THE MECHANISMS AND CAUSES OF PAPER DETERIORATION

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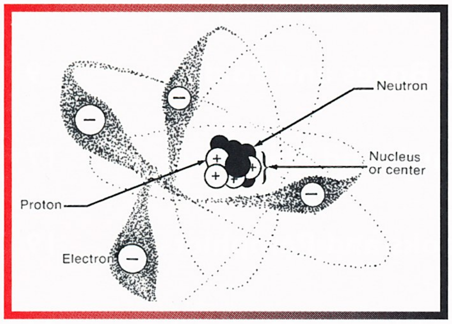
In the ancient Greek seacoast town of Abdera, 25 centuries ago, philosophers Leucippus and Democritus were teaching that all matter is composed of empty space and indivisible bits of matter called atoms. What little is left of Abdera is now only ruins. None of the written works of Leucippus have been preserved over the millennia, and only a few tantalizing fragments of the writings of Democritus still exist today. However, their insight that all matter consists of atoms is, today, the foundation upon which modern chemistry is based. To understand the chemical structure and acid deterioration of paper, we need to know how atoms combine into molecules which make up paper fibers.



The Atom

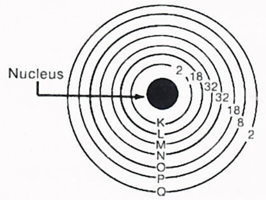
Today, physicists using massive particle accelerators are continually breaking atoms into even smaller, more fleeting, subatomic particles such as hadrons (pions, protons and neutrons), leptons (muons, electrons and neutrinos) and quarks. Although fascinating, the subject of subatomic particles would, at this point, unnecessarily complicate our efforts to understand the atom and its role in the deterioration of paper fibers.

The primary subatomic particles of atoms are protons, neutrons and electrons. Atoms have a dense nucleus consisting of positively charged particles called protons and neutral particles called neutrons. A negatively charged cloud of particles called electrons orbits the nucleus of the atom.

Protons and neutrons have almost 2,000 times the mass of an electron and, therefore, comprise nearly all the total mass of an atom. This means, for example, that perhaps only one ounce of our body weight is composed of electrons, the rest consisting of protons and neutrons; yet we will see that these electrons form the bonds which unite the atoms of elements such as carbon, hydrogen and oxygen into the molecules (cellulose) which comprise paper fibers.

The reason atoms of elements differ from each other is that they contain different numbers of protons, neutrons and electrons. For example, an atom of hydrogen contains one proton and one electron (hydrogen is the only element which has no neutrons). An atom of carbon contains six protons, six neutrons and six electrons, and an atom of oxygen contains eight protons, eight neutrons and eight electrons, while uranium contains 92 protons, 146 neutrons and 92 electrons.

Nearly all known elements exist in several isotopic forms. These isotopes are simply atoms of the same elements which have the same number of protons, but differing numbers of neutrons. For instance, the element calcium exists naturally in six isotopic forms. The calcium isotopes thus contain 20 protons plus 20, 22, 23, 24, 26 or 28 neutrons, respectively. Atoms can also exist as electrically charged species (called ions) meaning they have lost one or more electrons (positively charged species) or gained one or more electrons (negatively charged species).



major energy level	K	L	M	N	O	P	Q
maximum number of electrons	2	8	18	32	32	18	2

The electron cloud around the nucleus of an atom is composed of a number of different energy levels or "orbits". If energy is absorbed by an atom, one or more electrons may jump from a lower energy level to a higher one. When electrons return to a lower "orbit" or energy level, they emit radiant energy in the form of visible light, ultraviolet light, radio waves, x-rays or other wave lengths of the electromagnetic spectrum. The number of electrons present in each of an atom's energy levels or "orbits" enables a chemist to make predictions about its chemical properties. Atoms unite with other atoms to form molecules by sharing electrons between the orbits of each atoms. These chemical reactions occur primarily between electrons in the outer energy levels or "orbits" of one atom with another. When the electron clouds of separate atoms overlap and electrons are redistributed among the outer "orbits" of these atoms, we find that either one atom will lose one or more of its electrons to the other atom (ionic bond), or each atom will share one or more electrons with the other atoms (covalent bond). Since gaining or losing a negatively charged electron will cause one atom to have either a less positive (negative) or more positive total electric charge than the other atom, an electrostatic attraction is formed between the atoms. This attraction is the chemical bond.

Covalent Bonds

The three atoms, carbon, hydrogen and oxygen, when forming a cellulose chain (molecule), are held together by two types of chemical bonds. The covalent bond, which is the primary holding force between the glucose molecules making up a cellulose chain, and the weaker hydrogen bond which plays an important role in forming cellulose chains into adjacent sheets.

Covalent bonds occur when atoms share one or more pairs of electrons between their outer energy levels or "orbits". This rearrangement of outer energy levels is such that the electrons are not lost to an atom, but are shared between the orbits of the various atoms comprising the molecule. This sharing of electrons between orbits bonds the atoms "covalently" together into molecules. Atoms, such as carbon and oxygen achieve stability by having eight electrons in their outer orbits. However, an atom never has more than eight electrons in its outermost orbit. For example, potassium has only eight electrons in its "M" orbit and one electron in its "N" orbit, even though the "M" orbit of an atom is capable of holding up to 18 electrons. Chemical reactions occur between atoms as they seek to achieve a stable outer "orbit" (energy level) of eight electrons.

Hydrogen Bonds

Different atoms vary in their ability to attract electrons. Thus when atoms are covalently bonded together into molecules, the negatively charged electrons will spend a disproportionate amount of time orbiting the nucleus of the atoms which most strongly attracts them. This causes the molecule to exhibit electrostatic polarity because one end of the molecule will have a slightly more positive or slightly more negative charge than the other. These oppositely charged ends of the molecule are separated in the same manner as the oppositely charged poles of a magnet. In the case of hydrogen and oxygen atoms which are being held together by hydrogen bonding in adjacent cellulose molecules, the electrons spend more time orbiting the oxygen nucleus, which gives it a more negative charge and the hydrogen nucleus a more positive charge.

When molecules containing an oxygen atom bonded to a hydrogen atom (cellulose) approach each other, the electrostatic polarity of this bond will hold these molecules together. The positively charged hydrogen atom on one molecule will be attracted to the negatively charged oxygen atom on the other molecule. This attraction is called the hydrogen bond and is responsible for holding adjacent cellulose chains together to form sheets.

One additional bonding mechanism we find in paper fibers is Van der Waals force. Van der Waals force is actually a collection of three forces. 1) a dipole force such as the attraction you find between the negative and positive poles of two magnets; 2) an induction force such as that which causes a magnet to affect a non-magnetized piece of iron; 3) the intermolecular forces in non-polar materials. This is the very weak attraction all molecules have for each other. These forces act only at very short distances.

We know that atoms of hydrogen, oxygen and carbon are formed by combing protons, neutrons and electrons (see illustration 3). These atoms bond together chemically to form molecules of glucose as shown in illustration 4.

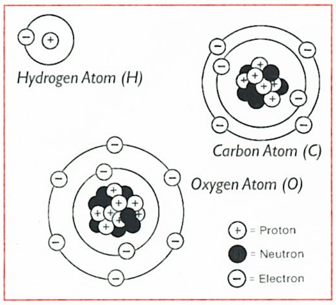


Illustration 3—Atoms of carbon, hydrogen and oxygen which combine to form the glucose units which comprise the cellulose molecule as shown in illustrations four and five.

