

History, Science and Storage of Cellulose Acetate Film Base

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1 - Introduction

Cellulose acetate began replacing the more flammable cellulose nitrate film earlier than assumed. French and Swiss manufactures were able to commercialize cellulose acetate as a solid plastic material that could be used as film in about 1904 and in 1908 Kodak introduced Safety base with the opening of a plant in Australia. There are three image formats in photography: emulsion layers (albumen & collodion), motion picture (MP) film and roll or sheet film used for still image photography.



Figure 1: Comparison of early professional MP films: (top) Pathéscope 28 mm on acetate base and (bottom) Eastman 35 mm on nitrate base; both in a good state of preservation.

Kodak began distributing cellulose acetate Safety base in 1909 with Eastman Safety Positive motion picture (MP) film. The next confirmed transition was in 1925 when Eastman Pan Portrait sheet film replaced Eastman Portrait (1913, nitrate). The transition process went on as long as 1951, depending on format.

Most amateur motion picture formats (small gauge, not 35mm MP film) used Safety base from their inception in 1912 because local laws required Safety base for amateurs; a notable exception was amateur 17.5 mm film slit from 35 mm nitrate stock. Eastman's 35 mm "professional" MP film was first released in 1889 on nitrate base; Edison used Eastman film for his 1892 camera and projector system. Professional motion picture formats created after the development of cellulose acetate base were often produced on Safety base, such as the 28mm Pathéscope. Significant dates in film base history can be found in [Table 1](#).

Still image film formats became commercial with Kodak's amateur roll film cameras (1889). Eastman's earliest professional sheet film (Portrait) was released almost a quarter century later (1913). Both films were on nitrate base. The replacement of nitrate sheet film with an equivalent Safety base film began in 1925; while the general movement to Safety base began in 1935. It is thought that all 35 mm roll still film was released on acetate base

starting in 1935. It is unclear when amateur roll film was first released on Safety base, but the transition was completed by 1938.

Link to [Table 5: Acetate Base Deterioration Correlated with Free Acid and A-D Strip Values](#)

2 - History of Cellulose Acetate in Photography



Figure 2: Pathé-Baby amateur film on acetate base with center sprocket holes.

2.1 - Motion Picture Film

Motion Picture (MP) film has a convoluted history. In general, acetate was used for amateur films while nitrate base was used for professional release. Many amateur motion picture film formats began life on acetate Safety base: Edison's Home Kinetoscope 22 mm in 1913; 9.5 mm (Pathé, 1922), 22 mm (Pathé, 1923), 16 mm (Kodak, 1923), Kodak 8 mm (1932), Kodak Super 8 mm (1938) & others. A history of small gauge formats is found at <http://www.saunalahti.fi/~animato/filmhist/filmhist.html> and an extensive list <http://www.xs4all.nl/~wichm/filmsize.html#variety> of motion picture formats are at http://en.wikipedia.org/wiki/List_of_film_formats. "Pathéscope" 28 mm (1912) was the first professional motion picture film to be released on Safety base.

Pathé pioneered the very popular European "home" gauge (amateur) 9.5 mm format called "Pathé-Baby" on Safety film base in 1922, it remained popular for decades. However, it wasn't until 1932 that Kodak introduced its small gauge, 8 mm, home movie format. It used 16 mm reversal stock; shot in an 8 mm camera, the reel was flipped to double length, split into two 8 mm wide strips, spliced together during processing.

The larger amateur format Cine-Kodak's 16 mm film was released nine years earlier in 1923, a year after Pathé-Baby (9.5 mm), both were on Safety base. Kodak's 16 mm film was destined to become the world's professional news and documentary

format, probably for its sprocket durability and increased resolution over the smaller 9.5 and 8 mm formats.

It was only Eastman's 35 mm "professional" motion picture film formats (first produced in 1889-92) that remained on nitrate base until 1948, when they were transitioned through 1951 to Safety base. A few early amateur formats such as Birt Acres' Birtac (1898, patented) 17.5 mm home movie format were split 35 mm stock which was manufactured in his film manufacture facilities. After about 1912, non-professional motion picture film formats were mandated to be on Safety base. All color film MP film was released only on Safety base.

2.1 - Still Image Roll Film Formats

Early roll film was on nitrate base. Most often, roll film is found in collections as single cut frames ranging in size from 2- $\frac{1}{4}$ " to 3- $\frac{3}{4}$ " by 3- $\frac{1}{4}$ " to 5- $\frac{1}{4}$ " http://en.wikipedia.org/wiki/Film_format; this can prove problematic when trying to distinguish early un-notched sheet from cut roll film. The roll film is often on a thinner base, which will be yellow to amber because it's on nitrate base. Early roll film was not sold independently, it was sold in the Kodak No.2 Kodak camera (1889) with the slogan "You press the button - we do the rest." The very earliest roll-of-negatives used paper base 1884, sold in Eastman's "Kodak" camera <http://www.kodak.com/global/en/corp/historyOfKodak/1878.jhtml?pq-path=2217/2687/2695/2699>, the Kodak name was used for the first the point-n-shoot camera.

The development of 35 mm still photography came in 1913 with the commercial release of the Tourist Multiple Camera (750 image magazine) http://findarticles.com/p/articles/mi_m1306/is_5_69/ai_101339583/, its 18 x 24 mm horizontal half-frames were very small. Professional photographers began using the full-frame 35 mm format, with its relatively larger but still small, 24 x 36 mm (1" x 1.5") vertical image frame in the 1930s with Leica and Zeiss camera systems. By 1934 Kodak began using Safety base for 35 mm roll film. Color film (Kodachrome) was released only on Safety base in 1935. It's not clear when the first use of Safety base in amateur roll film, prior to 35 mm roll film, however, all roll film was transition to Safety base by 1938.

