Time's Effects on Paintings

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Abstract: *Agents, not Time, act on paintings. The overt ones have always been understood, the subtle ones only recently: light, humidity, warmth, and pollution. If they are to be controlled, there must be a perceived need and a will to act. Attitudes in galleries have varied between two extremes: an expedient fatalism that gives precedence to the immediate public, and an obsessive caution that gives precedence to an unspecified future. Polemics develop partly because rate of deterioration has been vague. This paper reviews the current state of knowledge, and suggests guidelines for preventive conservation. Some are familiar: ideal RH is 50%; UV filters are essential; backing boards and glass give the best control of RH and pollution. Some are unfamiliar: 10% RH fluctuation should cause little cracking per century; a contemporary artist may use a palette that does not fade for centuries at several times "conservation levels;" figurative paintings of the last few centuries are often fading, just perceptibly, every few decades even at "conservation" light levels.*

Introduction

Time has culled paintings, arbitrarily. War and vandals, fire and flood. The rest, survivors, aged. As with our own ageing, we deny the bald fact of deterioration, and instead create transcendent side effects like ennoblement. Now, science blandly offers longevity, not by dramatic intervention but by a sort of hygiene, based on comprehension of deterioration. But it is a very tough sell. Hygiene is a tedious sell anywhere, but the art world sniffs particularly. Delightful poses—romance, anarchism, decadence, nihilism, futurism, humanism—all dealt in earthly transience, and only boring or dangerous people talked of permanence. Capitalist materialism though, has promised it all: the permanence of acquisition, and the transience of consumption. Of course, the promise cannot apply to the same goods, but galleries hope it can. After all, they have become a crucible of these beliefs: the wealth of their collections has grown "incalculable" (a veritable mystery of capitalism) yet consumption of the same art grows more than ever.

Acquisition drives the urge to protect; visual consumption drives the urge to loan and display. Galleries entrench the dichotomy by assigning the urges to different departments, typically conservation versus exhibition. Curatorial arbitrates. The protagonists can refer to myopic journals, research institutes, training programs etc. to augment arguments, but in practice, both rely on a few grimly defended articles of faith. After all is said and done, the institutional consensus then follows the same mix as the government's budget: one third politics, one third intuition, and one third facts. This is not necessarily a bad thing, but I would like at least to keep the politics explicit, the intuition mature, and the facts current.

What has this to do with Time and Paintings? Well, I am not about to enter the rarified air of the aesthetic "ravages of Time."[1] This has been elegantly addressed by others, recently by Hedley,[2] not to mention Gombrich, Berenson, and the rest. Instead, I will sketch out the politics, intuition, and facts of deterioration in a prescriptive framework. My cause is foresight, not analytic hindsight.

Time itself has no effect—in the cold, dark vacuum of space, paintings would outlast our race—but Time does have agents here on Earth. The agents in turn have access only if some custodian permits it. Galleries have always understood and combatted the obvious agents, but I am concerned here with subtle agents, those against which we plead ignorance or lack of influence; those that we picturesquely blame on Time: light, humidity, warmth, and pollution.

Politics and Intuition

Our politics determine how we balance the rights of today's public with those of tomorrow's, or whether we consider the question at all. (By politics, I mean social beliefs and values, not bureaucratic infighting.) We then intuit most components and the solution to the dilemma:

which tomorrow? what degree of change? how fast? how meaningful? and who cares? Within orthodox gallery traditions, two attitudes have flourished. One is this: of course we are careful, but an exact obligation to the future is meaningless. The identifiable, immediate need takes precedence over a vague angst about deterioration. Anyway, lots of old paintings still look great; they seem to have survived without all the paranoia. At best, this attitude fully engages the present and its public, but at worst, its fatalism simply rationalizes expedience. Of course, it had its optimistic myth—all those old masterpieces that still looked good, the proof of benign neglect. The fact is, old paintings are excused a multitude of flaws, and decrements are not noticed, short of catastrophe. A painting's descriptions deceive even further, because paintings become their non-physical reality—their creator, their history, their composition, imagery, symbolism, etc., even their market value. All belong to the painting *but are not the thing itself*, not its mortal body. These non-physical attributes essentially rest in the thing as a whole, and only vaguely in its constituent parts; but since they bear all the significance, no one wants to knock ten per cent off their value just because the paint deteriorated ten per cent. Besides, the attributes grew. They always grow, like inflation.

The other extreme is this: we have a sacred trust; preservation is more than a priority, it is the progenitor of our institution. Ethical display only occurs in a controlled environment at sanctioned light levels. All lending is perilous. Although self-righteous and poorly justified, this attitude has become sacrosanct amongst museum professionals, because it neatly places the burden of proof on its sceptics. Unfortunately, the result is lowest common denominator display conditions, usually bland and contrived. More importantly, it oversimplifies. What began as "best guesses" hardened into commandments in the 1970s (e.g. 50-150 lux, 50% RH ± 3%). These commandments could give a false sense of security—some colours will fade within a decade even at "conservation" lighting levels. These commandments could suppress unnecessarily—a painting in a durable palette (not infrequent) will be unchanged for centuries even at several times these light levels. These commandments could later prove dysfunctional—works on paper last longer at low relative humidity, not 50% RH; and the unorthodox building systems were unreliable. At best, the attitude provides fierce advocacy for the object, but at worst it obsessively enforces generalizations.

Of course, the politics of individuals are too malleable to be trusted, hence institutions must codify consensus.[3] As an individual, even Ruskin wobbled between expedience and sanctimony. Despite admitting earlier that his own Turner watercolours had faded badly,[4] he stated

> "properly taken care of—as a well educated man takes care also of his books and furniture—a water colour drawing is safe for centuries; out of direct sunlight it will show no failing on your room-wall till you need it no more . . . is it for your heir that you buy your horses or lay out your garden?"[5]

After opening with a bald lie, he deemed Turner's watercolours just another consumer item, albeit that of a gentleman. Besides, for his own Turners, years earlier he found them

> "even in their partial ruin marvellous . . . changed so harmoniously that I find in their faintness more to discover than to surrender as lost."[4]

Ruskin could justify better than most of us, but his actions had been ordinary—hang the paintings in nice light, and leave them. He would be castigated by his own rhetoric, if he thought paintings as important as buildings.

