THE DETERMINATION OF APPROPRIATE MUSEUM ENVIRONMENTS

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ABSTRACT

The choice of a range of temperature and relative humidity for the general museum environment must consider a number of factors related to the materials and construction of objects in the collection. These include critical transitions of the materials (such as glass transition and deliquescence points), physical and mechanical properties, chemical reactivity, and the effects of environmental changes within the allowed range. Changes caused by environmental fluctuations can be shown to be generally reversible (non-damaging) within a relatively wide (±10 to 15%) range in the moderate RH region. A range that is safe for the general collections and minimizes the number of inevitable exceptions can be determined. Other factors such as building design and construction, local climate, energy costs, and available funds and time then can be considered to develop a climate control strategy that maintains the climate within the ‘safe’ range while conserving energy, funds, and effort.

Key Words

environment, temperature, relative humidity, materials, physical, mechanical, chemical, properties

INTRODUCTION

The museum environment has a number of components, including temperature, relative humidity, light, vibration, pollutants, and particulates. Of these factors, the optimal value for vibration, pollutants, and particulates is zero. If objects are light sensitive, then light should be reduced to the minimum amount of visible light required for proper viewing (and preferably only during viewing). Temperature and relative humidity (R.H) differ from the other environmental factors in that they are interdependent, and their effects are much more varied and complex. A temperature or relative humidity acceptable for one object may be disastrous for another. Since temperature and relative humidity must be optimized rather than eliminated, satisfactory values or ranges must be determined and maintained.

Values for temperature in the general museum area (as opposed to storage) are restricted to the relatively narrow range in which people are comfortable. Thus relative humidity is the major variable of the general museum environment for which there is no obvious optimal value or range.

Relative humidity affects the preservation of objects in many ways. It affects physical, chemical, structural, and optical properties, and even the physical state of materials. It is a factor in many chemical reactions, and determines whether biological attack might occur. It affects the rate at which pollutants or contaminants can attack a material. It even affects the building structure itself if temperature differences cause condensation within the external fabric of the building. Changes in relative humidity also have effects, producing dimensional changes in hygroscopic materials that can result in strains, stresses, plastic deformation, or fracture.

Each of these factors may be more or less important for a specific type of material, and each material will be affected differently. As a result, considerations of different individual factors may suggest different optimal values or ranges of relative humidity, even for the same material. Research into the different effects of relative humidity leads not to an ever more accurate determination of the one optimal value, but to more or less overlapping, or even conflicting, recommendations (Erhardt and Mecklenburg 1994). Thus, no matter what value or range of relative humidity is chosen for the general museum environment, there will always be some objects that require either tighter control or separate and different conditions. Conditions other than those of the general environment can be provided through the maintenance of appropriate microenvironments.

This paper discusses considerations relating to the determination of suitable conditions of relative humidity in the general museum environment, with an emphasis on hygroscopic organic materials. In addition, some considerations relating to specialized storage environments also are presented.
CLASSES OF MATERIALS

Materials in the museum can be roughly separated into four different classes: those that are insensitive to relative humidity, those that require low relative humidity (possibly below a critical value), those that require RH values within a specific range, and those that respond to differences in RH throughout the RH range.

Materials Insensitive to RH

The class of materials that are insensitive to RH includes many inorganic materials: most ceramics and glasses and some metals and minerals. These materials are dimensionally stable with changes in RH, and are either chemically unreactive under any reasonable conditions or reaction is so slow as to be negligible. For example, some ceramics theoretically can re-hydrate, but do so very slowly so that changes can be ignored.

Materials Requiring Low RH

The degradation processes of a number of materials start or speed up as the RH is raised. Such processes include the corrosion of metals such as iron and bronze, and the oxidation or hydrolysis of minerals such as pyrite. In some cases, reaction stops or is negligible below certain values of RH. The corrosion of chloride contaminated bronze ('bronze disease') (Scott 1990) and the oxidation of pyrite (Waller 1989) both slow or stop at low RH.

Many materials contain or are contaminated with deliquescent salts. If the RH is above the value at which such salts deliquesce, they absorb water vapour from the air to form mobile electrolytic solutions. Such solutions can contribute to reactions such as corrosion (Evans 1960) or hydrolysis, or increase the susceptibility to pollutants (Padfield and Erhardt 1987).