2.2 - Sheet Film Formats

The first sheet film was on nitrate base, Eastman Portrait film sheet film was released by Kodak in 1913. By 1925, Kodak began to transition its sheet film manufacture onto the acetate Safety base, earlier than has been assumed. Eastman Pan Portrait (acetate, 1925) replaced Eastman Portrait (nitrate, 1913); no notch codes were used for these products. The sheet film formats generally replaced the more dimensionally stable collodion wet plates (1851-1930ish) and gelatin dry plates (1878-1930ish) used by professional photographers and in offset printing preparation (pre-press) and newspapers. David Horvath's 1987 Final Report to the NMA, *The Acetate Negative Survey*, can be found at <http://library.louisville.edu/library/ekstrom/special/AcetateNegativeSurvey.pdf>; it has a comprehensive list of notch codes (earliest use in 1935) and many dates for release and discontinuance of specific films.

2.3 - X-ray Film

X-ray sheet film was developed by Kodak in 1913 (thick nitrate base); two-side coated nitrate in 1918 <http://www.kodak.com/global/en/health/aboutHealthImaging/h19001929.jhtml?pq-path=5165>. By 1924, Kodak released Safety x-ray sheet film, but nitrate base use continued to 1933. Between 1938 and 1948/1951 Kodak http://www.kodak.com/US/en/corp/kodakHistory/1930_1959.shtml transitioned all film remaining on nitrate base; see details in [Table 1](#) below.

3 - Early Acetate Base History

Cellulose acetate plastic solid manufacture became commercial around 1903-4 for use as a textile fiber in both France and Switzerland. The Dreyfus brothers (France) are generally credited with the first successful spun fiber; later they developed a transparent film.

Eastman (Kodak) developed its own cellulose acetate base and opened a manufacturing plant in Australia in 1908 http://www.kodak.com/US/en/corp/kodakHistory/1878_1929.shtml. Kodak had probably been purchasing cellulose acetate base from other suppliers earlier. The Dreyfus brothers (1904) were producing cellulose acetate lacquers and film by 1908-10. They were selling 3 tons a day to Pathé Frères (Paris) by 1910 for non-flammable motion picture film base and to the French and German "Celluloid" industry, shortly thereafter http://en.wikipedia.org/wiki/Cellulose_acetate.

In 1912, Pathé (England & France) began distributing its "Pathéscope" 28-mm professional format film and equipment (professional) on Safety base. With a Lumiere Brother's patent, Pathé also began producing and distributing their biweekly newsreel for theaters, a new time-based media format they pioneered between 1910 and 1912 all over Europe <http://en.wikipedia.org/wiki/Pathé>.

Table 1: Significant Dates in the History of Acetate Base Film [[Return to Top of Document](#)]**Brown = Cellulose Acetate; Black = Cellulose Nitrate & Other; Blue = Color Film; Green = Sound on Film**

1839	Goodyear develops natural rubber , later replaced with synthetic rubber
1839	Eduard Simon discovered polystyrene (now used in Styrofoam cups)
1847	Louis Menard (France) and John Parker Maynard (Boston) independent inventor of collodion
1851	Fredric Scott Archer invents Collodion Wet Plate process
1863	Commercial celluloid hard plastic (cellulose nitrate) was developed by John Wesley Hyatt
1878	Edison patented sound recording using phonograph, was synced with film later
1885	Eastman announces " American Film " the first transparent photographic film
1889	Eastman markets first cellulose nitrate base used in roll (still) and motion picture products
1889	Eastman's first MP film on nitrate base: Orthochromatic Negative
1891	Edison & Dickson develop MP camera and projector technology, used Eastman 35 mm film
1903/4	Cellulose acetate plastic fiber & solid developed in Germany or Switzerland; no Mfg'r credited
1906-8	Kinemacolor first commercial color MP process (UK) two-color additive process, filter wheel w/alt B&W frames; overtaken by Prizma Color 1913-17 (US)
1908	Cellulose Acetate "film base" developed by Eastman; manufacture begins in Australian factory
1909	Eastman releases Eastman Safety positive MP film
1910	Acetate film base produced and sold by Dreyfus brothers (1904 developers; disputed claim)
1912	Pathé releases Pathéscope 28 mm professional MP format, only on acetate Safety base
1913	Prizma (I) developed by William Van Doren Kelley & Charles Raleigh
1913	Eastman Portrait sheet film introduced, transitioning from glass plate negatives
1916	Eastman introduces Kodachrome (1) subtractive color in MP formats
1916	Technicolor (I) two color additive (R & G filters in camera/projector) color MP process
1918	Prizma (II) Van Doren Kelley releases 2-color (R & B) subtractive process; lost suit to Technicolor
1919	Tri-Ergon (Engl, Vogt, & Massolle, German) developed sound process on film; Fox bought in 1926
1922	Pathé releases Pathé-Baby 9.5 mm home format
1923	Kodak releases Cine-Kodak 16 mm amateur format, B&W reversal film, positive upon development
1924	Cellulose acetate propionate introduced into the film marketplace
1924	Kodak releases x-ray film on Safety base
1925	Eastman Pan Portrait film, on Safety base, replaces Eastman Portrait the first sheet film
1928	Eastman Kodacolor 16 mm MP, 3-color (R, G & Blue-violet) additive lenticular (lens) technology
1929	Eastman Kodak produces integrated sound-on-film format, possibly Sonochrome Positive
1931	Kodak releases Kodalith sheet film (nitrate) for use in pre-press applications
1931	Verichrome (nitrate) panchromatic B&W replaced older roll films - finer grain, greater latitude
1932	Eastman Kodak introduces 8 mm home format , amateur film to compete with Pathé' 9.5 mm
1932	Tennessee Eastman began production of its first plastic - Eastman TENITE acetate base
1933	Kodak ends nitrate base x-ray film, one of the first uses of nitrate sheet film
1934	Kodak (Germany) introduces the 35 mm Retina Camera ; and 35 mm format film
1934	Eastman develops Triacetate Base material, but not used in Kodak MP film until 1948
1935	Kodak releases Kodachrome , color reversal film (positive) on 16 mm amateur film
1935	Cellulose acetate butyrate introduced into the film marketplace
1936	Kodak releases Kodachrome , color reversal film (positive) in 35 mm professional format
1936	Kodak releases "Magazine" Cine-Kodak 16 mm amateur format
1938	Kodak replaces nitrate base in 35 mm roll film for still photography
1939	Kodak replaces most nitrate base in film with Safety base in sheet film, except aerial
1939	Kodak introduces Super Sensitive Pan as sheet film, was well known as MP format
1939	Kodak introduces cardboard Redi-Mounts for color slides
1941	Kodak introduces Kodacolor - color negative film; must be printed to be a positive
1942	Kodak ends nitrate in aerial high-res films: mapping, surveillance & military applications
1942	Innovative Verichrome film (fine grain) first produce on acetate base
1945-8	Cellulose Triacetate generally introduced into the film marketplace
1946	Kodak introduces Ektachrome color reversal film (positive upon developing)
1948	Kodak uses triacetate base to replace nitrate base in 35 mm professional MP film, thru 1951
1949	Kodak ends nitrate base in the thinner sheet film used in film packs
1950	Kodak ends nitrate base for all remaining amateur roll films
1951	Kodak ends nitrate base in all remaining professional 35 mm MP film
1954	Kodak releases Tri-X (ASA 3-400) roll film, the first high-speed B&W emulsion
1955	Kodak develops Estar base for dimensional stability for film used in commercial printing processes

