage, retrieval, display, and dissemination.

Like microfilm, electronic digitization involves taking a "picture" of the page as it exists. Whereas microfilm stores a miniaturization of the page directly onto a gelatin emulsion on a polyester film base, digitization records the image of the page electronically as a series of 1's and 0's—known as bits. Microfilm images are stored on 35mm film, but digitized images may be stored on a variety of formats, including magnetic disk, optical disk, digital video tape, magnetic tape, and CD-ROM.

Image Quality

The silver-halide film typically used for preservation microfilming produces a high-resolution (sharp) image at approximately 1000 dpi (dots per square inch). Digital scanning is typically 200-400 dpi. Higher resolution is possible but adds considerably to storage cost. For example, doubling the number of dpi uses four times as much space on an optical disk. However, 300 dpi corresponds to the resolution of most laser printers and is an acceptable resolution for many applications.

Microfilming and digitization are only capable of reconfiguring an item—they do nothing to preserve it in its original state. In the case of straight text, the reconfiguration may be acceptable to the user, and even desirable if it facilitates access. However, those who need the original image for purposes of duplication, or who rely on a comparison of images to support their research, are not well served by surrogates. Neither microfilm nor digitization, for example, reproduces halftones clearly, and subtle gradations of color may be either entirely lost or distorted.

Preservation Medium

The use of microfilm as a preservation option is predicated on the assurance that microfilm is a permanent (300 years or more) storage medium. Although digital storage media are being constantly improved, manufacturers typically quote a mere 10 to 20-year storage life. Digital signals can, however, be regenerated indefinitely without loss, even though the medium might degrade. To do so costs money, and librarians are keenly conscious of the danger that the digital signals might not be regenerated in time to prevent loss.

Turn the Pages Once

Preservation reformatting—whether by filming or by electronic digitization—involves selecting and preparing materials to film. It also requires turning the pages one-by-one to make a copy. These parts of the process are the most labor-intensive —regardless of the choice of reformatting technology. It may be that the two will work together in the future. In one possible scenario, microfilm may serve as the means of capturing texts archivally, with those images being converted to digital form for dissemination and use.

Regardless of the reformatting technology used, the result is a duplicate copy of a previously-published work. The challenge for library bibliographic data bases is to clearly represent the intellectual work and its "multiple versions" to the library user. A plethora of formats and descriptions can impede instead of enhance access. Likewise the national data bases are used to record the information that a particular work has been preserved. This is the basis for contributions by many libraries to a coordinated nationwide preservation program.

The Solutions Applied

A combination of these solution to the brittle and acidic paper problem—cooler storage environments, mass deacidification, paper strengthening, and microfilming of brittle books—will allow Harvard to maintain its extraordinary collections for use. Modern paper, in its "new" alkaline form, will probably continue to be the most common capture, storage, and access technology used for library materials. However, the newer electronic and optical technologies combined with computer access are already changing the face of library service. These technologies will enhance access to information, including the information resident in several generations of brittle books that must be transferred to microfilm to save their intellectual content.