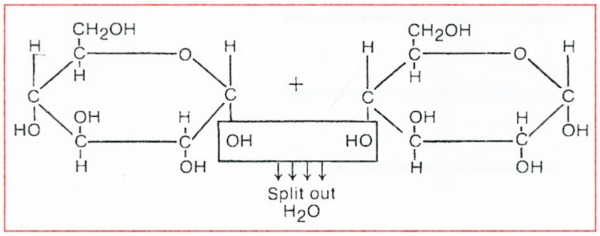
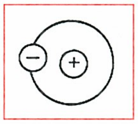
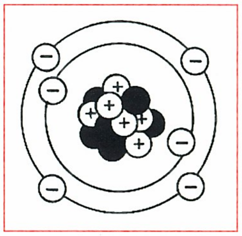


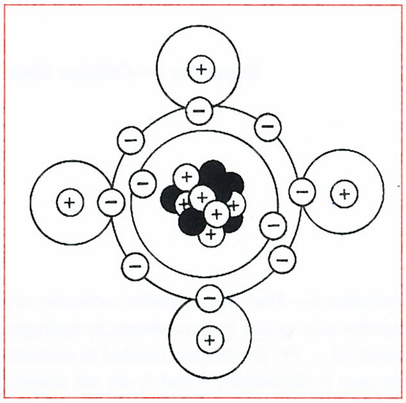
Illustration 4



Hydrogen Atom
1 proton, 1 electron



Carbon atom
6 proton, 6 electrons
(2 in "K" orbit, 4 in "L" orbit)



Methane molecule, CH_4 four hydrogen atoms sharing electrons (covalent bonding) with one carbon atom.

Illustration 2B. A molecule of methane, CH_4, showing four hydrogen atoms sharing electrons (covalent bonding) with one carbon atom. The single electron from each of the four hydrogen atoms combine with the four electrons in the "L" orbit of the carbon atom to form a stable outer orbit containing eight electrons.

Cellulose

Cellulose, from which our paper is fabricated, is built from glucose molecules bonded covalently together into long chains. Each alternating glucose ring of the cellulose molecule is flipped over and the water molecule (H2O) has been split out leaving an oxygen molecule between each ring. This chain or ribbon (the cellulose molecule) will continue for 3,000 to 5,000 glucose units (see illustration 5).

These long ribbon-like chains (molecules) are built up into "sheets" which are held together by the side-to-side hydrogen bonding between the chains (see illustration 6).

The sheets of cellulose (shown in illustration 6) are held in staggered layers, one on top of another by Van der Waals force. The geometry of the short, carbon-hydrogen bonds minimizes the distance between layers and, therefore, Van der Waals forces (which are proportional to the inverse of the sixth power of the intermolecular distances) are maximized (see illustration 7).

These small units of cellulose formed through side-by-side hydrogen bonding and layered by Van der Waals forces are called microfibrils. These microfibrils will crystallize (organize into units) into bundles by the same side-by-side hydrogen bonding and layer-to-layer Van der Waals interaction that formed the microfibrils. These bundles are then crystallized into fibers by the same side-to-side hydrogen bonding and layer-to-layer Van der Waals forces. The microfibrils have nearly perfect bonding, both side-by-side and layer-to-layer, but each successive stage of formation has a progressively less perfect degree of bonding because any imperfection in the first stages of crystallization will be progressively magnified during progression to the final fiber formation. These fibers are mixed with water and often other chemicals, beaten into a slurry and spread onto a forming screen. They are then pressed together and dried to produce a finished sheet of paper.

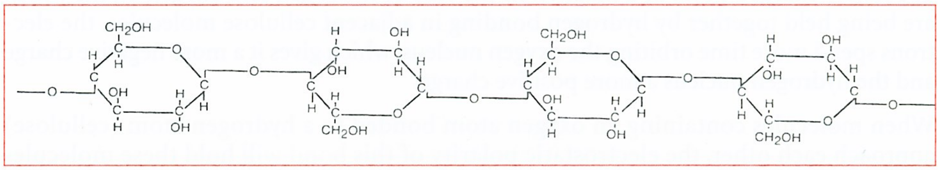


Illustration 5—Cellulose Chain

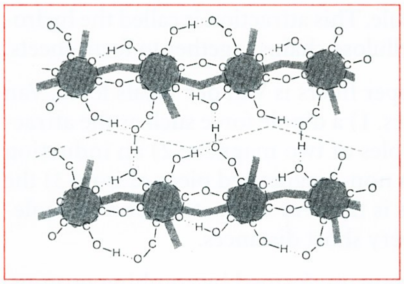


Illustration 6—The long ribbonlike molecules are held together side to side to form sheets, by hydrogen bonds (O . . . H). (Hydrogens bonded to carbons, as seen in illustrations 4 and 5, are not shown.)

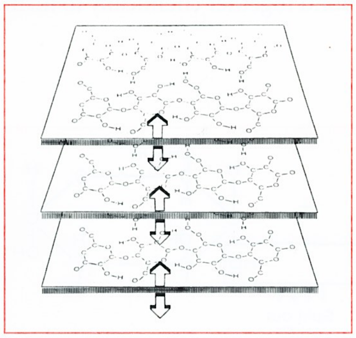


Illustration 7—The sheets of cellulose are held in staggered layers, one on top of another by Van der Waals force. The geometry of the short carbon-hydrogen bonds minimize the distance between layers, and therefore Van der Waals forces are maximized.

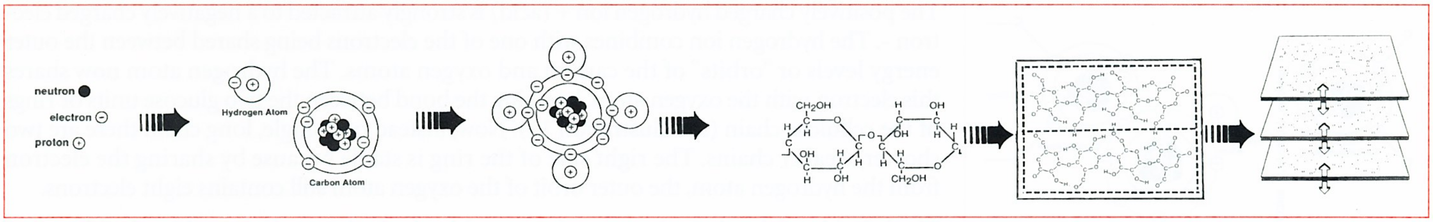


Illustration 8—Subatomic particles, protons, neutrons and electrons . . .

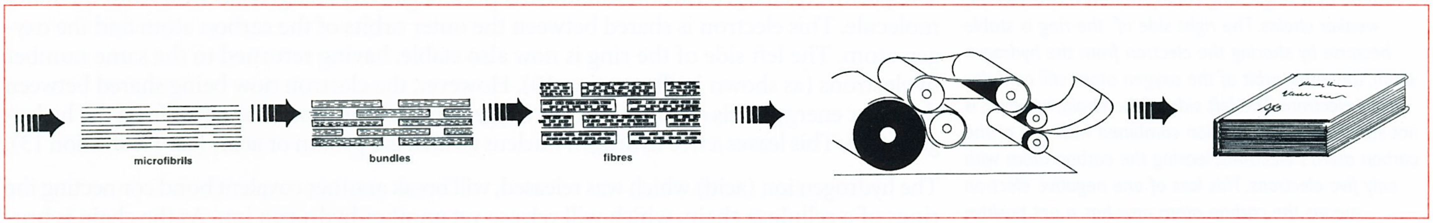
. . . combine to form atoms.

Atoms combine to form molecules.

Atoms of carbon, hydrogen and oxygen combine to form the glucose units which make up the long ribbon-like chain (molecule) of cellulose. This chain or "ribbon" continues for 3000 to 5000 units.

These long ribbon-like chains (molecules) are built up into sheets, which are held together by the side to side hydrogen bonding between the chains. (O . . . H represents hydrogen bonding.)

The sheets are stacked tightly into layers and held securely together by Van der Waals forces. This is a microfibril.



microfibrils

The microfibrils organize into bundles by the same side-to-side hydrogen bonding and layer-to-layer Van der Waals interaction that formed microfibrils.

The fibre is formed from bundles in the same way microfibrils and bundles were formed.

paper maker

paper products

Acid Deterioration

The paper just described and depicted in illustration 8 is a completely pristine sheet made entirely from long chain, alpha cellulose fibers with no additives or impurities of any kind. Alpha cellulose is the pure, long chain cellulose depicted in illustration 5. Unfortunately, most paper available today contains a variety of additives, impurities and other less stable plant products which cause acid deterioration of paper. Other culprits which also have a deleterious effect on paper are environmental and atmospheric acids and pollutants. As you may have surmised when reading about the construction of the paper fiber, the destruction follows essentially the same route but in the reverse direction. Acids attack the bonds which hold together the glucose rings, the cellulose chains, the microfibrils, the bundles and the fibers.