> ". . . it is again no question of expediency or feeling whether we shall preserve the buildings of past times or not. *We have no right whatever to touch them.* (Ruskin's emphasis) They are not ours. They belong partly to those who built them, and partly to all the generations of mankind who are to follow us. The dead have still their right in them: that which they laboured for, the praise of achievement or the expression of religious feeling, or whatsoever else it might be which in those buildings they intended to be permanent, we have no right to obliterate . . . Neither does any building

> whatever belong to those mobs who do violence to it. For a mob it is, and must be always; it matters not whether enraged, or in deliberate folly; whether countless, or sitting in committees; the people who destroy anything causelessly are a mob. . ."[6]

Although Ruskin assumed intentional destruction, lack of intent does not change his argument. Besides, he knew it was simple neglect that mattered most:

> "Take proper care of your monuments, and you will not need to restore them. A few sheets of lead put in time upon a roof, a few dead leaves and sticks swept in time out of a water-course, will save both roof and walls from ruin. Watch an old building with an anxious care; guard it as best you may, and at *any* cost, from every influence of dilapidation. Count its stones as you would jewels of a crown; set watches about it as if at the gates of a besieged city . . . Its evil day must come at last; but let it come declaredly and openly, and let no dishonouring and false substitute deprive it of the funeral offices of memory."[7]

Obviously, infinite stasis is not the goal; on the other hand, preservation for one human generation does seem a bit short. The goal lies between, hard to define, easy to ignore. Quantification is needed.

Facts

What exactly is "every influence of dilapidation"? Well, politics and intuition have played the dominant role in the polemics of Time and Paintings because the facts were scarce. This is changing.

Light

Since a painting must be seen to function—and seen to function often—it needs light, somewhere between 50 lux and 300 lux. (Lux is the unit of light intensity.) Contrary to popular belief, 50 lux is well above the transition to colourless "night" vision that occurs between 0.01 lux and 3 lux.[8] (See **Figure 1**) Virtually all the colour and most of the detail we will ever see is visible to a young eye at 30-50 lux.[9,10] The practical problem is the several minutes needed for adaptation to this low lighting; any exposure to bright light erases it. Our eye also ages. How much to accommodate failing eyesight is a dilemma, but twice as much light will give many older people equal access to the work.[9,10] To see well within dark colours also requires more light: two or three times as much.[11] Overall then, a young, adapted eye can see bright surfaces well at 50 lux, dark surfaces at 100-150 lux. For an old eye, the values are 100 lux for bright surfaces, 200-300 lux for dark surfaces.

There is no denying that resolution improves up to several thousand lux. To see not just "well" but luxuriously may need more light. Colours appear brighter as light increases; the higher the saturation, the stronger the effect. (See **Figure 1**) Between 10 and 100 lux, this means "more vivid and stronger"[8] colours, but beyond may not be desirable, as Mark Rothko said:

> "The light, whether natural or artificial should not be too strong: the pictures have their own inner light and if there is too much light the colour in the picture is washed out and a distortion of their look appears."[12]

The effect is slightly greater for blues and greens. (This is distinct from the Purkinje effect that emphasizes blues and greens below 3 lux.)

In a recent British experiment,[13] people were asked to judge the effects of various gallery light levels on "quality" scales (e.g. attractive/unattractive, tense/restful, drab/colourful) as well as "discrimination" scales (e.g. difficult/easy, detail discrimination, etc.) The results show great improvement between 10 and 100 lux, but much less betwen 100 and 400 lux, especially on the quality scale. (See **Figure 1**). The authors concluded that 200 lux is best, so the National Gallery in London followed suit. But even this conclusion is an opinion, since there is no sharp boundary in the data. In summary, whether or not a painting looks better in bright light is moot, but to deny it looks somewhat different would be obtuse.

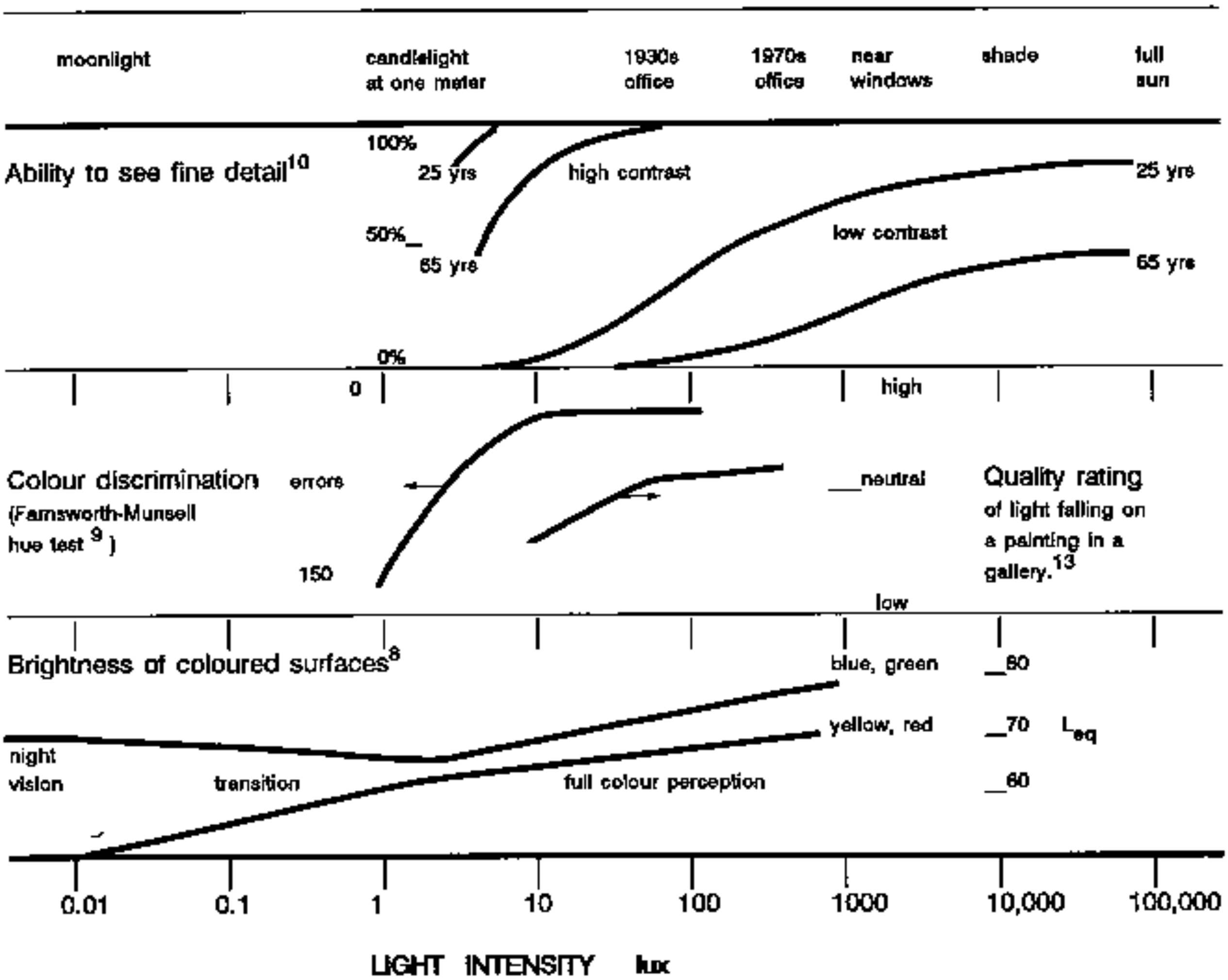

Figure 1 Light intensity and our eye.