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Shortly after acquiring US-Pathé (1927), Eastman released their first color film Kodacolor 16 mm (B&W film with lenticular-type with three color lenses over camera and projector) on acetate base in 1928. Tri-Ergon (German) developed sound on film in 1919; they were competing with Warner Bros delivering sound-on-disk synced to film (scene in MGM's *Singing in the Rain*, 1952) and Gaumont (#2 in France) Chronophonographe process patented in 1903; Vitaphone Warner Bros eventually

won format war producing thousands of sound films between 1926 and 1930. Motion picture film with sound capabilities was released by Kodak in 1929.

4 - Acetate Base Longevity

Acetate film is predicted to have an average lifetime of 55-60 years until reaching the L6 state (see Table 2) based on IPI's, Reilly (1993) publication. However, in the authors' surveys of west coast film collections, acetate base films have an average collection age of 60 years, with an average Deterioration State of L2. IPI predictions suggest that acetate base will reach the L2 state in 20 to 30 years (see Table 5). A collection with large group of acetate film that was 80 years old had an average state of L2.2. Some portions of this collection were at L5 - L6 (only usable with work) that matched IPI's predictions, while some film was found with a very slight curl (L1.5) or with no curl or yellowing (L1). Portions of many of the collections surveyed, had unfortunately been culled years ago by former workers; presumably the film was mistaken for L5 - L6 nitrate base which is unsalvageable. The degree of culling was almost impossible to determine, but it was estimated at 5-12%. The state of the culled film was impossible to determine. In the five surveyed collections, an average state of L2.1 was established for all Safety film using statistical analysis of random sample surveys (sampling rate ranging from 2% to 11%). At the 2007 PMG (Photo Materials Group of AIC) Winter Meeting, many conservators across the country reported the same sort of findings in their surveys.

Table 2: Deterioration State for Cellulose Acetate Film Base

State	Description
L1	No Deterioration
L1.5	Very Slight Curl, No Yellowing
L2	Slight Curl (shrinkage of base) & Possible Slight Yellowing
L2.5	Curled with Definite Yellowing
L3	Vinegar Smell, Shrinkage & Strong Yellowing
L4	Warp Begins
L5	Interlayer Bubbles Begin
L6	Channeling & Highly Distorted

For the purposes of comparison the following table lists the deterioration cycle for Cellulose Nitrate film base. The mode of deterioration is different. In mixed collections, confusion is common.

Table 3: State of Deterioration of Cellulose Nitrate Film Base

State	Description
L1	No Deterioration
L2	Yellow, Silvering-Out with Slight Curl
L3	Nitrate Smell and Film Distorted
L4	Amber Colored Base, Imaging Fading and Some Slight Sticky Feel
L5	Film Welds to Adjacent Film or to its Envelope, Permanently
L6	Brown Powder Present and Gelatin Liquefied

Acetate film base degrades by curling, yellowing, base shrinkage, interlayer bubbling, warping and then finally channeling; see Figures 6a-d. Channeling spreads as ridges develop in the gelatin layer due to the shrinkage of the cellulose acetate base, to which the gelatin pellicle is attached, while it maintains its original size. Even though the plane of the film distorts during deterioration, the gelatin pellicle is often not harmed. Sometimes, in sheets with a high degree of channeling, external pressure can cause the apex of the channel tent in the gelatin pellicle (see Fig 6b) to break. Generally, the pellicle is still very usable when separated from the base in a solvent bath (acetone) and wet-mounted (mild hydrocarbon solvent) for scanning using a hydrocarbon solvent. Degraded acetate base film can be salvaged.

4.1 - Comparison to Cellulose Nitrate Film Base

As fate will have it, some nitrate base film has been found to have greater longevity than the cellulose acetate film it replaced. It appears that some nitrate film base can have a longer lifetime than acetate film base, up to 500 years according to IPI [communication at 2007 PMG Winter Meeting]. The problem with nitrate film base is that the strong acid (nitric acid) that evolves from the degrading cellulose nitrate polymers. It will degrade the gelatin, a protein polymer, eventually liquefying the image emulsion making it completely useless. The weak acetic acid found in cellulose acetate film base will not utterly destroy the gelatin pellicle.

4.2 - Estar Film Base

When developed for photographic products, between 1904 and 1945, cellulose acetate film seemed to be the ideal replacement for the less stable and flammable nitrate products. However, it was only with the development of polyester film, called Estar base by Kodak in 1955-1960, that a truly chemically and dimensionally stable base was created. Both cellulose polymers show dimensional changes in response to humidity changes and immersion in water; polyesters films do not.

The only issue with Estar base is that sometime it is made thicker (0.007") and can have a higher Dmin or minimum density (gray base, slightly darkened) than the always clear triacetate base. Estar base can be so strong that it will damage motion picture cameras rather than break. Kodak does not sell Estar base camera original MP film.

According to Robert Shanebrook (2007, retired Kodak scientist) beginning in the 1990's most motion picture film was "printed for release" on Estar base. By 2000/1 Kodak was making all sheet film on Estar base. Most roll films are still made on acetate base, including motion picture camera originals. All film requires cold storage for preservation; the only exception is B&W silver-gelatin on Estar base. All color films require cold storage because of dye instability.