For materials described in this section, low RH is required. Some materials require an environment as dry as possible, while others are unreactive and insensitive to RH and dimensionally stable if the RH is below a certain value. Many such materials require drier conditions than are suitable for general collections. Such materials are best kept in separate low RH areas, or in dry microenvironments.

In addition to exhibited and stored objects, the museum building itself may require an RH below a certain value. If the outside temperature is below the dewpoint of the interior air, then condensation may occur in the exterior fabric of the building. This can result in rotting, staining, rusting, spalling, dripping, and other problems. Ideally, the dewpoint of the interior air should be below the temperature of the exterior air. This may result in extremely low interior RH values during cold weather in temperate and cold climates, however. Approaches to the problem include strategies such as vapour barriers, reduced interior temperatures and pressures, and other measures to minimize problems while still maintaining acceptable interior humidities.

Another factor, mould growth, places an upper boundary on RH. Mould growth is likely above about 75% RH, but becomes a factor below about 60% RH (Michalski 1993). Factors such as air flow and circulation also affect mould growth.

Materials Requiring a Specific RH Range

The number of materials requiring a specific RH range is quite small, restricted mainly to mineral hydrates that incorporate water into their crystalline lattice. These minerals are stable only within certain compound-specific RH ranges, losing water and powdering at lower RH, or gaining water and decomposing or dissolving at higher RH. The stability ranges for a number of minerals have been compiled (Waller 1980). Such materials must be kept in separate microenvironments if the overall RH is not maintained within their range of stability.

Materials Responsive to RH throughout the RH Range

Most organic materials are sensitive to differences in RH throughout the RH range. This can be illustrated by a typical moisture absorption isotherm for cellulose shown in Figure 1. There is no range over which the moisture content remains constant. Any change in RH produces a change in moisture content. This leads to changes in chemical reactivity, structural and physical properties, and dimension. Differences in dimensional responsiveness to RH changes within an object can result in stresses that, if large enough, cause plastic deformation or fracture. Any attempt to determine an optimal value or range for such a
material (or composites that incorporate it) must allow for all of these factors. The choice is complicated by the fact that some deterioration processes of these materials speed up or occur only at low R.H. The R.H. range chosen is often a compromise.

Cellulose, which is the structural component of many museum objects, provides an example of the way these factors can be taken into account in determining an appropriate or optimal range for hygroscopic materials. The first step is considering the nature of absorbed water in hygroscopic materials.

**Water in Cellulose**

Cellulose contains many polar, reactive groups, specifically the hydroxyl groups of the glucose molecules that are the building blocks of cellulose. These groups can form hydrogen bonds to, and bind very tightly with, water molecules. Cellulose at very low R.H. contains little or no water, but as the R.H. is raised cellulose rapidly picks up water. This accounts for the steep curve of the isotherm at low R.H. in Figure 1. This 'bound' water absorbed at low R.H. is held very tightly by the reactive groups, and in fact can be regarded as part of the structure of the cellulose 'matrix'. The isotherm curve flattens out once the reactive sites are covered, and cellulose absorbs water at a much slower rate as the R.H. is raised through the middle range, i.e., cellulose is less responsive to R.H. change in this region. As the R.H. is raised further, capillary absorption increases and the rate of absorption with R.H. change increases. Capillary absorption in fact occurs throughout the R.H. range, but is most important at higher R.H. (above about 50%). Water absorbed through capillary action, so-called 'free' water, is not tightly bound, is mobile, reactive, and behaves much more like liquid water. Bound and free water can be differentiated by methods such as thermodynamic studies of the heat of absorption of water. Figure 2 separates the isotherm of Figure 1 into bound and free water.

**Reactivity of Cellulose vs. R.H**

The main reaction of cellulose under 'normal' conditions is hydrolytic cleavage of the cellulose chain. This type of reaction is dependent on R.H. Figure 3 plots the rates of hydrolysis at different points along the cellulose chain vs. R.H., along with curves fit to the data (Erhardt and Mecklenburg 1995). The rates of the reactions correlate with the amount of free water from Figure 2, also plotted. The hydrolysis of cellulose can be reduced to minimal levels by reducing the relative humidity.