Ten to a hundred times the light may or may not yield small gains in visibility, but it definitely wrecks paintings ten to a hundred times faster. Pigments fade or darken, mixtures shift colour; original meaning not only disappears but is replaced by spurious meaning.

In **Figure 2**, some historic pigments are categorized, and their lifetimes given for various light intensities. For the same pigment at the same strength, sensitivity to light changes only about 2 to 1 between the various media.[14] Thin glazes and tints of a given pigment are up to five times as sensitive as the full strength colour.[15] Thus, carmine in an oil glaze and carmine in a watercolour glaze are *equally* fugitive.

In the past, artists knew some colours were fugitive (e.g. yellow lake, crimson lake, carmine lake, and gamboge).[16] Only dim and infrequent light permitted them to survive a century or more. In the nineteenth and twentieth centuries, cheap palettes contained even more fugitive colours.

The intermediate pigments form a crux for paintings: more brilliant than the permanent colours, stable enough to seem durable over a few years. A heavy carmine, madder lake, and alizarin crimson are intermediate,[17] although they do vary from worst to best in the order given. Many vermilions also lie in this range, although they darken rather than fade. Ironically then, it is the painter's representation of ourselves, our own

PERMANENT		DURABLE		INTERMEDIATE			FUGITIVE			
	ISO	8	7	6	5	4	3	2	1	
carbon blacks	cadmiums*			alizarin (madder) lake				carmine lake		
ultramarine				full	half	tint		gamboge***		
ochres, umbers								quercitron lake***		
iron oxides			vermilion							
terre verte						carmine				
azurite						full	tint			
CS 98-62 Class I**										
ASTM D4303 Class I**										
		30	10	3	1					at 10,000 lux
		300	100	30	10	3	1			at 1,000 lux
		1,000	300	100	30	10	3	1		at 300 lux
		6,000	2000	600	200	60	20	6	2	at 50 lux

YEARS+ TO FIRST PERCEPTIBLE COLOUR CHANGE++

* Cadmiums (red, yellow) may in fact be permanent, but the data so far places them at the high end of durable.
** These U.S. artists' paint standards include both permanent and durable colours in their top category.
*** These yellows were also part of many greens, such as Hooker's green, sap green, Prussian green.
\+ 3000 hours per year, i.e. 300 days x 10 hours.
++ Almost complete loss of the colour takes about 30 times longer, less for tints.

Figure 2 Light damage to some important pigments.[17,19] This chart assumes good UV filtration, and ignores other effects on permanence such as pollution.

flesh, that we now see at all stages of decay. As Villers and Hedley note,[18] considerable art historical bombast flounders on faded reds. Fortunately, storage during changes in taste, dim walls of pre-electric houses and churches, even yellow varnish, dirt, and overpaint, all contributed to survival. If galleries do not want further noticeable change in these colours every few decades, they cannot exhibit them permanently, even at 100-300 lux.

The durable category has great significance for twentieth century art. New pigments such as cadmium red offered brilliance and durability. Standards of permanence came into being. Some artists followed these guidelines, so it seems unfair to light their work in the same way as vulnerable pieces. Even 1,000 lux for a century will only just affect the weakest in this category. For works where the artist is still alive, or the palette is known, lightfastness information can be obtained, and a specific prediction made about the painting's light sensitivity, or lack thereof.

Permanent pigments do not necessarily give permanent paints. The organic media themselves lose gloss and exhibit chalking outdoors, but over 90% of this damage is caused by ultraviolet radiation (UV).[19] Historically, daylight bounced off walls and ceiling was low in UV, as was light from flames. Today, galleries can easily filter UV. With low UV lighting, all organic media enter well into the durable range; those with early photosensitizing titanium white and some zinc whites may not make it into this range unless violet is filtered to 410 nm.

Relative Humidity

Relative humidity fluctuations have caused most craquelure and cupping in paintings. Proof lies in the typical crack pattern shown in Figure 3. This is one of the clearest examples of the pattern that I know, taken from an oil painting on canvas, *Jam of Logs on the Little Shawinigan* by Cornelius Krieghoff, hanging at Government House, Ottawa. The absence of most cracks and cupping in the areas of the painting directly above the stretcher bars is due to an absence of most humidity fluctuations. The wooden stretcher bars moderate humidity in the linen, ground, and part of the paint layers above them, but only for a day or so after a change in ambient RH. Luckily, this is enough to moderate the 36,500 day/night cycles per century. The Krieghoff also had an oval frame liner that moderated humidity in the top layers at the perimeter, hence the exceptional condition of the perimeter of this painting. Conservators have also noted that paintings on wooden panel stretchers, or with a second primed canvas behind, show much less craquelure than normal.

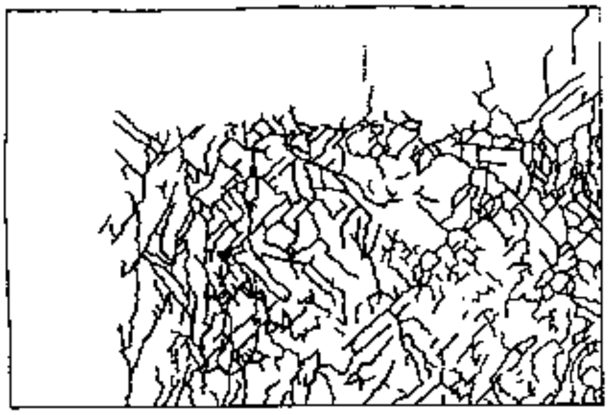

Figure 3 Crack pattern in the top left quadrant of the Cornelius Krieghoff painting, *Jam of Logs on the Little Shawinigan* (Department of External Affairs, Ottawa).

Slow chemical ageing of the paint does play a role, but relative humidity fluctuations cause the largest and fastest changes in tension. Measurements of both new and old oil painting samples show the response in Figure 4.[20,21,22] Tension at low relative humidity is in the size, ground, and paint layers only; the linen goes slack. The only role of the linen is to bridge old cracks like a "safety net."[23] *The amount of keying-out of the stretcher is critical; it determines which tension line the painting lies on.* As cracks grow, they relieve tension in the painting, but routine keying-out in humid weather simply resets the tension, so cracks develop further when humidity drops.

In rooms with uncontrolled humidity, proper backing boards should reduce the rate of cracking of paint layers by several times, and by even more for paintings with thicker paint. Simple and effective backing boards have been tested at the Canadian Conservation Institute (CCI).[24] By also placing the painting under glass (discreetly in the frame; not touching, of course) and adding a little more humidity buffer, the rate of cracking will drop to almost nothing, as it did for areas of the Krieghoff that were protected on both sides.