5 - Cellulose Acetate Manufacture and Chemistry

The manufacture of cellulose acetate polymers is done by substituting an acid group $[-COCH_3^{-1}]$ in the place of alcohol groups $[-OH^{-1}]$, which bristle from the surface of the anhydroglucose (cellulose) polymer; see Fig. 3a. The acetic acid and sulfuric acid (catalyst) used in substitution process can remain in the solid even after processing, as "inherent vice." Current best-practice manufacture of cellulose acetate removes all residual acid.

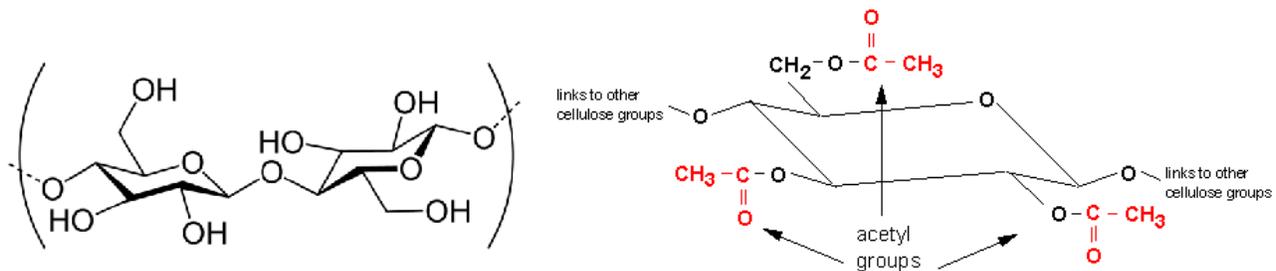


Figure 3a & b: The two dimensional representation on the left (Fig. 3a) shows cellulobiose, a cellulose dimer, they are found nestled against each other in extremely long chains within plant fibers. On the right (Fig. 3b) is a slightly different type of 2D representation, showing the substitution of acetate groups $[-COCH_3]$ for the alcohol groups $[-OH]$ on a single cellulose monomer. This substitution creates cellulose acetate: Safety base.

Each cellulose molecule has 3 alcohol $[-OH]$ side groups; two anhydroglucose molecules make up a cellulobiose dimer (Fig 3a); the dimers exist in vastly long polymer chains in plant fibers. The substitution of the side groups can never be greater than 2.76 because three acetyl groups won't fit on the bulk polymer chains. The higher the rate of substitution (1.5 to 2.76) the more stable the polymer. [Scientificpsychic.com](http://www.scientificpsychic.com) has a simple food-based explanation of carbohydrates that includes cellulose <http://www.scientificpsychic.com/fitness/carbohydrates2.html>.

Early acetate film was made at lower substitution rates, making them more unstable. Diacetate film had substitution rates ranging from 1.5 to 2.3. General use of triacetate base began in about 1934. Kodak announces triacetate base (2.76 substitution rate) for 35 mm MP film; in 1950 it won Oscar for Safety film.

Table 4: Dates for the Start and End of Acetate Film Production

Polymer	Sheet Film	Roll Film	MP Film
Cellulose diacetate	1925-1950	1910-1935	1908-34
Cellulose acetate propionate	1930-1945	1924-1945	NA
Cellulose acetate butyrate	1935-present	not used	NA
Cellulose triacetate	1934/45-2000/2	1934/45-Pres	1948-Pres

Modern Kodak triacetate film has no residual acid upon creation. Triacetate was thought to be quite stable until about 20-25 years ago. After about 15-20 years of triacetate use, in the late 1960s, it was found that even the triacetate material made with the highest possible substitution rate showed (a) a minute loss of weight and (b) the presence of acetate groups in the head space (air in a sealed

container) above bulk film. Table 4 lists the commonly accepted dates for the use of the various acetate polymers in film.

While cellulose diacetate use predominates in the beginning, cellulose acetate butyrate, developed concurrently with triacetate, was used by some manufacturers until late in the 20th century for its specific properties. The advantages of acetate butyrate are better weathering characteristics than either cellulose acetate or acetate-propionate; tougher than cellulose acetate; and lower moisture absorption than cellulose acetate. Brands other than Kodak made more use of the butyrate alternative.

6 - Acetate Base Film Deterioration

IPI reports (*IPI Storage Guide for Acetate Film*, Reilly, 1993) that after about 40 years at standard museum storage conditions (70°F/21°C @ 50% RH) the steady natural loss of acetate side groups (acetate radicals) will lead to a free acid content of 0.5, which produces a A-D Strip color of green. The free acid content of 0.5 is equated with the L3 acetate deterioration state; see [Table 5](#), p 7). See the [first paragraph of Section 4](#) for a discussion of observation made from modern (1995 to 2007) surveys of acetate film base collections made by the author.

The “everyday” definition for vinegar syndrome is the smell of vinegar from film. The IPI definition for the “Onset of Vinegar Syndrome” is the presence of 0.5 free acid. Film in that state will create a solid green A-D Strip, from a normal blue unused strip, yielding an A-D Strip value of 1.5 [private communication with IPI’s Doug Nishimura].

Some folks also believe that Vinegar Syndrome is an infectious condition; however, there is no “bug” which spreads Vinegar Syndrome. Acetate base deterioration develops in a steady state over time, unnoticed at first, then changing its rate of acid creation, blossoming into Vinegar Syndrome. VS could appear to develop in a short time, if a collection had not been monitored with A-D Strips on a routine basis. From experience, a 1% random sample every 5 years should produce reliable information on the state of a collection.

The scientific jury is still out on the issue of the effects of “background level of acetic acid” found in a storage room, influencing the creation of VS in film that is below a free acid content of 0.5. Background level of acetic acid in a storage room is produced by out-gassing from film cans/boxes or drawers of sheet film. The stored film may be at 0.5 free acid content; more or less. By the time acetic acid escaping from film cans or storage boxes mixes with room air, it is at much lower concentrations. The concentration is so low that it could not diffuse back into naturally aging acetate

base that would have much higher acid content. Diffusion is only favored when molecules are moving from regions of higher concentration to lower, not the other way around. Very specific high levels of acetic acid are needed to push materials that are in the “initiation phase” (see below) into the autocatalytic state.