At low R.H., crosslinking of cellulose occurs. This is due in part to the uncovering of the reactive groups with the loss of bound water. In addition, the loss of bound or structural water can lead to collapse of the pore structure and inter-fibrillar interstices of materials such as paper and wood, along with reductions in reactivity as access to the cellulose molecules is reduced. Changes induced by severe drying are only partly reversible, and are less so if crosslinking is allowed to continue for a long time.

Thus, the reactivity of cellulose is minimized by reducing the R.H. to the point at which most of the free, reactive water is removed, but enough bound water remains to cover the reactive groups and prevent crosslinking and structural collapse. This minimum occurs somewhere around 30% R.H., (isotherms vary depending on factors such as percent crystallinity and processing of the cellulose). Since the isotherm is relatively flat just above this point, though, the R.H. can be raised up to 50% or 60% without significantly increasing the reactivity of the cellulose, (significantly being a relative term, in this case a factor of two or three, as compared to the large increases that occur at very high R.H.).

**Physical Properties of Cellulose Versus R.H**

Of the basic physical properties that are important in determining the ease with which damage occurs at constant R.H., three can vary with changes in R.H. These are the modulus (stiffness), strain-to-yield (deformation required to cause permanent distortion), and strain-to-failure (deformation required to cause fracture or breakage). Absorbed water affects these properties by acting as a plasticizer. Figure 4 plots the modulus of cottonwood in the cross-grain (primarily tangential) direction. The modulus is relatively constant up to about 50% R.H., then falls off rapidly, losing two-thirds of its maximum value by 100% R.H. This behaviour indicates that it is primarily the free absorbed water that acts as a plasticizer and affects the stiffness. This material exhibits little change in stiffness in the range below 50% R.H., which includes the 30-50% R.H range suggested from the considerations of chemical reactivity. In this relatively flat portion of the isotherm, there is little change in water content, thus little change in these properties.

Similar conclusions result from a consideration of the strain required for failure. Figure 5 plots both the strain-to-failure and strain-to-yield of cottonwood in the (primarily) tangential direction. The strain-to-failure (amount of stretching required to cause fracture) is relatively constant (between 1 and 2%) up
to about 60% RH, above which it increases dramatically. Again, there is little difference in a wide range that includes the 30-50% RH range. However, the prevention of total failure is not stringent enough a goal. Permanent distortion can be avoided by not exceeding the strain-to-yield, which is relatively constant at about 0.004, (0.4%). Deformations less than this are elastic, with the material returning to its original shape and size once the deforming force is released. Absorbed water does not seem to affect this property.

These data dispel the myth that materials are necessarily brittle and/or stiff at all low RH values. This idea may have resulted from the fact that the crosslinking of materials stored at very low RH (less than 20-30%) can result in reduced strain-to-break, which can be interpreted as brittleness. In fact, if very low RH is avoided, important physical properties are relatively insensitive to RH within the flat portion of the isotherm.

Similar results have been found (Tumosa 1996) for the properties of a number of materials, including samples of paper from a book published in 1804. Such results, combined with those of a study that showed that paper loses strength with little change in modulus during aging (Erhardt and Mecklenburg 1995), indicate that while paper may become weaker on aging, its stiffness and response to RH changes do not change significantly.

Effects of RH Fluctuations on Hygroscopic Materials

Cellulosic materials absorb and desorb water and consequently change dimension as the relative humidity changes. If a material is unrestrained, this absorption and desorption is reversible in a quite wide range of relative humidity, and a material simply expands and contracts with changes in relative humidity. It is only when a material is restrained, either internally or externally, that this tendency to change dimension can cause stresses and resulting damage. If the relative humidity is reduced, wood will try to shrink. If it is held rigidly and prevented from shrinking, stresses develop. If these stresses are large enough, they result in permanent deformation or fracture.

Figure 6 shows stress-strain curves for a piece of cottonwood at various relative humidities. The horizontal axis is displacement, and the vertical axis is the stress, or force per cross-sectional area, corresponding to that displacement. Changes in dimension produced by changing the RH are also represented. This is shown by moving along the horizontal (zero stress) axis, and is why the stress-strain curves for different values of RH start at different positions along the horizontal axis. The curves are separated by the change in length due solely to changes in RH. Each curve is linear and reversible in the initial stage, but then becomes nonlinear and non-reversible as permanent deformation occurs.