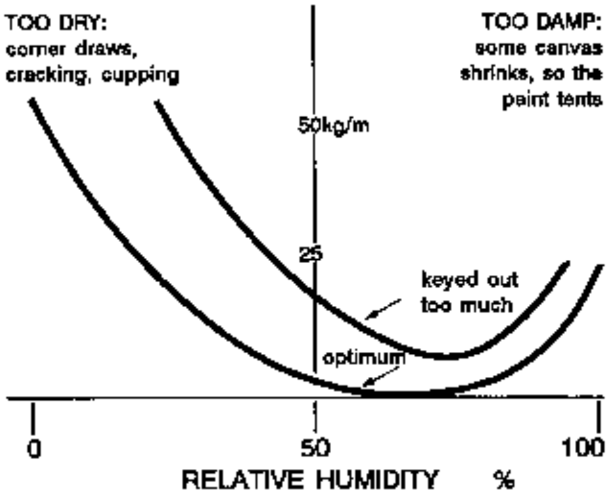

Figure 4 Tension in an oil painting as a function of relative humidity and keying-out of the stretcher.

The anathema of framing with glass and the dependence on expensive building systems then beg the question: what are the tolerances to humidity change? Speed is known, magnitude can only be estimated. Exposed canvas, size, ground, and very thin paint layers respond to changes in relative humidity within a few minutes; heavy impasto may take days to respond.[25] With a backing board in place, thin paintings respond in an hour, but most paintings take several hours or more to respond.[26] A board or glass in front of the painting extends this protection to many days. All of this becomes critical in relation to the ubiquitous day/night humidity fluctuation: 36,500 per century. Studies of fatigue in other polymers show that cracks start at a flaw and *grow a finite amount each and every cycle.*

Brittle polymers that grow a millimeter of crack after 100 stress cycles need 30,000 cycles at one half the stress.[27] At about one tenth the stress, cracks cease to grow at all. If paintings in uncontrolled buildings, like the Krieghoff cited, develop complete craquelure in a century, then to reduce this rate three hundred fold would require one half of the stress. Historic buildings typically show 20-40% RH variation daily,[28] so restriction to 10-20% RH variation daily should see crack growth become imperceptible for millenia, i.e. ± 5% would be conservative, ± 10% probably fine. The average RH should be above 40% to keep the painting less brittle, and to avoid corner draws. Constant tension will also grow cracks slowly, so paintings at stable humidity must not, need not, be stretched tight. A slightly loose painting is not growing cracks, unless it is hit.

At 70% RH, risk of mould is climbing rapidly, and light-fading of carmine[29] and acid attack within the canvas is double that at 50% RH.[30] Given all of the above, and other factors of weather, building design, and human comfort, a setpoint between 40% and 60% RH is reasonable. International consistency for loans has favoured 50% exactly.

Warmth

How can I berate warmth? Only because a grab-bag of chemical deterioration depends on it, and mitigation by other means is much more risky. Many slow chemical processes fall to one half their rate for each 4-8°C temperature drop.[31] Those that have been studied are shown in **Table I**. The yellowing of varnishes and media that becomes very noticeable in a few decades at 25°C might be put off for centuries by keeping the painting at 10°C. In fact, we do not know how far old oil and tempera will unravel chemically; the only guarantee lies in low temperature.

Pollution

Only a few pollutants have been studied in relation to paintings, and these are summarized in **Table II**. Two types of damage occur: colour change and strength loss. In the past, the emphasis lay on sulfur compounds produced by coal fires and industry. These weakened canvas and paper supports, and darkened lead whites. Now, automobile exhaust provides ozone and nitrous oxides that fade lake pigments.

Unlike light damage to colours, pollutant damage to colours varies greatly with medium. Lean paints fade faster, hence watercolour and gouache are very susceptible.[32] Exposed watercolours at concentrations typical of the worst urban levels (e.g. Los Angeles) can fade some colours in well under a year.

Mitigation need not be elaborate. As with humidity control, a tight backing board and a tight glass in front will reduce the rate of attack several hundredfold. Pollution levels inside buildings can be as much as ten times lower than those outdoors, simply by keeping doors and windows shut, and fresh air makeup to a minimum.[33]

Guidelines for Preventive Conservation

The natural custodial response to the facts is a groan, but I simply bear the message. The next few years promise considerably more knowledge, but only in detail and precision; basic phenomena will not change. Politics will always stay at the core: there must be both a perceived need and a will to act, if the effects of Time's agents are to be reduced.

But, I am a pragmatist. What short list of suggestions do I offer?

Guidelines for Light

Ultraviolet filters are essential, and non-contentious anyway.

The gallery must learn the sensitivity of the colours of its paintings. It is not an impossible task, just unfamiliar. *If at all possible, sample palettes of contemporary works should be acquired along with the work. This could easily be tested and exact sensitivity obtained.* (CCI is preparing guidelines for this procedure.)

Table I:
Some Inherent Deterioration of Traditional Paintings, and the Effects of Temperature Where Known

Form	Rate at 21°C or Cause other than warmth	Drop to half rate	Mitigation; Reversal
Varnish			
yellowing			
dammar in turpentine	'unacceptable' in 5 years[38]	8°C[38]	add antioxidant; replace varnish
	taffy colour in 100 years	"	
dammar in toluene	'unacceptable' in 20 years[38]	"	" "
	taffy colour in 400 years	"	
copals	yellow brown in 20 years[39]	4-8°C[31]	"
vinyl resins	none visible in 30 years[39]	"	
methacrylate resins	none visible in 30 years[39]	"	
Oil Medium			
oil yellowing	most occurs first six months[40]	4-8°C[31]	select low-yellowing oil; light may fade some yellow
oil "drying" 1 : film formation	within days to weeks[41]	"	
oil "drying" 2 : plasticizer loss	decades to centuries[42]	"	replace plasticizer?
oil "drying" 3 : disintegration	centuries (if no UV)	"	no reversal
pentimenti from oil drying 2,3	decades to centuries	"	
bloom 1: fatty acids from oil drying 2,3, or their soaps	decades to centuries[42]	"	remove bloom
Pigments			
azurite in oil, turns green	due to oil yellowing[43]		
azurite in tempera darkens,	later additions of oil, varnish[44]		remove oil or varnish
" turns green (murals)	malachite, due to high RH		
" turns black (murals)	tenorite, due to alkalis[45]		
smalt turns grey, grey/green (16th, 17th C.)[46]	could happen immediately, so dry pigment 'strewn' on wet oil; also could occur later, rate unknown[47]		
ultramarine turns grey, in oil	medium whitened by high humidity, or discolouration of smalt admixture[48]		
" " " in ink	acid attacks the pigment, see Table II		