Free acid is generated within film solids when acetate groups (acetate radicals) break away from the side chain sites on the cellulose backbone; see Fig. 3b; the acetyl groups [-C=O-CH₃] are shown in red. The free acetic acid only slowly out-gases into the surrounding room air because diffusion is a slow process. This is why festooning and forced-air changes don’t alter the onset of Vinegar Syndrome, according to IPI.

Acetate deterioration has two stages (a) initiation and (b) autocatalytic; see Figure 4. The plot line shows a very clear change in the rate (slope of curve) at a free acid content of 0.5 (y axis). The **initiation stage** takes about 40 years at museum conditions (70°F @50%RH), while the next stage takes about 15 years to reach the L6 state.

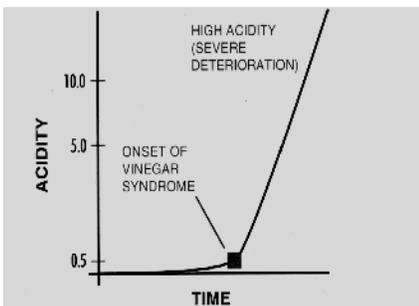


Fig. 17 Time-versus-acidity curve for acetate film. The autocatalytic part of the curve occurs at about 0.5 free acidity, the point chosen as the basis for predictions of the onset of vinegar syndrome in the Guide.

Figure 4: Two-stage deterioration of acetate base, from IPI’s Reilly (1993) p13.

Using A-D Strips to test film samples, held in sealed containers for 24 hours, the initiation stage ranges from 0.0 A-D (blue) to 1.4 A-D (green tint on edges of blue strip). The pH sensitive dye in the A-D Strip responds to the “free acid” (acetic acid) content that has migrated out of the polymer solid into the head space (air) within the film can or box. See Figure 5 and [Table 5](#) for comparison of all parameters and IPI age predictions.

When the free acid content within the cellulose acetate polymer is high enough, the acid in the film further catalyzes deterioration without being consumed, and thus, remains available to do further damage. That is, the rate of free acid production is greater than the rate of diffusion of free acid out of the film. This stage is referred to as the **autocatalytic phase** and is significantly faster than the **initiation phase**.

A-D Strip values for autocatalytic phase runs from A-D 1.5 (green) to 3.0 (yellow), the highest acid content the strips can measure. The amount of free acid in the film during the relatively short autocatalytic phase runs from 0.5 to 10, and sometimes even higher. The yellow color of the A-D Strips confirms a maximum free acid content of 3.75, more free acid can be generated by the film, but it cannot be discerned by an A-D Strip. While knowing the actual free acid content above 3.75 may be intellectually satisfying, the fact that the autocatalytic phase is well underway is the significant piece of information. Taken with the physical condition observed by trained workers, the progression of deterioration process can be easily identified, from L3 to L6. The autocatalytic stage often progresses over a very short period, 10-20 years, depending on storage conditions and inherent vice in the film. Cold storage is the only technique that can be used to slow Vinegar Syndrome; see [Section 8 on Cold Storage](#).

6.1 - Use of IPI A-D Strips

A-D Strips, distributed by IPI, can be used to determine the deterioration state of acetate film. They are small pieces of blue paper with a pH indicating color dye and a humectant. The humectant draws in water vapor so that a "dry" pH reading can be produced. When in contact with the head space around acetate film for 24-hours, in a sealed container, they give an indication of the state of vinegar syndrome deterioration in that specimen. They are an invaluable preservation tool in film collections.

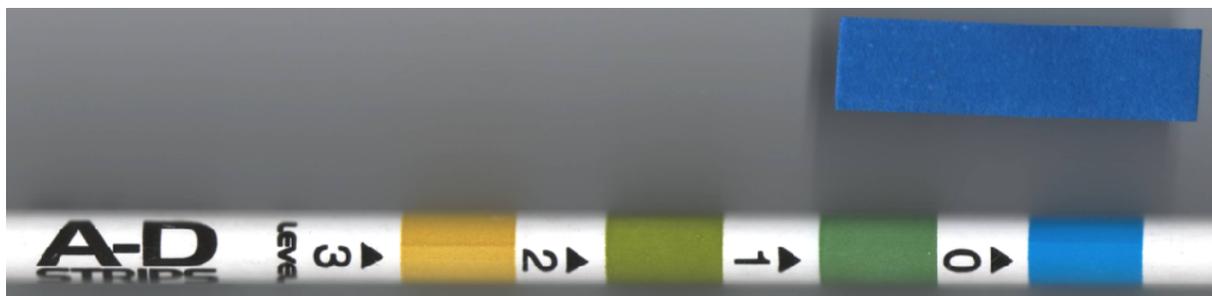


Figure 5: Unexposed blue A-D Strip in the up right corner; after exposure, use the color evaluation tool that comes with the A-D Strips (pencil). They can be purchased from the Image Permanence Institute (IPI) at the Rochester Institute of Technology (RIT), 70 Lomb Memorial Drive, Rochester, NY; 716-475-5199 ipiwww@rit.edu; they also sell IPI preservation publications on the Permanence of Acetate Base and Color Film.

Table 5: State of Acetate Base Deterioration Correlated with Free Acid and A-D Strip Values [\[back to top\]](#)

1	2	3	4	5	6
Age in IPI Yrs	State	Condition Description	Free Acid Value	A-D Strip Color	A-D Strip Value
0	L1	No Deterioration	0.05	Blue	0.0
10	L1.5	Very Slight Curl, No yellowing	0.1	Blue	0.5
20	L2	Slight Curl & Possible Slight Yellowing	≈ 0.15	Blue with Green Edges	0.75
30	L2.5	Curled with Definite Yellowing	≈ 0.2	Mottled Blue-Green	≈ 1.0
40	L3	Vinegar Smell, Shrinkage & Yellowing	0.5	Green	1.5
45	L3.5	As Above, but Greater Degree	0.7	Yellow-Green	2.0
48	L4	Warp Begins	1.1	Yellow-Green	2.5
50	L5	Bubbles Begin	4.0	Yellow +	3.0
55	L6*	Channeling & Highly Distorted*	10.0	Yellow ++	3.0

* Film in this state can still be salvaged, at some expense.