How do these tests, conducted at constant RH, relate to effects caused by changes in RH? Figure 7 is a detail of Figure 6. The worst case assumption is that a sample is fully restrained and not allowed to change dimension or respond to changes in RH. If the RH is reduced from 48%, the sample tries to shrink, but cannot, and stress develops. This is equivalent to moving vertically, staying the same length but with increasing stress. If the RH is reduced to 23%, the plot ends at a point on the 23% RH stress-strain curve. This demonstrates a fundamental principle found to be true for all of the materials tested (Mecklenburg et al. 1995a). The stress in a sample is a function of the final conditions of strain and RH; the path to a specific condition does not matter. Keeping the dimension constant and lowering the RH results in the same stress as allowing the sample to shrink freely as the RH is lowered, and then stretching it to the original length. This means that the effects of RH changes can be calculated from a series of stress-strain tests conducted at constant, but different, values of RH.

The only additional information required is the change in dimension caused by changes in RH. Measurements of the changes in dimension caused by RH changes, as well as the amount a material can be reversibly stretched, allow the calculation of the minimum safe RH fluctuations that can be allowed without irreversible deformation or fracture (Erhardt et al. 1995, Erhardt et al. 1996, Erlebucher et al. 1992, Mecklenburg 1991, Mecklenburg et al. 1992, Mecklenburg et al. 1994, Mecklenburg et al. 1995a, Mecklenburg et al. 1995b, Mecklenburg et al. in press, Mecklenburg and Tumosa 1991a, Mecklenburg and Tumosa 1991b, Mecklenburg and Tumosa 1996, Richard et al. in press). Figure 8 shows the result of such calculations for cottonwood. Larger fluctuations than those shown are safe if the worst case conditions (total restraint, long exposure and full response to the extreme RH values) are not met. The rate of change in RH does not affect these allowable fluctuations. An interesting feature of the calculations is that the allowable fluctuations are not uniform, but depend on the starting relative humidity. Not
surprisingly, the greatest allowable fluctuations for most organic materials are in the 30-60% R.H range, the flat portion of the isotherm where they are least responsive to changes in relative humidity. If there is no response, there is no mechanism for environmental mechanical damage.

Similar measurements and calculations for a wide range of materials (not just cellulose) yield similar results, with allowable fluctuations of at least ±10 to 15% or more in the moderate R.H range. For example, comparisons of new and seventeenth-century samples of Pinus sylvestris L. (Scots pine) showed that wood in an uncontrolled environment exposed to centuries of wide variations in temperature and relative humidity can survive with no significant change in physical properties, and only minor indications of chemical deterioration (Erhardt et al. 1996).

Such calculations refute another myth, that objects at high R.H can more readily ‘equilibrate’ to R.H changes. In fact, allowable fluctuations are small at high R.H because hygroscopic materials are very responsive to R.H changes in that region. Any so-called ‘equilibration’ of restrained materials at high R.H to other than small changes involves irreversible plastic deformation (damage).

Effects of R.H Changes on Composite Materials
If the material properties of the components of a composite structure are known, similar calculations of the overall response of the composite, and the strains and stresses induced at each point, can be made (Erhardt et al. 1995, Mecklenburg et al. 1994, Mecklenburg and Tumosa 1991a, Mecklenburg and Tumosa 1991b, Mecklenburg and Tumosa 1996, Mecklenburg et al. in press, Richard et al. in press). Figure 9 shows the swelling isotherms of a number of materials, including the components of a typical panel painting. In the moderate (30-60% R.H) range, such materials in a composite object respond to R.H changes similarly, and the materials shrink or swell together, producing little or no stress in the individual layers. At low (below 30%) or high (above 70%) R.H, the differences in response start to exceed safe values. Wood and glue respond much more to changes in R.H than, for instance, oil paint. In an oil on wood panel painting, the massive wood layer controls the response of the composite. At high R.H, the wood swells and stretches the paint layer, while at low R.H the wood shrinks and compresses the paint. Thus, R.H-induced cracking of the paint, if it occurs at all, is caused not by low R.H, but by high R.H, while low R.H can result in buckling and cupping of the paint layer. A more detailed discussion of such calculations can be found in the references (Erhardt et al. 1995, Mecklenburg et al. in press, Richard et al. in press).