What is an acid? A simplified, but acceptably accurate description is that an acid is any substance which can donate a proton. Earlier it was mentioned that the hydrogen atom is the only element which has only one proton in the nucleus and one electron in "orbit". When hydrogen loses that negatively charged electron, it becomes positively charged (an "ion"), consisting of only one proton. This proton is strongly attracted to negatively charged electrons which overlap and share outer energy levels or "orbits" with other atoms to form the chemical (in this case, covalent) bonds which hold the long chain, cellulose molecule together.

The oxygen atom (0), shown connecting the two glucose units (rings) in illustration 9 has formed a covalent bond by sharing the six electrons in its outer (L) "orbit" with one electron from each carbon to form a stable outer "orbit" of eight electrons. The two hydrogen atoms each share their single electron with the three electrons each carbon atom has left. Combined, this provides another stable outer orbit of eight electrons. Now an acid (a hydrogen ion - proton [H+]) is introduced (see illustration 10).

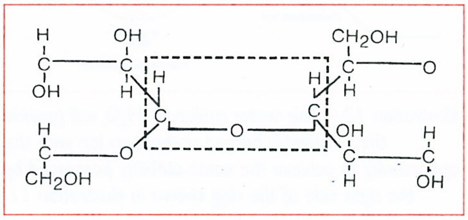


Illustration 9—The covalent bond connecting the two glucose units (rings) is shown within the dotted area.

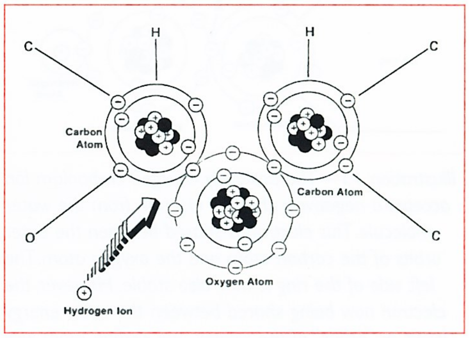


Illustration 10—The positively charged hydrogen ion = (acid) seeks a negatively charged electron.

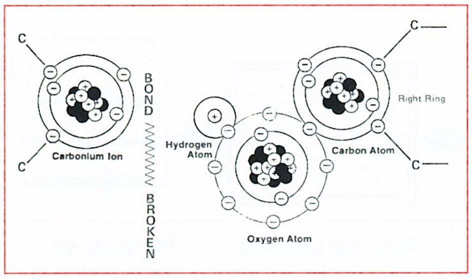


Illustration 11—The hydrogen ion combines with one of the electrons being shared between the outer energy level or orbits of the carbon and oxygen atoms. The hydrogen atom now shares this electron with the oxygen atom, breaking the bond between the two glucose units or rings of the cellulose chain. Now, instead of a single long chain, there are two shorter, weaker chains. The right side of the ring is stable because by sharing the electron from the hydrogen atom, the outer orbit of the oxygen atom still contains eight electrons. The left side of the chain, however, is not stable. The hydrogen ion combined with one of the carbon atom's electrons, leaving the carbon atom with only five electrons. This loss of one negative electron means the carbon atom now has a net positive charge, so it is now a cabonium ion.

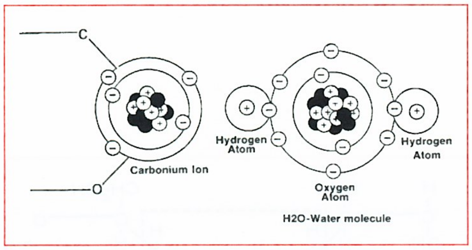


Illustration 12—This water molecule, H_2O, will provide the positively charged carbonium ion with the opportunity to achieve the same stability possessed by the right side of the ring shown in illustration 11.

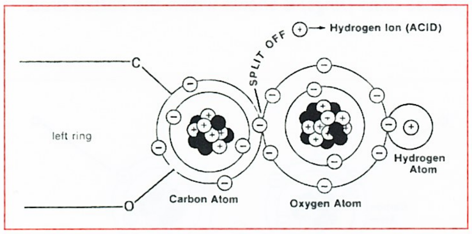


Illustration 13—The positively charged carbonium ion accepts a negatively charged electron from the water molecule. This electron is shared between the outer orbits of the carbon atom and the oxygen atom. The left side of the ring is now also stable. However, the electron now being shared between the outer energy levels or "orbits" of the oxygen and carbon atom was taken from the hydrogen atom. This leaves a hydrogen ion = (acid) free to break another covalent bond between the ring in a cellulose chain.

The positively charged hydrogen ion + (acid) is strongly attracted to a negatively charged electron -. The hydrogen ion combines with one of the electrons being shared between the outer energy levels or "orbits" of the carbon and oxygen atoms. The hydrogen atom now shares this electron with the oxygen atom, breaking the bond between the two glucose units or rings of the cellulose chain (see illustration 11). Now, instead of a single, long chain there are two shorter, weaker chains. The right side of the ring is stable because by sharing the electron from the hydrogen atom, the outer orbit of the oxygen atom still contains eight electrons.

The left side of the chain, however, is not stable. the hydrogen ion combined with one of the carbon atom's electrons leaving the carbon atom with only five electrons. This loss of one negative electron means the carbon atom now has a positive charge, so it is now a carbonium ion. The positively charged carbonium ion now seeks to achieve the same stability possessed by the right side of the ring shown in illustration 11. The presence of a water molecule will provide the opportunity for the carbonium ion, and the left side of the ring, to become stable (see illustration 12).

The positively charged carbonium ion accepts a negatively charged electron from the water molecule. This electron is shared between the outer orbits of the carbon atom and the oxygen atom. The left side of the ring is now also stable, having returned to the same number of electrons (as shown in illustration 10). However, the electron now being shared between the outer energy levels or "orbits" of the oxygen and carbon atom was taken from the hydrogen atom. This leaves a free hydrogen nucleus (which is a proton or acid) (see illustration 13).

The hydrogen ion (acid) which was released, will break another covalent bond connecting the rings of a cellulose chain, which will release yet another hydrogen ion. As the chain is broken into successively shorter lengths, it becomes progressively weaker. When one half to one percent of the bonds are broken the paper will be virtually useless. When the cellulose chain is broken, it also weakens and often breaks the hydrogen bonds which bind the ribbons, or chains, into sheets. The layers held by Van der Waals forces suffer the same fate. The hydrogen bonds are relatively weak, having a bond strength of 3 to 6, compared to the bond strength of 86 for the carbon-oxygen bond shown in illustrations 9, 10, and 11. The hydrogen bonds' strength comes from the close proximity of the hydrogen atom to the oxygen atom.

The geometry of the covalent bonds connecting the rings in the cellulose chain is such that the hydrogen atoms are forced into a certain plane close to the oxygen atoms. A long chain results in a stronger, more rigid structure with higher strength hydrogen bonds. As the chain is broken into shorter and shorter lengths, this rigidity is lost. The hydrogen and oxygen atoms are no longer forced into planes of close proximity and the bonds can progressively weaken and break. Like the hydrogen bonds, Van der Waals forces are weak (with a bond strength of 2 to 10) relative to the covalent bond holding the rings in the cellulose chain together. Also, like the hydrogen bond, Van der Waals forces are weakened and broken when the covalent bonds connecting the rings break chemically (by acid). The strength of Van der Waals forces are also dependent on the geometry of the short carbon-hydrogen bonds, which minimize the distance and, therefore, maximize the strength between the layers. As the chain is broken and rigidity is lost, the carbon-hydrogen bonds are no longer so strongly forced into the geometric plane which keeps the layers at a minimum distance from each other. A loss of strength is then suffered in the bonding between the layers.