The table above is based on the conversion between (i) free acid (column 4) and (ii) A-D Strip values (column 6) supplied by IPI. The Condition Descriptions (column 3) are the author's observations made in collection surveys between A-D Strip values (column 6) produced by the film and the actual physical conditions noted. The far left column (1) is based on the data given in the IPI, Reilly (1993) publication for the year of deterioration require to reach a specific free acid content, while stored under standard museum environment (70°F at 50% RH) for their entire existence.

Using tables provided in the publication, the prediction for lifetime storage in a room at 60°F and 50%RH doubles the time-to-L3-state, from 40 to 80 years. Unfortunately, no one can predict the conditions film has seen when outside the control of a collection's storage space, such as storage in an attic at 100°F and 80% RH during summer conditions (failure in 6 years for year round exposure) and at 15°F and 20% RH during the winter (3500+ years at the conditions, e.g., cold storage).

6.2 - Vinegar Syndrome (VS)

Acetic acid evolves from cellulose acetate film naturally. At a certain point the natural deterioration becomes Vinegar Syndrome. At some point the out-gassing can be smelled by humans. Acetic acid is vinegar minus the gourmet refinements, thus the name Vinegar Syndrome. VS is an autocatalytic process where the products of decomposition persist increasing the rate of degradation; it has a very specific definition: 0.5 free acid content. Natural deterioration of Safety base film is not VS. A specific content of free acid is needed to create the material condition called VS.

In naturally aging of cellulose acetate film, acetate side chains slowly detach from the cellulose backbone, creating acetate radicals. The acetate radicals diffuse to an area of lower concentration, the film surface. The acetate radicals combine with water vapor in air to form acetic acid. Eventually they detach from the surface into the surrounding air. When the acetic acid is released into room air it mixes in and is diluted; it may or may not become noticeable to humans depending on many variables. Mixing and dilution in room air is relatively fast. If the room has normal room air exchange rates, the acetic acid may be outside before it is noticed.

The room may have an odd unidentifiable smell, especially if there is degrading cellulose nitrate base (sour, well rotted fruit), cardboard and paper (musty burned wood) in the same space. If the material is contained in a film can or small storage box, the concentration will stay high in the head space (air) of the container. When the container is opened, the concentration may trigger a direct human smell response or just a mild non-specific allergic reaction (sneeze). Opening several containers in a row may be required for a human to make the identification, or build the concentration before it will be noticed. Once opened, a container will have to be closed and set aside for 24 hours, so it can regain its concentration, to be checked again.

The speed of the VS reaction is governed by the amount of acetic acid, free radicals (inherent vice) water and energy (heat) present; the higher the temperature and humidity, the faster the deterioration.

Caution: Acetic acid can be a skin and pulmonary irritant to some humans. Workers can develop an allergy, if one doesn't exist initially. In some, the allergy precludes working in film collections without a respirator. Workers can become so sensitized to the out-gassing that they develop skin reactions.

6.3 - Defining the Deterioration State of Acetate Film

A standard was developed to define the state that acetate film base, similar to the nitrate base deterioration state protocol; see Table 2 & 3 for comparison. Acetate deterioration state L1 equates to no damage, no curl is present; L1.5 shows a very slight curl because of very slight base shrinkage, but no yellowing. L2 has slightly more curl and probably has a slight yellow tint.

Amateur roll film often has a slight curl even when new, due to the lack of emulsion-side coating, or degree of thickness; thus, curl is not a definitive sign of deterioration in 1935-80 roll films. Use A-D Strips to confirm observations. More modern amateur roll films have thicker coatings and do not show as pronounced a curl.

Sheet film with no markings (notch codes or edge printing) and square cut edges, which is flat to slightly curled, it was probably from a film pack. If the ends of the sheet film have marks from an adhered attachment and no markings it was from a film pack. Individual images with edges that are not cut square may have been cut from a roll of negatives. If thin sheet film has no "Safety Film" marking, is yellow and flat, it is probably nitrate base film. If the film is slightly dimpled, with finger tip sized marks, it is definitely made with nitrate base.