It is possible to calculate the stresses and strains generated throughout an object by R.H changes if the appropriate properties (stiffness, yield points, dimensional R.H isotherm) are known, and to determine if safe values are exceeded anywhere in an object. It is obviously impractical to do this for every object. To set limits for the general museum environment, however, it is only necessary to consider the worst cases. In general, the allowable fluctuation for a composite is at least as great as that for the most R.H-responsive component. Most materials have at least a ±10 to 15% R.H allowable fluctuation when equilibrated to moderate R.H. It can be seen in Figure 9 that even a material such as ivory that is generally considered especially ‘sensitive’ to R.H changes is really no more sensitive than tangential wood. For most materials and collections, environmentally-induced mechanical damage can be avoided if the R.H is kept between 35 and 60% R.H. Other considerations, such as chemical stability, favour keeping the R.H at the low end of this range. Again, it must be emphasized that these calculations of allowable fluctuations are based on worst case considerations, and many materials and objects can be subjected to even greater fluctuations without sustaining mechanical damage.

As discussed in previous sections, no general environment will be suitable for all objects. Unless these exceptions form an unusually large percentage of the collection, however, maintaining separate microenvironments usually requires less trouble and expense than basing the general environment on the requirements of only a few objects.

CONDITIONS OTHER THAN ROOM TEMPERATURE
An underlying assumption is that museum collections, with few exceptions, are stored, exhibited, and studied at room temperature. This is unfortunate, because the increases in the chemical stability of most organic materials possible with cold storage are much greater than those that can be achieved by modifying the relative humidity within a reasonable range. For instance, Figure 3 shows that lowering the R.H from 60 to 30% can reduce the rate of degradation of paper
by a factor of three to five times. In the same study, a
determination of the activation energies of these
reactions showed that their rates could be
approximately halved by each 5 °C reduction in
temperature (Erhardt and Mecklenburg 1995).
Lowering the storage temperature from room
temperature (20 °C) to -15 °C (a temperature
achievable with standard single-stage mechanical
refrigeration) produces over a hundredfold increase in
expected chemical stability.

Physical considerations are the main factor in
determining whether a material or object can safely be
stored at low temperature. Temperature changes
produce dimensional changes, and therefore can
produce strains and stresses much as changes in R.H.
An approach similar to that used in determining the
mechanical and physical effects of changing the
relative humidity can be used to evaluate the effects of
temperature (Edelebacher et al. 1992, Mecklenburg et
al. 1994, Mecklenburg and Tumosa 1991b,
Mecklenburg and Tumosa 1996, Mecklenburg et al.
1992, Richard et al. in press). Measurements of
properties such as the thermal expansion coefficient,
and the modulus, strain-to-break, and strain-to-yield
as a function of temperature can be used to calculate
the effects of temperature changes. Other subtle
factors also must be considered. These include glass
transitions that can change physical properties, and
shifts in the isotherm that can change the equilibrium
moisture content even at constant R.H.

Figure 11 illustrates the results of a comprehensive
approach to the determination of safe conditions for
the cold storage of photographs that takes into
account chemical, physical, and mechanical
properties. Photographs, especially those produced by
some colour processes, are inherently unstable enough
that noticeable degradation of image quality can occur
in as little as thirty to fifty years at room temperature.
Cold storage is the only practical preservation
approach. The recommended environmental range in
Figure 10, is based on an analysis of a number of
factors, including the complex relationship between
temperature, pressure, relative humidity, and moisture
content, and the behavior of photographic gelatin
(McCormick-Goodhart 1995). At room temperature
(20 to 25 °C), photographs are mechanically stable in
the 35 to 60% R.H range (line AB). Above this range,
there is a risk of crossing the glass transition boundary
(the dotted line). Beyond this line, gelatin softens and
photographs stick together. The numbered contour
lines are lines of equal permanence. The lifetime of a
photograph in the conditions along Line 10 will be
approximately ten times that for the same photograph
in the conditions defined by Line 1. These values are
based on data for the temperature and R.H.
dependence of a number of important chemical
reactions of photographic materials. The shift of the
safe region to a lower R.H range at lower
temperatures takes into account the fact that the
moisture content of gelatin and other organic
materials such as those used in film bases is a function
of both temperature and relative humidity. A
photograph in an airtight enclosure with a minimal
airspace goes directly from Point B to Point C with
no change in moisture content if cooled from 25 °C
to -25 °C. Such conditions, attainable with simple
packaging and standard freezers, extend the predicted
lifetime of photographs to many thousands of years.