This combination of interrelated forces and chemical reactions is the primary cause of the massive amount of deteriorating paper artifacts found in libraries and archives throughout the world today.

Hopefully, you now can understand not only the devastating effect acid has on paper, but the mechanism via which this deterioration occurs.

What Causes Acids to Be Present in Paper?

Impurities such as lignin, hemicellulose and hydrolyzed cellulose oxidize and produce substantial quantities of acidic degradation products. Alum-rosin sizing [Al2(SO4)3. 18H2O] added during the paper making process is a prime acid producer. Various deteriorative byproducts, such as acetic acid, are produced as paper and film age naturally. These by-products of deterioration then catalyze (cause) further degradation reactions. This "deterioration-from-within" is responsible for the fact that pages adjacent within a book will deteriorate more quickly than if they were removed and stored individually. Acidic gases and pollutants from the atmosphere such as oxides of nitrogen and sulfur dioxide, form sulfuric and nitric acid. Other culprits are ozone, various peroxides, peroxyacl nitrates and cupric and ferric ions which promote carbohydrate acid through the oxidation of carbonyl and hydroxyl groups. There are also many indoor sources of deleterious pollutants and chemicals. For example, deteriorative agents such as formaldehyde, peroxides, formic acid, and acetic acid can be emitted by wood, plywood, particle board and chipboard. Protein-based glues and wool can yield sulfides. Fumes from an underground parking area can cause elevated interior levels of oxides of nitrogen, and sunlight entering a building can be responsible for increased photolytic reaction rates, resulting in concentrations of oxidative and acidic molecules such as ozone, peroxides, nitric acid and other nitrogen-containing molecules which are present at higher levels inside than outdoors. Acids also migrate from adjacent acidic materials, which is why we can't line an acid box with "acid free" paper and expect it to remain acid-free.

What Can We Do to Protect Paper From Acids?

Insist that the paper you use bemade from high quality fibers (preferably, alpha-cellulose) without alum-rosin (acid) sizing and with a maximum 30 parts per million of iron and .7 parts per million copper. Specify and use papers that are free from lignin. Lignin is a very large complex organic molecule which binds the cellulose together in a tree. While a papermaker can increase his paper yield per tree to 95% by using the lignin (as opposed to 35% maximum for pure cellulose), the lignin will greatly hasten a paper's demise by breaking down in myriad different ways to yield many different acids and peroxides (which can also damage photographic materials). A commonly used qualitative test for lignin is the Phloroglucinol (1,3,5-Benzenetriol) test. This test was designed to indicate the presence of lignin in quantities of 6 percent and higher. Since even small amounts of lignin can cause significant problems, you should not rely on this test. A quick visual clue to the presence of lignin is the color of a paper or board. The brown kraft color of standard (and some "acid free") shipping and packing containers comes from the lignin in the paper. This same lignin produced color is often seen in the center portions of "acid free" solid and corrugated boards, so you should exercise caution (or preferably switch to lignin free materials) if you are using products made from these types of boards. Apparently, some time ago, some people were taught that lignin was present only in groundwood (mechanical wood) pulps. This, of course, is not true. While mechanical wood pulps do contain lignin, unbleached (brown) kraft pulps such as those produced in vast quantities in the U. S. for corrugated shipping containers and kraft wrapping papers also contain essentially their full original complement of lignin. As mentioned, mechanical wood pulp products such as those commonly found in newspapers, pizza and shoe boxes, and low quality mat/mounting board also contain lignin. Some papers are available which are partially or "semi" bleached. These papers and boards are a lighter brown color than their unbleached counterparts. However, they still contain lignin. Our Lig-free® Type I paper and boards are fully bleached alpha cellulose which we have dyed a pleasing light tan color with special fade and bleed proof dyes to mask any soiling which may occur with extended use. These Lig-free® papers do not contain lignin.

Alkaline Buffers

A generally accepted level of alkaline buffer added to paper intended for archival use is three to five percent. There are exceptions to the inclusion of alkaline additives, particularly with regard to papers meant for the preservation of certain protein based textiles and photographic materials, but we will address this issue later. Typically the alkaline buffer used in paper is calcium carbonate (CaCO3). Remember, an acid is any substance which can donate a proton, and we have seen the havoc a proton can inflict upon the bonds holding our paper together. A base, such as calcium carbonate, is any substance that accepts protons. The negatively charged (basic) hydroxal unit (OH) combines with the positively charged (acidic) hydrogen ion (H) to form water. Assuming enough alkaline buffer (calcium carbonate) is available, the potential exists for the acid to be neutralized before it can damage the paper. This is why it is important to have alkaline buffering in all paper products used in conservation except, as mentioned earlier, those intended for use with certain protein-based textiles and photographic materials where excess alkalinity could potentially cause problems.

Molecular Traps

As important as alkaline buffering is, conservation scientists now realize it does have important limitations. Alkaline buffering does not deliver the degree of protection we once assumed it provide to our collections. If an acid migrates to, or arises from within (in the form of a by-product of deterioration), or forms from a pollutant coming into an alkaline buffered paper, and, if this acid is in contact with a particle of alkaline buffer, the acid will be neutralized. However, if the deteriorative molecule is an oxidative species such as a peroxide, or an acid precursor like an oxide of nitrogen or sulfur dioxide, or a pre-acidic by-product of deterioration, it will not react with the alkaline buffer. Instead it continues through the paper housing (i.e, box, envelope, folder, mount board, etc.) and damages the artifact you are attempting to protect. If a suitable molecular trap is contained within the alkaline buffered paper, it can capture and remove those harmful molecules which passed by the alkaline buffering. Our General Purpose MicroChamber Paper and MicroChamber boxboards (except the MicroChamber/Silversafe boards) contain both activated carbon and our SPZ zeolite. The black side of the General Purpose MicroChamber paper (also used in the MicroChamber boxboards) contains alkaline buffers and an especially effective activated carbon. The white side of the paper contains alkaline buffers and our modified proprietary hydrophobic, acid-resistant SPZ zeolite which we developed and engineered after extensive research to perform the specific functions necessary to protect your collections. Our SPZ zeolite removes acids, aldehydes, ammonia, pollutants such as SO2 and NOx, and despite the incorrect information seen in a competitor's catalog, it does remove oxidative gases, even in very low concentrations (see doorway and bus photos subjected to ANSI standard IT 9.15-1992 oxidative gas tests in MicroChamber test section on our website, www.conservationresources.com/ under "Catalogs/downloads", MicroChamber Technical Info). This SPZ zeolite was engineered to remove all of the known deteriorative molecules that threaten our collections, even those with very low polarization levels.

Efficacy of Molecular Traps in MicroChamber Papers

Acids: It is interesting to note that our molecular traps are significantly more effective than an alkaline buffer at removing acids, and unlike buffered-only papers, they will remove by-products of deterioration such as aldehydes which form acetic acid. This is important because acetic acid is the primary by-product of deterioration produced both by paper and by photographic materials. "One of the most dangerous pollutants to paper is acetic acid ... As the effects of acetic acid build up in a paper artifact, it accelerates degradation ... My goal was to identify materials that would be most effective at absorbing and retaining acetic acid, and that would be suitable for use in preserving artifacts. I looked at about 18 different materials, including activated carbon, clays, calcium carbonate, and several zeolites ... The activated carbon and one of the zeolites-called SPZ, (the zeolite Conservation Resources developed for use in Artcare board, conservation boards, papers and materials) performed significantly better than the other physical adsorbents ... based on its adsorption and retention of acetic acid-which can be assumed to inhibit cellulose deterioration-the SPZ zeolite, incorporated in Artcare (and) MicroChamber technology (products), is a very viable material for preventative conservation applications"[1]

The results from our tests using gas chromatography show that if we have equivalent papers—for example a 65 g/m2 interleaving paper, or a 130 g/m2, .006" thick envelope paper, or a standard 250 g/m2 archival file folder paper in both MicroChamber paper and buffered paper, the MicroChamber papers have 170 times the acid-removal capacity of the buffered papers. In other words, the buffered paper would have to be replaced 170 times before you would need to replace the MicroChamber paper.