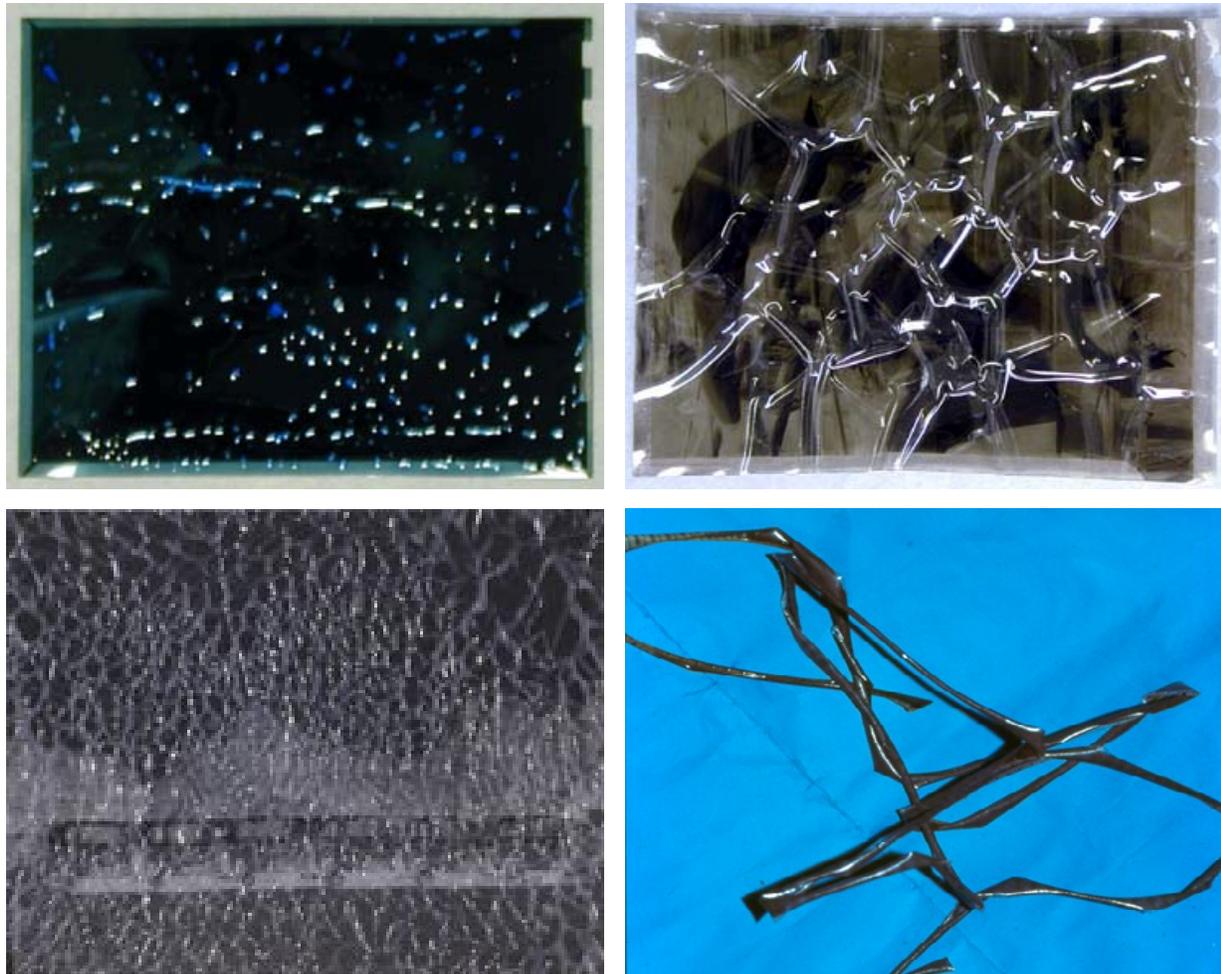


Figure 6a-d: (a) acetate film with interlayer bubbling, some of the bubbles are filled with plasticizer, sometimes the liquid crystallizes; (b) acetate film showing the normal type of channeling found in sheet film; (c) acetate film with small-scale channeling, less common than 6b; (d) 1/2" acetate base video tape showing curling caused by shrinkage of the base relative to the other layers.

Table 6: Deterioration State for Cellulose Acetate Film Base [Same as Table 2; Similar to [Table 5](#)]

State	Description
L1	No Deterioration
L1.5	Very Slight Curl, No Yellowing
L2	Slight Curl (shrinkage of base) & Possible Slight Yellowing
L2.5	Curled with Definite Yellowing
L3	Vinegar Smell, Shrinkage & Strong Yellowing
L4	Warp Begins
L5	Interlayer Bubbles Begin
L6	Channeling & Highly Distorted

Yellowing is a sign of deterioration, but is not as sensitive as the degree of curl. Yellowing develops as the base deteriorates and saturated double bonds are created on the cellulose polymer chain.

Curl develops when there is shrinkage in one layer relative to the others. The loss of acetate side chains (vinegar smell) decreases the mass (size) of the base layer, only. Because the gelatin layer does not undergo those changes, a curl develops due to size differences of the dominant layers.

Interlayer bubbles develop from two sources, apparently. One explanation is the point source loss of adhesions between layers as a result of base shrinking within the film. Others have postulated that bubbles develop from a concentration of plasticizer exuding from the film solid, causing a local layer separation. More probably, the bubbles are point-source mechanical separations, where plasticizer

that is separating from the shrinking base, then collects. Figure 6a shows bubbles between layers with liquid plasticizer present.

Channeling - Figure 6b shows classic channeling, it is the mechanical resolution of the differences between the sizes of the two dominant layers making up the film. The channels are tents formed by the larger top gelatin layer sitting on the smaller acetate base. Often there is a thin protective coating sitting on top of the gelatin, as a very thin layer, influencing behavior. Figure 6c shows advanced channeling in another sheet film with less typical channeling behavior seen in a country with predominately Kodak film. Figure 6d shows curling in acetate based 1/2" acetate video tape.

7 - Detailed Analysis of Film Conditions Found in Storage

The following list collects the common modes of film deterioration. The upper section of Table 7 includes those problems common to film base deterioration, or sometimes mistaken for base deterioration. The lower section, [Other Film Problems](#), covers film deterioration that is sometimes mistaken for base deterioration.

Table 7: Step-by-Step Description of the Acetate Base Deterioration Process

Conditions Associated with Film Base Deterioration

Light Yellowing: very early base deterioration

Yellow: acetate base deterioration

Dark Yellow: acetate base deterioration

Canary Yellow: anti-halation dye remaining after poor processing or washing

Light Amber: advanced acetate or early nitrate base deterioration

Amber: advanced nitrate base deterioration

Dark Amber: advanced nitrate base deterioration

Localized Brown, Amber or Yellow Stains: processing fault or accident

Localized Brown Stains: gross processing fault

Pink Film: anti-halation dye remaining after poor washing

Blue Film: anti-halation dye remaining after poor washing

Cyan Film: anti-halation dye remaining after poor washing

Canary Yellow (process yellow from CMY dye set): anti-halation dye remaining processing

Orange Film: masking layer in color negatives, film is often flat or with very slight curl

Curl with no Color: if film is new and in excellent condition (no color) curl due to high humidity

Slight Curl: minor acetate base deterioration

Curl: prolonged base deterioration

Distorted Curl and Yellow: advanced acetate deterioration, curl and warp combined

Highly Distorted Film Plane and Brown: possible nitrate base deterioration

Channeling, broad, 1/2" apart: common L6 advanced acetate base deterioration

Channeling, small, 1/8"- 1/4" diamonds: less common L6 advanced acetate base deterioration

Silvering-out: presence of acidic conditions, probably early nitrate base deterioration

Silver Tarnish: sulfide tarnish on surface silver (metal), yellow, amber, brown, blue, red & black

Other Film Problems

Imaging Bleaching: nitrate base deterioration, among other uncommon faults

Broken Film: mechanical damage possibly due to base embrittlement from nitrate deterioration

Sticky Film: softening of gelatin layer due to advanced nitrate deterioration

Film Stuck to Envelope: advanced nitrate deterioration

Safety Film Stuck to Envelope: water damage or adjacent to film w/ adv. nitrate deterioration

Color Fading: normal color dye deterioration

Color Shift of Image Color: fading of one or more dyes, shifting the color away from normal

Lifting Emulsion (usually seen on glass plate negatives): loss of layer adhesion

Lost Emulsion (usually only seen in glass plate negatives): water damage with mechanical action

7.1 - Descriptions of Major Faults

The order is generally related to the significance of the faults related to the deterioration of acetate base film.