Such deviations from 'room temperature' are
practical only in storage areas or specialized
microclimate exhibit cases. Cold storage also presents
challenges of design and access. Nevertheless, cold
storage for suitable collections can be integrated
effectively with overall museum energy cost
objectives and reasonable policies that balance the
conflict between preservation and access.

CONCLUSIONS: GENERAL
RECOMMENDATIONS FOR R.H SETTINGS

Clearly, there is no one ideal R.H for the general
museum environment. This is made clear in Figure
10, adapted and updated from Erhardt and
Mecklenburg (1994), which provides a comparison of
the ranges suggested by various factors. An
environment maintained between 35-60% R.H may
be the best general compromise. The R.H can be
allowed to vary (at any rate) within this region with
little risk of mechanical damage. However, any
overall setting must be a compromise, and there will
always be exceptions that will have to be treated
separately, either buffered to maintain a specific R.H
range or housed in a microenvironment with a
different R.H. As shown in the section on R.H
fluctuations, objects conditioned to high R.H are
susceptible to damage if exposed to low (or even
moderate) R.H environments. Metals such as bronze
and iron should be kept in the dry end of the 35-60%
R.H range, if not drier.

The combined costs of maintaining both the
general and specialized environments also must be
considered and balanced. The installation and running
costs of equipment and facilities designed to maintain
'constant' conditions can be prohibitive. Allowing both short-term and seasonal fluctuations in the environment can greatly reduce costs. For example, allowing the R.H. to drop to 35% in the winter and rise to 50% or 60% in the summer may reduce the running costs of humidification and dehumidification, and may even eliminate the need for large capacity or multiple stage systems.

Setting the R.H. range and determining the exceptions requires an understanding of the effects of R.H. as well as a thorough knowledge of the materials in a collection, the ability to determine which objects and materials must be treated differently, and an understanding of the costs and problems involved in maintaining specific environments.

REFERENCES


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**Figure 1** Moisture absorption isotherm of cotton. (From Urquhart 1960)

**Figure 2** Absorbed water in cotton differentiated into 'bound' and 'free' water. Bound water is absorbed and held tightly starting at low R.H. Free, or capillary, water is less tightly bound and absorbed primarily at high R.H. (From Urquhart 1960)
Figure 3  Hydrolysis of cellulose produces glucose and glucose oligomers. The rates at 80°C of the reactions that yield each product correlate with the amount of free absorbed water. (Reaction rate data from Erhardt and Mecklenburg 1995, absorbed water curve from Urquhart 1960)

Figure 4  Modulus (stiffness) of cottonwood as a function of relative humidity

Figure 5  Strain-to-yield and strain-to-failure for cottonwood in the tangential direction as a function of relative humidity.

Figure 6  Stress-strain curves for cottonwood at various relative humidities. The curves are displaced on the X-axis by changes in dimension due solely to changes in R.H. (From Erhardt et al. 1995)
Figure 7  Detail of Figure 6. Drying while held at constant length produces the same stress as when allowed to shrink during drying and then stretched to the original length. (From Erhardt et al. 1995)

Figure 8  Allowable fluctuations for cottonwood as a function of starting relative humidity. A stress-free sample restrained at 50% RH can be raised or lowered to 68% or 31% RH without permanent deformation, and lowered to 13% RH before failure. These values are for the tangential direction. Allowable fluctuations in the radial and longitudinal directions are much larger. Larger changes also are possible if the sample is not restrained, or if not exposed to the RH extremes long enough to fully respond.

Figure 9  Dimensional moisture isotherms for some materials typically found in museum objects. Most materials are relatively insensitive to RH changes in the moderate RH range. Moisture isotherms for most other materials fall within the range seen here.
Figure 10  Ranges of relative humidity suggested by consideration of various factors. No value or range is suitable for all objects, but a relatively wide range is safe for many types of objects. Adapted from Erhardt and Mecklenburg (1994).

Figure 11  Factors involved in determining environmental ranges that are safe for the storage of photographs. With suitable packaging, photographs can move freely within the shaded area without generating damaging stresses or crossing the glass transition (T_g) boundary. Relative chemical stability (indicated by the numbered lines) is greatest in the lower left section of the mechanically safe region.
THE INTERFACE BETWEEN SCIENCE AND CONSERVATION

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