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[1] From an interview with James Druzik, Senior Scientist, the Getty Conservation Institute, printed in the October 2003 Decor magazine.

By-products of deterioration: MicroChamber papers are very effective at removing pre-acidic by-products of deterioration, such as aldehydes. These pre-acidic deteriorative by-products pass unaffected through traditional buffered paper because the deteriorative by-products do not react with the alkaline reserve in buffered papers. If we assume all of the acetaldehyde (a precursor to acetic acid) removed as deteriorative by-products by the MicroChamber paper will become acetic acid, we find the MicroChamber paper can remove what would become 231 times as much acid as would form if only the buffered paper were present.

Pollutants: MicroChamber products do provide protection against common oxidative and acid gaseous pollutants such as ozone (O3), oxides of nitrogen (NOx, NO, NO2), sulfur dioxide (SO2), as well as H2S, CS2, ammonia, formaldehyde, peroxides and a great many other such molecules which can harm collections. The traditional alkaline buffers in conservation papers do not react with or remove these deleterious molecules. Furthermore, such molecules can pass unaffected through even the thickest buffered boards2, where they can contact and damage collections housed within these buffered boards and papers. If, for example, we look at New York City and at Los Angeles, the EPA (The U.S. Environmental Protection Agency) gives us the maximum hourly rate of a variety of pollutants measured in these two cities for one year. Using these maximum concentrations, we can calculate the maximum amount of a pollutant such as SO2 in one liter of air. Exposing a 24 x 36 MicroChamber folder to a fresh liter (slightly more volume than a quart container) of polluted air every hour, we find, at the maximum hourly concentration level of pollutants measured in New York and Los Angeles, the MicroChamber folder has the capacity to remove the SO2 in NY city for 8219 years, and in LA for 26,224 years. Obviously if the air exchange is increased this figure will be lower. For example, if the air flow rate into the folder was increased to 10 liters per hour, the figures would drop to 1233 years for NY City and 3933 years in Los Angeles, CA. Of course the MicroChamber product will also pick up other harmful molecules, in addition to the SO2. Therefore to the extent these other molecules are present and removed, the maximum quantity of SO2 which can be removed will be lowered—but these figures do at least provide a point against which you can form a comparison between the effectiveness (zero) of buffered products and of MicroChamber products.

The preservation advantage offered by our new MicroChamber boards and papers, which contain both specialized proprietary molecular traps and alkaline buffers, is quite striking. While traditional alkaline buffered conservation papers and boards do provide an advantage over acidic commercial products, this improvement does not begin to approach the phenomenal gain in protection offered by MicroChamber products over traditional alkaline buffered products. Alkaline buffered paper is a technology of the 1960s. MicroChamber materials give you the advantage of technology from the 1990s. MicroChamber products offer new opportunities in preventative conservation, increased life and thus reduced preservation costs for all collections. See the MicroChamber product verses traditional buffered-only test results on our website.

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2. Guttman, C. M. and Jewett, K. C. 1993 "Protection of Archival Materials from Pollutants: Diffusion of Sulfur Dioxide through Boxboard", *Journal of the American Institute for Conservation* 32:81-91. Also, see MicroChamber test section on our website.

pH

The pH scale is a "yardstick" used to measure the number of hydrogen ions (H+ [acid]) in solutions. The pH scale runs from 0 to 14. The lower numbers refer to acid solutions, while the higher numbers refer to alkaline or "basic" solutions. At pH 7 (neutral) the concentration of hydrogen ions equals the concentration of hydroxide ions. Any solution with a pH lower than 7 has more hydrogen ions than hydroxide ions in solution. Any solution with a pH higher than 7 has fewer hydrogen ions than hydroxide ions in solution. The pH scale is a logarithmic progression. This means numbers on the pH scale are based on powers of ten. A pH of 2 therefore, indicates ten times fewer hydrogen ions than a pH of 1, pH 3 has ten times fewer hydrogen ions than pH 2 and one hundred times fewer hydrogen ions than pH 1. A pH of 4 has ten times fewer hydrogen ions than pH 3, one hundred times fewer hydrogen ions than pH 2, and one thousand times fewer than pH 1.

Since we have seen how hydrogen ions break the bonds holding the cellulose chain together, and since pH is the measurement of these acid ions, are we, therefore, able to specify a paper with a pH of 7.0 or higher with the expectation that it will be archival? The answer, unfortunately, is no! For one thing weak acids may not be fully disassociated. Therefore, you do not always get an accurate picture of acids present by measuring pH. Let's imagine someone offered you a brown kraft paperboard. It is purportedly "acid free" and, in fact, the pH is 8.0. On further examination you discover that the paperboard contains no alkaline buffering such as calcium carbonate. Now the paperboard is, in a technical sense and at least initially, "acid free". However, this paperboard should not be used for archival preservation. There is no alkaline buffer present to neutralize the acids from pollutants in the surrounding environment, and the paper is full of lignin which will break down and form acids which will sever the bonds holding the cellulose chain together. Adding alkaline buffering to a paper which is full of lignin will not keep this paper "acid free". Remember, if one half to one percent of the cellulose bonds are broken, the paper will be virtually useless. It also will be a source of acid which can migrate to and damage adjacent materials.

Therefore, we should never rely only on the term "acid free" to specify a paper we intend to use for conservation purposes. It is important to know the pH of a paper product but pH must be used in conjunction with other specifications to be meaningful. We will look at the specifications required to insure a paper is archival, shortly.

Degradation of Paper by Light

Absorption of light will not directly cleave a bond in the cellulose chain. However, certain additives, impurities, dyes, and metals such as iron (Fe++++, Fe++) will absorb energy from light which raises their electrons to a higher energy orbit. When this energy is released to the cellulose, bond cleavage can result and this, in turn, can allow oxidative degradation. Incidentally, this same mechanism is used by plants to provide the energy to grow the cellulose we use to make paper. A molecule of chlorophyll, for example, absorbs quanta of light energy from the sun, raising its electrons to higher energy levels. When the electrons fall back to lower energy levels, they release the same amount of energy they absorbed. This energy is used by the plant cell to fuel the chemical reactions which produce simple sugars.

Oxidation of Cellulose

This degradation is found when oxygen is absorbed at certain sites on the cellulose molecule. With this oxygen absorption we will find an increase in oxygen containing groups such as carbonyls and carboxylic acids. As this greatly increased level of acid is released, the cellulose will be hydrolyzed (meaning the covalent bond between the rings in the cellulose chain will be broken, forming two shorter chains and releasing a hydrogen ion) (see illustrations 10 through 13). Oxidation will also cause color changes in paper, particularly if such impurities as lignin, iron, alum sizing and hemicelluloses are present. Hemicelluloses are polysaccharides (multiple sugar units) which have many "branches", so they do not "stack" or fit tightly into microfibrils like alpha cellulose (glucose units).

Enzyme Degradation and Mechanical Damage

Enzymes are protein catalysts coded for by that very newsworthy molecule, DNA, and assembled from amino acids in the ribosomes of living cells. Enzymes such as endoglucanases and cellobiohydrolase can cleave the bonds connecting the cellulose chain at any link. This subject is really beyond the scope of our discussion, but if you are interested in additional information, your local paper conservator will be able to answer any questions you may have.

Mechanical damage can result in splayed, split or broken fibers which can weaken paper just as surely as bond cleavage between the rings in the cellulose chain. Remember, the longer the chain, the stronger and less mobile the structure. The hydrogen atoms are forced into a plane close to the oxygen molecules and the hydrogen and oxygen atoms connecting the sheets are able to form better hydrogen bonds. For essentially the same reasons, the strength of Van der Waals force connecting the sheets into layers is maximized. This is the reason you should request a paper with high strength and durability even when it seems unimportant for your particular requirement. Say, for example, you are trying to choose a thick, stiff paperboard for use in making cloth wrapped book boxes. Perceived stiffness is basically a function of thickness, but a thick board constructed from multiple plys of paper with high physical strength characteristics, such as high folding endurance and tear resistance, will be manufactured from good, long fibers. This board will be much more resistant to damage over an extended period of time, and not be as likely to harbor acids from bonds broken by hydrolysis (see illustrations 10 through 13) that can migrate to historical paper artifacts stored within it.