Although artists' manuals warn about various pigment mixtures reacting with each other, such statements are generally speculative. Only mixtures of emerald green with cadmium red, yellow, or lithopone have been shown to cause problems in oil.[49]

Form	Rate at 21°C or Cause other than warmth	Drop to half rate	Mitigation; Reversal
Supports			
weakening of linen, cotton:			
uncontaminated, no UV	millenia[50]	4-8°C[31]	
exposed to acid pollutants	decades to centuries (Table II)	"	
oil on unsized fabric	decades[51]	"	
oil on sized fabric	centuries, if no pollution[52]	"	
weakening of wood	millenia[53] (if no damp or UV)	"	
" plywood, hardboard	centuries to millenia[54]	"	
" artists' board	decades to centuries[55]	"	
weakening, yellowing of paper	decades to millenia[33] depends on acidity	"	

Table II:
Miscellaneous Pollution Effects

Form	Mechanism	Control; Mitigation
Surface Accretions		
yellowing	tar aerosol deposition (smoke)	****, no smoking
darkening	particulate deposition ("dirt") e.g. carbon, fly ash	****
bloom 2	ammonium sulfate crystals formed from air pollution gases[56]	****
bloom 3	mineral deposit from atomizing humidifiers[57]	avoid such humidifiers
bloom 4	organic residue from corrosion inhibitors in steam humidifier on central boiler[58]	
Medium		
linseed oil darkening	alkali from new concrete[59]	wait 1-2 years before occupancy
Pigments		
lead white in tempera		
turns black, lead sulphide	H_2S in air pollution[60]	****
	H_2S from bacteria in glue medium[61]	avoid high humidity
turns brown, lead dioxide	peroxides from micro-organisms[61]	avoid high humidity
lead white in oil	oil protects pigment, no darkening noticeable in centuries[62]	
calcium carbonate forms sulfate in fresco and lean paint, causes spalling[62] in oil, is well protected	SO_2	****
massicot, minium, turn brown	peroxides from micro-organisms[61]	avoid high humidity
fading of orpiment, realgar, gamboge, cochineal lake, mauve, in lean paint	NO_2 in air pollution (automobiles) just noticeable fading in 5 years or less at typical urban levels (exterior)[63]	****
fading of orpiment, madder lake in lean paint	O_3 in air pollution (automobiles) just noticeable fading in 2 years or less at typical urban levels (exterior)[64]	****
ultramarine in ink fades	acid air pollution (SO_2)[48] substantial fading in poster inks	****

N.B. Pigments that react in a few years in lean paint (e.g. watercolour) will take millenia in oil media covered by varnish,[32] so problems are rarely seen in oil paintings. Unvarnished temperas and acrylics will fall in between: quick if matte, slow if glossy.

Form	Mechanism	Control; Mitigation
Supports		
weakening of linen	SO_2 acidifies linen, one third strength loss in twenty years exposure in London[65]	****

**** Enclose by glass and backing board, or filter the room air.

Four clarifications emerge:

1) Bad news: fugitive colours last only decades if displayed 10% of the time, centuries if displayed 1% of the time. These might be old works previously covered, or new pieces such as mixed media, found objects, or just cheap paint.

2) Good news: a painting with a durable to permanent palette will tolerate several hundred lux for centuries. If some artists have paid the price of a permanent palette—literally, and figuratively—then surely their work should be rewarded in its lighting.

3) Quandary: intermediate colours, such as the standard reds for skin tones, will have partly survived centuries if lucky, but will show just noticeable change every few decades if permanently displayed.

4) Fine-tuning between 50 and 300 lux is more a question of visibility than damage rate. For real reasons of nuance, an artist may ask for even more.

Guidelines for Relative Humidity

The only change from past recommendations is a better understanding of tolerance, and emphasis on the backing board. To avoid mould, reduce light-fading, and reduce acid attack of the canvas: stay below 60% RH. To keep the paint layers more flexible, corner draws down: stay above 40% RH. For consistency across institutions, 50% RH makes sense. To reduce crack development, keep RH stable: ± 10% will cause little cracking per century, ± 5% even less, *if the correct canvas tension is achieved by proper keying-out of the stretcher.* In Canada, *reliable* winter humidification is much more important than summer dehumidification. Always install airtight backing boards. In uncontrolled buildings, use glass in the frame, extra buffer in the back, to achieve ideal conditions. Oil paint is much more vulnerable than acrylic to humidity change.

Guidelines for Warmth

A 50% decrease in deterioration at 17°C compared to 21°C is not worth the categorical leap in public discomfort, so 21°C remains realistic in display areas. Since humidity and stress problems can arise each time a painting changes temperature rapidly, short term cold storage is more risk than benefit; only long term storage has potential application: 5°C would slow yellowing and chemical disintegration several times over, -10°C would virtually put it on hold. Implementation would have the same complications as photographic cold vaults—soluble but tedious.[34] Low temperature remains the most broadly beneficial act and the most unrealistic. It may make sense for ephemeral contemporary pieces, where the curator wishes to "freeze" decay that is rapid at room temperature.

Guidelines for Pollution

Paintings in some Canadian cities are at moderate risk from sulfur dioxide and automobile smog. Acrylics, watercolours, and gouache are much more vulnerable to pollution than varnished oil paint.[32] The best control is provided by a backing board behind and glass in front of the painting. Ventilation of the building should not be any more than that which is essential for human comfort; reserve collections can have no ventilation. Keep air intakes away from local pollution sources, such as heavy traffic and chimneys. Failing these precautions, elaborate filtration systems may be necessary. (CCI may be contacted for specific advice.)

In writing my list of guidelines, I have tried to avoid presumptions of politics and intuition. I provide implications rather than standards; only institutions themselves can incorporate other parts of the decision.

Conclusions

Over the last few decades, restorers became conservators. Then, through self-anointment and institutional default, conservators became the "light, humidity, packing police." Today, all museum professionals recognize preservation as one of the museum's functions,[35] so conservators can return to the role of expert counsel. Dogmatism can give way to specificity, *if* we want. For the mountain of mediocre art, we are uneasy about thwarting the merciful effects of Time. For great paintings, Time seems more cruel than merciful: how fast are we prepared to consume the work? For example, will we admit our intention to fade all red lake colours one perceptible notch every few decades, given only thirty notches at most to consume? It is not surprising then that institutions avoid such specificity. It is easier to invent a single, well-intentioned value for lighting, pollutants, humidity etc., to be applied without further judgement and with random benefits.