MicroChamber Technology and the History of Archival Boards in the U.S.A.

The first attempt at producing an archival board for preservation housings in North America was made in the 1960s. This first boxboard, gray with a red pulpy center and a pH of 6.5 was considered to be at the leading edge of archival storage technology. Information that acids were the root cause of paper deterioration was beginning to be widely disseminated among those concerned with preserving documents, books and works of art on paper. By today's standards, this mildly acidic board would be unacceptable for use as a preservation housing; however, at the time, its production was quite an achievement. The board mills of this era all utilized acid paper making systems, and even this mildly elevated pH level caused severe problems for the mill which produced it.

This was the period when Frazer Poole was beginning to lead the US Library of Congress preservation program into new areas. The Library quickly established new standards which required a pH of 8.5 for preservation housing boards. The paper adapted for this purpose was an unbleached (therefore brown) kraft. It retained its full complement of lignin, and no alkaline buffer was added. Unfortunately it did not retain its alkaline pH for long. The solution to this problem was thought to be the addition of calcium carbonate as an alkaline buffer. However, as time passed, it became apparent that the addition of alkaline reserve did not prevent the pH from dropping into the acidic range in boards containing lignin.

Further progress was made in 1979 when Conservation Resources introduced the first gray boards made with quite low levels of lignin and alkaline buffering distributed evenly throughout the entire board. In 1980 another advance was made Conservation Resources introduced the first lignin-free and sulfur-free alkaline buffered board, produced initially for the Library of Congress.

The goal, until very recently, was to produce stable archival papers and boards which would not break down and contribute to the deterioration of the collection housed within them. With the removal of lignin and other substances which promoted further deterioration, and with the inclusion of alkaline reserve throughout the board, we thought we had achieved the ultimate in archival storage housings: a truly non-reactive housing that met our passive preservation goals. However, as observational and experimental knowledge increased, it became apparent we needed to find additional methods of dealing with the shortcomings of contemporary archival alkaline buffered preservation materials.

Preventative Conservation

It was becoming evident that by-products of deterioration produced as paper, film and other organic materials aged, played a prominent role in deterioration, as did harmful oxidative and acidic molecules found in the environment surrounding archival collections. People understood that pollutant molecules such as ozone, sulfur dioxide, and oxides of nitrogen could damage their collections. These pollutants also damage buildings, statues and even living ecosystems. However, until recently, most people generally did not realize that indoor pollutant levels could be quite high. {"Indoor pollutants are present in much higher concentration than those found outdoors, and can be significantly more harmful to artifacts than typical open-air pollution....We were seeing damage from pollutants occur even in a controlled museum environment.”[3]} Indeed these compounds can even be produced indoors by a variety of materials and furnishings, as well as by heating equipment and various appliances. Deleterious pollutants and chemicals produced inside include deteriorative agents such as formaldehyde, peroxides, formic acid, and acetic acid, which can be emitted by wood, plywood, particle board and chipboard. Protein-based glues and wool can yield sulfides. Fumes from an underground parking area can cause elevated interior levels of oxides of nitrogen, and sunlight entering a building can be responsible for increased photolytic reaction rates, resulting in concentrations of oxidative and acidic molecules such as ozone, peroxides, nitric acid and other nitrogen-containing molecules which are present at higher levels inside than outdoors. Acids and other harmful molecules also migrate from adjacent acidic materials. Because the artifacts we save degrade over time and produce by-products of deterioration, and because they are generally housed together in high density storage areas, harmful compounds tend to accumulate in higher concentrations within the storage area.

Another common misconception used to be that the alkaline buffering in archival papers and boards dealt effectively with these deleterious compounds. Conservation scientists now realize it is important to understand that the protection conferred by alkaline buffering does have limitations. If an acid migrates to, or arises from within (in the form of a by-product of deterioration), or forms from a pollutant coming into an alkaline buffered paper, and if this acid is in contact with a particle of alkaline buffer, the acid will be neutralized. However highly reactive oxidative gases such as ozone and peroxides are not acids, and pollutants such as sulfur dioxide and oxides of nitrogen do not become sulfuric or nitric acid until they combine with oxygen and water to form these acids. Dr. Charles Guttman and his team from the U.S. National Bureau of Standards published important research (“Protection of archival materials from pollutants: diffusion of sulfur dioxide through boxboard”, *Journal of the American Institute for Conservation* 32: (1993) 81 - 92) showing how readily pollutant molecules pass through alkaline buffered boards. Obviously severe damage to a collection can occur when these harmful molecules pass through an archival paper or board, unaffected by the alkaline buffer, and react with or form acids on the artifact housed within the archival container.

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3. From an interview with James Druzik, Senior Scientist, the Getty Conservation Institute, printed in the October 2003 Decor magazine.

MicroChamber Archival Materials

We have invented and produced a new generation of archival boards and papers which address the shortcomings of traditional alkaline buffered products. By including a mixture of specialized activated carbons and/or specially designed and formulated SPZ zeolite with our alkaline buffers, we produce MicroChamber paper and boards which overcome the limitations of conventional alkaline buffered products. Activated carbon is inert porous graphite, and zeolites are microporous structures such as crystalline aluminosilicates. They do not “react” with the molecules they eliminate, but rather remove and neutralize them. Molecules removed by our MicroChamber papers include acids such as ethanoic (acetic) and methanoic (formic) acid, phenols, aldehydes, hydrogen peroxide, ozone, sulfur dioxide, hydrogen sulfide, carbon disulfide, oxides of nitrogen, ammonia and formaldehyde.

When we look at the evolution of papers used for preservation purposes, it is clear they all have a common theme, which is passivity. Inactive became a superlative when applied to these traditional conservation papers and boards. The goal was primarily to avoid harming a collection, a problem so many people had experienced when using acidic papers and boxboard housings. While conventional buffered papers and boards do display a degree of effectiveness with acids, they are not as effective as they could, or should be. Moreover, they do not address the issue of deteriorative compounds other than acids. MicroChamber products do address these issues. MicroChamber materials actively work to protect your collection, as opposed to the role of the traditional buffered only paper, which is to passively avoid self deterioration.

MicroChamber papers and boards have been used in aging tests with both new alkaline buffered book pages, and with old, naturally aged acidic book pages. MicroChamber products have been tested with photographic negatives and with photographic prints (all MicroChamber and Artcare papers and boards produced have passed the PAT test). MicroChamber materials have also been tested with newspapers, works of art on paper, animation cells, and paper directly soaked with acid. They have been used to line shelves and drawers, to act as scavengers in exhibit cases, to wrap artifacts for shipping, and for myriad other non-traditional uses. Of course they are also playing an important role as boxes, folders, envelopes and other conventional housing forms.

During the past few years, MicroChamber and Artcare products have become widely used throughout the world. Often customers contact us with success stories involving problems these products have solved for them. Some of these uses may be useful to you, whether now or sometime in the future.

MicroChamber papers and boards have eliminated smoke and other odor problems with many different collections including textiles, and they have been extremely effective when used with negatives suffering from 'vinegar syndrome', where they remove the acetic acid, resolving odor problems, and allowing the collections to be handled again, as well as significantly improving their odds of long term survival. They are also used for cold storage of deteriorating acetate sheet photographic film, where it is reported that according to IPI A-D strips, it appears quite effective at absorbing acetic acid. Of course one would expect these results because a MicroChamber paper has the capacity to remove 170 times as much acetic acid as an equivalent buffered paper.