Given a willingness, however, to face consumption explicitly, one must correlate physical change to value change—rather a large issue. All cultures have their own sacred objects: a rock, medicine bundles, or great paintings, that must pass intact from generation to generation, but for each object the mix of physical and metaphysical criteria for "intact" changes. The rock is obviously robust, a well-chosen metaphor on which to build a faith. The medicine bundle is symbolic, so its meaning does not rely on physical detail but on cultural context. Our paintings, though, have their essence in the physical. They are vulnerable precisely to the extent that they are not sacred or context-dependent at all but profane, sensual, immediate. In fact, when paintings become sacred, either to the Church or the Gallery, their physical details become simultaneously taboo and incidental. Whosoever dares list the disfigurations of the Mona Lisa must follow with a pious affirmation of its status as Relic. Mass communication also reduces paintings: with photographs and text as the dominant means of knowing art, so much of the *real* thing is unknown that its loss goes unnoticed. Slow deterioration of Barnett Newman's *Voice of Fire* will be as easy to miss as its purchase was to ridicule, if one *knows* the painting only by its photograph.[36]

Essentially, the slow agents of Time obliterate, distort, or convert *some* colours. *The changes to a subtle image are far too complex for the mind's eye to compensate.* Cracks spread a veil across the painting. Colour change and cracking cannot be undone, and they cannot be stopped, but they can be slowed. The other effects: weakening, cupping, draws, bulges, and sagging can largely be undone, but prevention is preferable.

The dilemma of the gallery is the same as that of the artist: appearance versus permanence. For artists, the priority has always been clear. Even old masters selected impermanent pigments if no permanent pigment gave the right colour. Elsewhere in these *Proceedings*, Christopher Pratt states that he would rather see his work brightly lit for a short period than dimly lit for much longer.[37] Artists prefer to have their paintings travel widely, and wear and tear faster, than leave them in one safe place. They generally refuse the protection of glass, even though it substantially reduces discoloration, cracking, and weakening over time. Artists can be iconoclasts, but galleries cannot.

Notes

1. John Russell, "Art Preservation: A Race Against the Ravages of Time," *New York Times*, Sunday, 5 May 1985, Section 2, pp. 1, 18.

2. Gerry Hedley, *On Humanism, Aesthetics and the Cleaning of Paintings*, Reprint of two lectures, 1985, mimeograph available from Canadian Conservation Institute, Department of Communications, 1030 Innes Road, Ottawa, Ontario, K1A 0C8, Canada.

3. See Sandra Lawrence, "Conservation Policies for Museums," in these *Proceedings*.

4. J. Ruskin, *Notes by Mr. Ruskin on his Drawings by the late J.M.W. Turner, R.A.*, Fine Arts Society, London, March 1878, pp. 9, 29, no. 26. This quote and reference are taken from M.B. Cohn, *Wash and Gouache* (Cambridge, Massachusetts: Center for Conservation and Technical Studies, Fogg Art Museum, Harvard University, 1977); see her note 38 on p. 62.

5. J. Ruskin, letter to *The Times*, London, April 1886. Quote and reference taken from M.B. Cohn, p. 64 (see Note 4 for reference).

6. J. Ruskin, *The Seven Lamps of Architecture*, (London: George Allen and Sons, 1908), p. 358.

7. Ibid., p. 357.

8. M. Ikeda, C.C. Huang, and S. Ashizawa, "Equivalent Lightness of Colored Objects at Illuminances from the Scotopic to the Photopic Level," *Color Research and Application*, vol. 14, no. 4, 1989, pp. 198-206.

9. P. Boyce, "Visual Acuity, Colour Discrimination and Light Level," *Lighting in Museums, Galleries and Historic Houses* (London: The [British] Museums Association, 1987), pp. 50-57.

10. *An Analytic Model for Describing the Influence of Lighting Parameters upon Visual Performance*, vol. 1, *Technical Foundations*, CIE No. 19/2.1(TC-3.1), 1981; vol. 2, *Summary and Application Guidelines*, CIE no. 19/2.2(TC-3.1), 1981 (Paris: Commission Internationale de L'Éclairage, 1981). Unlike visibility data previously used by conservation science, (see for example Note 9) these articles introduce "visual performance"—our ability to see complex details while under a time constraint. As such, it has great relevance to the viewing of paintings. In addition, the graphs (see for example Figure 1 of this article) are sigmoidal, so the transition from "I didn't see that" to "I saw it as well as I can" is clear. Visual performance declines with age even faster than visibility. The older viewer can partly compensate by taking longer to view the painting, but should the gallery force that on a group already more prone to museum fatigue?

11. Although very black surfaces may reflect only one tenth as much light as a middle grey, one should not ask for ten times the light to see detail. The viewer expects these to be dark, vague surfaces, and explores other cues, such as gloss differences at different viewing angles. On the other hand, coloured surfaces three to four times less bright than those seen well at 50 lux are not "very dark," so it seems reasonable to give them three to four times the light.

12. Mark Rothko, Letter to Bryan Robertson on how to hang an exhibition at Whitechapel Gallery, cited by M. Compton in the catalogue *Mark Rothko* (London: The Tate Gallery, 1987), p. 59.

13. D. Loe, "Preferred Lighting with Conservation in Mind," *Lighting in Museums, Galleries and Historic Houses* (London: The [British] Museums Association, 1987), pp. 36-49.

14. Light-ageing tests on samples of watercolours and oil paints from the same manufacturer (*circa* 1920), carried out at CCI, showed that carmine in a glaze, vermilion at full hiding, and other pigments, when applied at similar intensity, showed no significant difference in fading rate between watercolour and oil. If anything, the carmine left residual colour longer on the paper fibers than in the oil. (See also the review article given in Note 19).

15. Pigments and dyes have a "full tone" concentration in any medium beyond which the colour gets only slightly darker. A pale tint (1/50 concentration) typically shows a drop in lightfastness of 1-2 ISO steps, i.e. a factor of about 2-5. If the artist uses a strong tinting pigment or dye at a concentration well above full tone, then it may be several times more lightfast than the full tone.

16. R. Mayer, *A Dictionary of Art Terms and Techniques* (New York: Thomas Y. Crowell, 1975).

17. A review of the lightfastness data is being undertaken by the author. Some of it has been published in the review article of Note 19.

18. C. Villers and G. Hedley, "Evaluating Colour Change: Intention, Interpretation and Lighting," *Lighting in Museums Galleries and Historic Houses*, Bristol Conference, (London: The [British] Museums Association, 1987), pp. 17-24.

19. Stefan Michalski, "Damage to Museum Objects by Visible Radiation (Light) and Ultraviolet Radiation (UV)," *Lighting in Museums, Galleries and Historic Houses* (London: The [British] Museums Association, 1987), pp. 3-15.

20. M.F. Mecklenburg, *Some Aspects of the Mechanical Behavior of Fabric-Supported Paintings*, Report submitted to the Smithsonian Institution, February 1982.

21. Debra Daly and Stefan Michalski, "Methodology and Status of the Lining Project, CCI," *Preprints, 8th Triennial Meeting, ICOM Committee for Conservation*, Sydney, Australia, 1987, pp. 149-152.

22. Gerry Hedley, "Relative Humidity and the Stress/Strain Response of Canvas Paintings: Uniaxial Measurements of Naturally Aged Samples," *Studies in Conservation*, vol. 33, No. 3 (August 1988) pp. 133-148.

23. Marion Mecklenburg coined the phrase during a conversation with the author.

24. Debra Daly and Mark Boyle, Internal Report, Canadian Conservation Institute, Department of Communications, Ottawa, Ontario, K1A 0C8, Canada, 1988. Contact the first author.

25. Typical weight versus time curves for linen/size/ground/paint exposed to a change in RH are given in Note 21. These measurements represent the sized canvas only. A very thin oil ground and paint will be about 100 μm thick and will respond within 10 minutes. Response time varies with paint thickness squared, so a 1 mm film will take 1,000 minutes (17 hours) and a massive impasto of 5 mm will take 17 days.

26. The times in Note 25 assume the paint film has moisture entering or leaving from both sides. With an impermeable backing board, the largest capacity layer, the canvas, must get its moisture through the least permeable layer, the paint. With a 100 μm paint film, the system will take several hours to respond, 1 mm paint will take a week and 5 mm will take two months. Craquelure, unpainted canvas, or a leaky backing board will make response times lie somewhere between the values of Note 25 and 26.

27. A.G. Atkins and Y.W. Mai, *Elastic and Plastic Fracture* (Chichester, UK: Ellis Horwood, 1985), p. 546.

28. I have looked at dozens of thermohygrograph records from historic houses over the years, and 20% fluctuation daily is common, 40% unusual but not rare. Climate normals for Ottawa show August average RH at 7 A.M. is 85%, at 1 P.M., 52%. Winter fluctuations would be due to sun and stoves going down overnight, for example 25°C/15%RH changing to 10°C/55%RH.

29. C.W. Bailie, R.M. Johnston-Feller, and R.L. Feller, "The Fading of Some Traditional Pigments as a Function of Relative Humidity," *Materials Issues in Art and Archaeology, Materials Research Society Symposium Proceedings*, vol. 123, Proceedings of the Symposium held 6-8 April 1988, Reno, Nevada (Pittsburgh: Materials Research Society, 1988) pp. 287-292.

30. Specific data for linen and cotton ageing are not available, but lignin/cellulose fibers such as pulp paper show this dependence on RH. See a review in Note 33.

31. The temperature difference to double the lifetime (T_{dl}) has been measured for a few museum materials: weakening and yellowing of paper, 4-6 °C, see Note 33; dark fading of colour photographs, 5.3 °C, see Note 33; yellowing of varnish, 8 °C, see Note 38.

32. Specific data on oil media and varnishes are not available, but known permeabilities of various resins to H_2S, SO_2, NO_2, range between 1E-14 and 1E-12 cc/cm Pa s, i.e. 2E-18 to 2E-16 kg/m Pa s. See: J. Brandrup and E.H. Immergut, *Polymer Handbook*, 3rd edn (New York: John Wiley, 1981). A thin varnish is 10 μm thick, permeation will be 2E-13 to 2E-11 kg/m^2 Pa s. If there is no protective layer over the pigment, and if it reacts quickly with the pollutant, then the gas flux is only limited by the boundary layer of still air near the object, about 2 cm thick, with a permeance of 1E-8 kg/m^2 Pa s. Thus the rate of attack of a coated pigment is 500 to 50,000 times slower than an uncoated pigment. Even the 1 μm layer of medium above a glossy, unvarnished oil paint will reduce rate of attack by 50 to 5,000 times. To visibly darken a lead white paint might take a 2 μm layer of pigment particles half converted to sulphide, i.e. about 0.3 g/m^2. Given an unusually high concentration of 10 μg/m^2 of H_2S, such darkening would take 1 year for uncoated lean paint, but 500-50,000 years for the varnished paint.

33. Stefan Michalski, *Humidity, Temperature and Pollution in Libraries and Archives*, 1988. A draft mimeograph is available from Canadian Conservation Institute, Department of Communications, Ottawa, Ontario, K1A 0C8, Canada.

34. Stefan Michalski, "Retrieval from Cold Storage," *Report No. EDR 1612*, mimeograph available from Canadian Conservation Institute, Department of Communications, Ottawa, Ontario, K1A 0C8, Canada.

35. Stephen E. Weill, "Rethinking the Museum," *Museum News*, vol. 69, no. 2, 1990, pp. 56-61.

36. Barnett Newman's *Voice of Fire* a large oil on canvas, was purchased by the National Gallery of Canada in 1989 for close to $1.8 million. The purchase provoked many angry letters to the editor of the *Ottawa Citizen*, questions in the House of Commons, queries by a Commons' committee, etc. The painting was described in the media as "three vertical stripes."

37. See paper by Christopher Pratt, "Conservation and Curatorial Issues: An Artist's Thoughts" in these *Proceedings*.

38. R.H. Lafontaine, "Decreasing the Yellowing Rate of Dammar Varnishes Using Anti-oxidants," *Studies in Conservation*, vol. 24, 1979, pp. 14-22. The data in Figures 4, 5 and 6 has been interpreted on an Arrhenius plot as follows. Turpentine samples: time to reach 10% T change at 50°C (1590 hr) and 22°C (11,400 hr), the slope of the line predicts 8.0°C drop will half rate compared to 20°C. Toluene samples: time to reach 2.5% T change, at 50°C (761 hr) and 22°C (9,350 hr), predicts 7.2°C will half rate. Together with the value derived from de la Rie of 8.4°C (See Figure 5 in E.R. de la Rie, "Photochemical and Thermal Degradation of Films of Dammar Resin," *Studies in Conservation*, vol. 33, 1988, pp. 53-70) an average of 8°C has been taken. Lafontaine's data is important because it includes room temperature data collected over two years, with and without modest lighting (700-1000 lux.) He also determined what various people considered "unacceptable" yellowing, which averaged 20% T change (at 380 nm). Judging from curves in Figure 4, 20% change takes three times as long as 10% in the turpentine samples, and twenty times as long as 2.5% does for toluene samples, so the room temperature data has been extrapolated accordingly, to 5 and 25 years respectively. Based on Figure 2, a strong yellow colour—"taffy"—takes about ten times as long again, 50-250 years. The estimates are all consistent with experience—paintings needed "cleaning" every 50 years or so.

39. E.H. Jones, "The Removal of Varnish," in R.L. Feller, N. Stolow and E.H. Jones, *On Picture Varnishes and Their Solvents*, revised and enlarged edition (Washington: National Gallery of Art, 1985). See Table 8-1, p. 173. Thickness of the films is unavailable.

40. H. Rakoff, F.L. Thomas and L.E. Gast, "Reversibility of Yellowing Phenomenon in Linseed-based Paints," *J. Coatings Technology*, vol. 51, 1979, pp. 25-28.