We've also received a variety of reports from people delighted with its effectiveness when used to remove smoke and fire related odors from prints, books, papers, African masks, wood carvings, textiles, furniture, ivories, bronzes and various other works of art. A collector of paperback novels called because he was so delighted that MicroChamber paper had eliminated what was becoming an increasingly strong order from the by-products of deterioration emitted from his collection. We've had comparable comments from others with similar collections of newspapers, comic books, films and various ephemera. Additionally, it has been used for preservation in animation cell mats and to remove the build-up of plasticizers being emitted by a collection of stuffed toys. One gentleman even used it to eliminate the new car smell (likely due to VOCs) he found a bit overwhelming. The point is the material is both very effective and very versatile. Most, if not all of the molecules causing the offending odors are also responsible for the deterioration we all seek to prevent. The molecular traps in MicroChamber and Artcare papers and boards have been engineered to remove deleterious molecules even when they are present in extremely low concentrations. Clearly any collections will be better off if harmful substances are removed as they become present, before levels are allowed to increase to the point where we can smell them.The graphs and color photographs of test results shown on our website in the MicroChamber test section will help demonstrate the capacity and efficacy of these materials. You can quickly see the preservation advantage offered by MicroChamber and Artcare boards and papers is spectacular. While traditional alkaline buffered conservation papers and boards do provide an advantage over acidic commercial products, this improvement does not begin to approach the phenomenal gain in protection offered by MicroChamber and Artcare products over traditional alkaline buffered products. Alkaline buffered paper is a methodology of the 1960s. MicroChamber materials offer you technology from the 1990s. Browse through the MicroChamber test section on our website and look at the test results comparing the MicroChamber products to the traditional buffered-only products. MicroChamber products provide new opportunities in preventative conservation for all collections.

Specifications for Archival Papers

We will break these specifications into two parts. The first part will deal with those requirements needed to insure the chemical purity of an archival paper or paperboard. The second part will show how you can insure that high quality, long chain cellulose has been used to make your archival paper by specifying certain minimum physical strength parameters that must be met. These are, in fact, the specifications we use for our Lig-free Type 1.

Specifications for Lig-free Archival Papers

PART ONE

1. The paper should be made from fully bleached, alpha cellulose pulp. It should be free of lignin, ground wood, waxes, plasticizers, reducible sulfur, oxidizing chemicals and potentially harmful non-cellulose products. It should be free of particles of metal with a maximum 30 ppm Fe and .7ppm Cu. The board shall be hard sized with chemically saturated organic compounds to a Cobb size test of not more than 100 grams per square meter (TAPPI) T-441 (os-69). The surface of the paper should be smooth and free from knots, shives and abrasive particles.
2. pH range: The paper should have a pH of not less than 8.5 nor more than 10.2.
3. sizing: Alkaline sizing should be used in place of alum-rosin sizing.
4. alkaline reserve: The paper should contain a minimum of 3% calcium carbonate (CaCO3), or other suitable alkaline buffer.

PART TWO

(These strength specifications are for .010" thick paper.)

5. abrasion test: The paper shall show maximum fiber loss of one-tenth of one percent after 100 cycles according to TAPPI 476.
6. smoothness test: The paper should show a minimum smoothness of 195 Sheffield units following TAPPI UM-518 test.
7. folding endurance test: The paper should withstand a minimum of 1,000 double folds in the weakest direction at 1kg. load after conditioning according to TAPPI T 511.
8. internal tear resistance (Elmendorf): The paper shall have a minimum tear resistance of 350 gr. per sheet after conditioning TAPPI T414.
9. stiffness test: The paper should have 2800 stiffness units in the machine direction and 1400 stiffness units in the cross direction in accordance with TAPPI 489.
10. bursting strength: The paper should have a bursting strength of 300 pounds per square inch when tested in accordance with TAPPI T 807.

PART THREE

(This part pertains to those papers which are colored [dyed] such as our Lig-free , Type I.)

11. color Unless otherwise specified the outer surface of the paper should be natural tan dyed with light-fast and non-bleeding dye.
12. fading test: When the paper is exposed in a standard fadeometer TAPPI UM-461 for 30 hours, the difference in brightness TAPPI T 452, measured on the exposed and unexposed portions of the sample shall be less than 5 points.

As we have mentioned, certain textiles such as silk and wool and certain photographic materials may be at risk in an alkaline environment. We, therefore, have developed a special non-buffered paper for use with these materials. The specifications are:

Photographic/Textile Conservation Paper

PART ONE

1. The paper shall be made from fully bleached alpha cellulose pulp. It shall be free of lignin, groundwood, particles of metal, waxes, plasticizers, alkaline buffers, col-

oring agents, reducible sulfur, oxidizing chemicals, additives and potentially harmful non-cellulose products. The surface of the paper should be smooth and free from knots, shives and abrasive particles.

2. pH range: The paper shall be in the neutral range.
3. sizing: Alkaline sizing shall be used in place of alum-rosin sizing.
4. alkaline reserve: The paper shall not contain calcium carbonate (CaCO3) or other alkaline buffers.
5. sulfur content: The sulfur content shall be less than .0008% reducible sulfur as ASTMD 984-74 or TAPPI T 406, su 72.
6. tarnishing properties: The paper shall be non-tarnishing as per accelerated tarnishing test ASTMD 2043-69 and TAPPI T 444, T 564. The paper must also pass the silver tarnish test developed by T. J. Collings and F. J. Young, London, England.

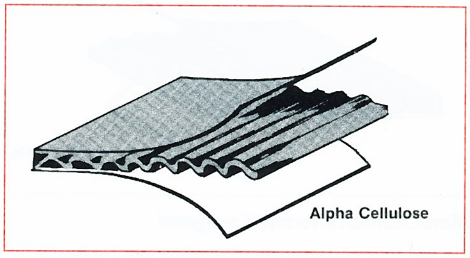
PART TWO

This paper meets the same high fold (minimum 1000 double folds in the weakest direction at 1 kg.) and other strength requirements as Lig-free , Type 1 in 5 through 10, part two.

PART THREE

Not applicable since no coloring should be added to this paper.

MicroChamber/Silversafe and Lig-free Type II boards for the Preservation of Archeological Specimen, Photographic Materials and Textiles



Lig-free®, Type II Corrugated

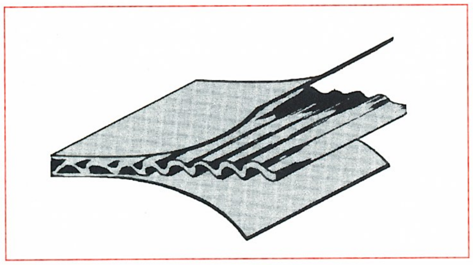
outside liner and corrugated medium are Lig-free®, Type I (pH 8.5, 3% alkaline buffer, no lignin) inner liner is the pH neutral, non-buffered photographic/textile conservation paper.

We have developed and currently manufacture two archival boards which we are using to make containers for the storage and preservation of photographic images and proteinaceous artifacts such as ancient skills, parchments and leathers, textiles (silks and wools), anthropological artifacts including insect collections, horn, bone, hides, teeth, feathers and albumin and gelatin emulsions commonly used in photographic prints and negatives. Before we describe our new boards, we would like to briefly explain the structure and composition of proteins and the process by which they are assembled in a living cell. Outlining these fundamentals of protein structure and function will give people a better understanding of our reasons for developing these boards.

A protein is a long chain (polypeptide) of x-amino acids (2-amino carboxylic acids) which fold into various three dimensional conformations, thereby controlling access to the reactive chemical groups in the particular three dimensional patterns. There are 20 different amino acids which can be placed end to end in any order to comprise the "links" of this polypeptide chain. Unlike cellulose, which is comprised of a long chain of identical glucose rings, the protein can exhibit considerable diversity because of the vast numbers of sequences of amino acids which are possible and the fact that each of these amino acids has a different reactive group called a side chain, which is the primary determinant of the property of a given protein. Also, protein molecules are often comprised of not one, but several different polypeptide chains.