41. With a catalyst such as a drier or drying pigment present, linseed oil generally forms a tough film within a few days, i.e. oxidation forms most of the crosslinks that are possible across the triglycerides. Without catalysts or some UV, drying may take weeks. See the discussion in N. Stolow, "Solvent Action," in R.L. Feller, N. Stolow and E.H. Jones, *On Picture Varnishes and Their Solvents*, revised and enlarged edition (Washington: National Gallery of Art, 1985).

42. Common experience indicates that oil paintings increase markedly in stiffness over the first century or more. The cause is probably loss of the unpolymerized component of the oil (triglycerides) that act as plasticizer, 10-20% by volume. These degrade to free fatty acids (and other compounds, see Stolow in Note 41 above), as does some of the polymerized component. Evaporation calculation predicts a 1mm paint film with 1% of a particular free fatty acid would lose it in 100 years if it is one of oleic, stearic, or azaleic acid; or in 10 years if it is the more volatile palmitic acid. Impasto several times thicker will take several times longer. Given that the initial decay to free fatty acids may take decades, depending on the oil, pigment, temperature, and humidity, these times are the shortest likely. R. Scott Williams at CCI has analyzed blooms and transferred images from oil paintings. He found blooms contained all the fatty acids above, mainly as soaps. They represent situations where free fatty acid is produced faster than it can evaporate, i.e. decades. He found transferred images to glass were primarily palmitic, because it is ten times more volatile. (R. Scott Williams, 'Blooms, Blushes, Transferred Images and Mouldy Surfaces: What Are Those Distracting Accretions on Art Works?' *Proceedings of the 14th Annual IIC-CG Conference*, 1988, pp. 65-84; offprint available from Canadian Conservation Institute, Department of Communications, Ottawa, Ontario, K1A 0C8, Canada).

43. Rutherford J. Gettens and Elisabeth West FitzHugh, 'Azurite and Blue Verditer,' *Studies in Conservation*, vol. 11, no. 2, 1966, pp. 54-61.

44. Rutherford J. Gettens and George L. Stout, *Painting Materials: A Short Encyclopaedia* (New York: Dover Publications, 1962), p. 95.

45. Daniel Gutscher, Bruno Mühlethaler, Armin Portmann and Armin Reller, 'Conversion of Azurite into Tenorite,' *Studies in Conservation*, vol. 34, no. 3, 1989, pp. 117-122.

46. Bruno Mühlethaler and Jean Thissen, 'Smalt,' *Studies in Conservation*, vol. 14, no. 2, 1969, pp. 47-61.

47. Joyce Plesters, 'A Preliminary Note on the Incidence of Discolouration of Smalt in Oil Media,' *Studies in Conservation*, vol. 14, no. 2, 1969, pp. 62-74.

48. Joyce Plesters, 'Ultramarine Blue, Natural and Artificial,' *Studies in Conservation*, vol. 11, no. 2, 1966, pp. 62-91.

49. Rutherford J. Gettens and Frank W. Sterner, 'The Compatability of Pigments in Artists' Oil Paints,' *Technical Studies in the Field of the Fine Arts*, vol. 10, no. 1, 1941, pp. 18-28.

50. A late Egyptian ibis mummy from a recent excavation, (circa 2,000 BP) with an unknown sizing, was treated by the author during an internship at the Royal Ontario Museum in 1979. The linen casing had the colour and apparent strength of a new fabric. This was distinct from the inner wrappings which were increasingly brown and 'charred' towards the centre, much like the popular image of such wrappings, and resulting from acidic contents.

51. Colour field paintings (cotton impregnated with oil paint) have been reported within the conservation field as suffering unusually rapid deterioration, i.e. within a decade. The acids released by oil paint are responsible.

52. Although most canvases become brown and very weak within a century or two, this is probably due to acidic pollution. Canvases of similar age but covered by a panel stretcher, tight backing board, or a blind lining can appear quite sound.

53. A wooden boat (the 'solar boat') was stored for several millenia in a tomb near the great pyramid of Cheops. Relative humidity would have been very stable, somewhere between 40% and 60%. It is now in a museum nearby. The wood has a warm brown colour, and appears quite sound.

54. The wood component in plywood and hardboard has not been chemically modified, so it should last as well as wood (Note 53). The adhesives are the weak link. Early plywoods with glue adhesive have lasted centuries already, as long as not exposed to damp.

55. Artists' boards, e.g. academy board and canvas board, are all based on a paperboard core. Paperboard can contain 'practically anything of a fibrous nature . . . groundwood . . . chemically reduced pulp . . . old newspapers, cartons, (etc.)' Graham Ireland, *Paperboard on the Multi-vat Cylinder Machine* (New York: Chemical Publishing Co., 1968.) Therefore it has a lifetime typical of low cost paper, i.e. variable, from decades to centuries.

56. Norman Bromelle, 'Material for a History of Conservation,' *Studies in Conservation*, vol. 2, 1955, pp. 176-188.

57. Anon., 'Curing a Museum's Blooming Problem . . . The Trick is in the Treating,' *Technology and Conservation*, vol. 4, no. 2, 1979, pp. 6-8, 10, 16.

58. Paula Volent and Norbert S. Baer, 'Volatile Amines Used as Corrosion Inhibitors in Museum Humidification Systems,' *International Journal of Museum Management and Curatorship*, vol. 4, no. 4, 1985, pp. 359-364.

59. K. Toishi and T. Kenjo, 'Some Aspects of the Conservation of Works of Art in Buildings of New Concrete,' *Studies in Conservation*, vol. 20, no. 2, 1975, pp. 118-122.

60. Rutherford J. Gettens, Hermann Kühn and W.T. Chase, 'Lead White,' *Studies in Conservation*, vol. 12, no. 4, 1967, pp. 125-139.

61. Julia P. Petushkova and Natalie N. Lyalikova, 'Microbiological Degradation of Lead-Containing Paintings,' *Studies in Conservation*, vol. 31, no. 2, 1986, pp. 65-69.

62. Rutherford J. Gettens, Elisabeth West FitzHugh and Robert L. Feller, 'Calcium Carbonate White,' *Studies in Conservation*, vol. 19, no. 3, 1974, pp. 157-184.

63. Paul M. Whitmore and Glen R. Cass, 'The Fading of Artists' Colorants by Exposure to Atmospheric Nitrogen Dioxide,' *Studies in Conservation*, vol. 34, no. 2, 1989, pp. 85-97.

64. Paul M. Whitmore and Glen R. Cass, 'The Ozone Fading of Traditional Japanese Colorants,' *Studies in Conservation*, vol. 33, no. 1, 1988, pp. 29-40;

65. S. Hackney and G. Hedley, 'Measurements of the Ageing of Linen Canvas,' *Studies in Conservation*, vol. 26, no. 1, 1981, pp. 1-14.

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