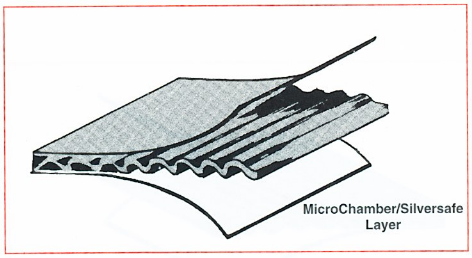
The construction of a protein begins when an enzyme (which is also a protein) called an RNA polymerase uncoils the DNA double helix in the nucleus of a cell, exposing six bases or nucleotides at a time. Each three adjacent nucleotides (called a codon) designates, or "codes for", a specific amino acid. Heterogeneous nuclear RNA (hnRNA) is formed using the DNA template to acquire a complimentary sequence of nucleotides to those found in the gene (DNA) being expressed.

Messenger RNA (mRNA) formed from the hnRNA leaves the nucleus of the cell with the precise number and sequence of nucleotides required to code for the specific protein called for by the DNA (gene) in the nucleus of the cell. The mRNA travels through the



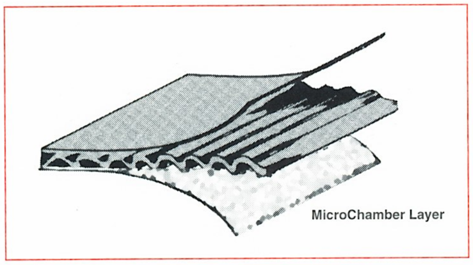
Lig-free®, Type I Corrugated

both outer liners and the corrugated medium are made from pH 8.5, buffered, lignin free lig-free®, Type I. This is used for record storage boxes and other containers which will house paper documents and artifacts.



MicroChamber/Silversafe Corrugated

outside liner and corrugated medium are Lig-free®, Type I (pH 8.5, 3% alkaline buffer, no lignin) inner liner is tan MicroChamber paper with a thin (not laminated) liner of pure white pH neutral, non-buffered Silversafe Cotton conservation paper.



MicroChamber®, Corrugated

outside liner and corrugated medium are Lig-free®, Type I (pH 8.5, 3% alkaline buffer, no lignin) inner liner is MicroChamber General Purpose paper with a gray layer containing a special activated carbon and alkaline buffers, and a white layer containing our proprietary zeolites and an alkaline buffer.

cytoplasm of the cell to a site comprised of four molecules of RNA and many different proteins called a ribosome.

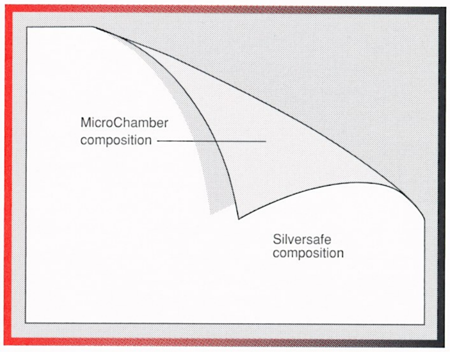
In the ribosome transfer RNA, consisting of three nucleotides (a codon) and the amino acid specified by the codon, attach to three complimentary nucleotides on the mRNA. As the ribosome moves sleeve like down the length of mRNA, the transfer RNA continues to combine to the next three complimentary nucleotides on the mRNA bringing the next amino acid to the growing polypeptide chain. As the amino acid carried by the tRNA is attached to the polypeptide chain, the tRNA is released to the cytoplasm where it combines with another amino acid. This process continues with the polypeptide chain of amino acids growing longer and longer until the ribosome comes to a terminator sequence on the mRNA. The completed polypeptide is detached into the cytoplasm where it folds into its specific three dimensional conformation and becomes a protein. It is when it is in this final three dimensional conformation that it exhibits those properties we associate with this specific protein.

The side chains of the amino acids are ionic and, therefore, form electrostatic bonds between each other which hold the protein into its particular conformation. Changes in pH affect the ionic forms in which the side chains of the amino acids exist and, therefore, changes in pH also affect the formation of bonds by proteins. In order for an electrostatic bond to exist between side chains, both positive and negative changes must be present. Raising the concentration of H+ (increasing the acidity) decreases the number of charged caboxylate ions and the carboxylate group on the side chains lose their charge. If the concentration of H+ is lowered (made alkaline) the H+ will leave the ammonium group which will lose its charge. It follows then that these bonds are generally most stable near neutrality. Also, for these amino acids with both carboxylate and ammonium groups, there is a pH value at which the number of negatively charged carboxylate groups will be exactly the same as the number of positively charged ammonium groups. Various points along the side chain will be more negative or more positive than others which allows the bonding to continue, but the total charge will be zero. This is the isoelectric point of the protein and the pH at which this isoelectric point occurs is where the protein is least reactive and, therefore, most stable.

If the pH, or isoelectric point, of the protein is altered, the side chains of the amino acids comprising the protein will lose their ionic forms and the electrostatic bonds between them will be broken. The protein can then unravel from the distinct form which gave it the properties we associated with this specific protein and become a polypeptide again. In addition, the peptide bonds between the amino acids are now exposed to the possibility of clevage by hydrolysis. By comparison, if we break the covalent bonds in a cellulose chain, we do not alter the properties we associated with the paper. It looks the same and feels the same. It just gets weaker.

This sensitivity and the potential magnitude of damage, coupled with the persistence of several conservators and conservation scientists, prompted us to look for an alternative to highly alkaline buffered papers for the long term storage of proteinaceous artifacts. Our objective was to invent an archival material from which we could make containers that would in no way harm or interfere with the artifact stored within it. A very pure, neutral, non-buffered paper which was itself at its isoelectric point would provide precisely the neutral, non-reactive environment we wanted. We added a thick layer of alkaline pH, alkaline buffered paper to the neutral pH, non-buffered paper which forms the interior of our containers. These boards, which we call Lig-free Type II, provide a securely neutral, non-reactive, sulfur free interior while the outer plies of the board contain alkaline buffering. This was the first, and until recently, the only boxboard available which which addressed the needs of collections felt to be sensitive to an alkaline environment. We added a thick layer of alkaline pH, alkaline buffered paper to the neutral pH, non-buffered paper which forms the interior of the containers.

Lig-free Type II is currently available in a corrugated board. The outer liner and inner corrugated medium are alkaline pH, alkaline buffered paper while the inner liner is a neutral, non-buffered paper. This board is strong, exceeding 250 lbs. pressure per square inch bursting strength, and rigid. It is especially good for making large textile boxes which can then be shipped and stored flat, for backing boards, and for use as a support in conservation work. In Lig-free boards, all the buffered papers are light tan in color while the non-buffered papers are white, so it is easy to see which side is buffered and which is not buffered. All the papers used in these boards, both buffered and non-buffered are pure long chain cellulose and they are free of lignin, sulfur and other deleterious substances. Complete specifications are detailed under the headings "Lig-free Type II" (alkaline pH, buffered paper) and "Photographic/Textile Conservation Paper" (neutral pH, non-buffered paper).



Now we also offer MicroChamber/Silversafe products, the first boxboards and papers able to address both the needs of alkaline sensitive collections, and the shortcomings of alkaline-buffered-only archival storage products in dealing with pollutants produced both indoors and outdoors, and by-products of deterioration. Standard MicroChamber boxboards combine alkaline buffers, activated carbon and zeolite molecular sieves, offering your collection the greatest protection available from acids, by-products of deterioration and pollutants. Now MicroChamber/Silversafe boxboards provide a combination of buffered Lig-free board for strength, thickness, and support, coupled with tan MicroChamber paper faced with a surface of neutral pH, unbuffered, soft white cotton Silversafe paper. These products were developed so the advantages of MicroChamber technology could be combined with neutral pH, unbuffered cotton Silversafe paper, for use with protein-based textiles such as silks and wools, and with certain photographic materials, and other artifacts which collection managers feel may benefit from the neutrality of unbuffered cotton coupled with the protective security offered by MicroChamber materials. MicroChamber/Silversafe products are currently available in folders, folder paper, negative enclosure paper and envelopes, as well as solid-fiber and corrugated boxboards, backing boards and support boards.

For more information on MicroChamber boards and papers, the first archival housing materials for preventative conservation, please see the MicroChamber test results and information section elsewhere in this catalog, our web site, www.conservationresources.com or call 1 (800) 634-6932.