7.1.1 Curl is generally the most sensitive sign of acetate base deterioration. The degree of curl is a good indicator of degree of deterioration as the base shrinks relative to the gelatin emulsion. The natural loss of acetic acid from acetate base decreases its mass. The gelatin emulsion does not

undergo this loss. Mass loss occurs during both stages of acetate base deterioration, curl is the best overall indicator of base deterioration. Curling is due to a mismatch in layer dimensions. In a layered structure, when one layer shrinks or expands relative to another, curl, is the resulting physical distortion. Curl away from the emulsion is due to deterioration. Curl way from the base is generally due top swelling of the gelatin by humidity or moisture. Curl, distorted curl and warp are stages in the acetate deterioration process. The development of yellowing generally follows the onset of curl.

7.1.2a Yellowing is a precursor to both types of base deterioration. The substrate carrying the silver-gelatin emulsion image is a plastic that is either cellulose acetate or cellulose nitrate polymers. Until degradation begins, the base remains a neutral color, except where noted. The gelatin layer can yellow if it has been poorly processed (washed) or exposed to exhausted fixer, but this is not common. Small colloidal (size) silver particles look yellow by transmitted light, due to developing-out of unfixed silver left in the film after processing. Brown and orangish-brown color is more than likely nitrate base deterioration. Color is a sign that deterioration is underway, but it can be present in acetate base before the free acid content is great enough to be called Vinegar Syndrome. Acetate film tends to stay yellow and not become orange or brown as does nitrate base film; yellowing is slower in acetate base film. If the film is yellow and flat, suspect nitrate base.

7.1.2b Orange staining is advanced nitrate base deterioration, as is, broken film, sticky film, film stuck to an envelope and image bleaching. Another source of **orange** is the **masking layer** used in **color negatives**; it is very different color than nitrate deterioration which is browner and less red.

7.1.2c Amber of yellow stains in localized regions is often due to chemical spills, accidents or processing faults. Discoloration with a hard edge are often due to light striking a portion of film while partially covered with something opaque, that could be a stack of negatives. This can also happen with sheets of film left on a light table for a prolonged time, a long weekend.

7.1.2d Pink, Magenta, Blue, Cyan and Process Yellow: Uncharacteristic colors in the film are indications that the anti-halation dyes were not completely removed during processing. The canary yellow color is a process yellow dye, from the CMY dyes used in the film before processing. It has a different tone than yellow discoloration which is less pure yellow, a more amber tone of yellow. Anti-halation dyes minimize the scatter of light within the film and between dye layers that could lead to a bloom of light (darkness in a negative) around bright objects. This is residual dye in the emulsion; in general, there is no harm.

7.1.3a Silvering-Out and mirroring are synonymous terms. The process occurs in most silver-based photographic materials. The actual process is not completely understood, but some of the process correlates to prolonged exposure to acidity as observation by numerous conservators.

Photographic images are created with very small light sensitive silver particles. Because their surface area is so large, relative to the amount in the emulsion, they are highly susceptible to chemical activity. Silver and many silver compounds are fairly reactive materials. In the case of silvering out, silver ions move from the image silver particles to the surface of the photographic media. The $[-Ag]^{-1}$ ions combine with other silver ions and reduce, to produce silver metal on the surface of the image. The appearance is that of a mirror on the surface of the photograph and thus it is sometimes referred to as mirroring. Because image silver has moved from the image to the surface, the term silvering-out has also been adopted, and is the preferred term. Silvering-out lowers the density of the image and increases the background, decreasing the overall tonal range of the image. The process cannot be reversed; the imaged density loss is permanent. Lowering acidity, by removing acidic envelopes, and lowering the rate of reaction by lowering storage temperature are the method of controlling the fault.

The exact reason for the process has not been confirmed. The driving forces are known to be acidity, humidity and age of material. Higher humidity encourages the process by making the silver ions more mobile in swelled gelatin layers. As with all chemical reactions, heat plays a critical role. Lowering the temperature slows the process, for every 10°C decrease the rate halves. There are undoubtedly other factors that participate in the process. The most common observation is for acidic enclosures (envelopes) and attachments to create a high degree of silvering-out. A greater degree of silvering-out is seen in darker regions (Dmax) of the image. Silvering-out is seldom seen in areas of thin image density [Dmin]. Borders of an image often show silvering ahead of other areas. This is probably from direct contact with the environment, be it acidic envelopes, pollutant gasses or humidity. The air is "cleaned" of acid or sulfides as it migrates into the center of the package.

Once the silver has moved to the surface, it is no longer part of the image. Strong light or viewing at an angle will help to view a heavily silvered-out image. In general, scanning is blocked by silvering-out; a wet mounting (in Stoddard's solvent) helps with the problem, but does not eliminate the blockage fully.

Silvering-out can be removed by experienced technicians, and only on some materials. The surface deposits can be removed using two processes, abrasion and chemical treatment. Research has shown that both treatments damage the surface microscopically. I prefer mechanical abrasion with a vinyl eraser, because it is more controllable and does not wet the photograph. This is especially important for degraded materials. Silvering-out on negatives is more problematic and sometimes impossible to remove by any means.

7.1.3b Silver Tarnish of silvering-out in acidic environments, silver migrates to the surface and deposits on the surface as silver metal (silvering-out; see above). Silver reacts with sulfur ions (H_2S gas, other $[-S^{-2}]$ sources) to build layers of colored material in a very predictable pattern ranging from pink, yellow, red, blue, brown and ending with dark gray or black as the thickest layer. The darker the silver tarnish, the thicker the sulfide layer. The source of the sulfide cannot be known without experimentation, but it can be guesstimated based on conditions and experience. The most probable source of sulfide $[-S^{-2}]$ is from sulfite $[-SO_3^{-2}]$ or sulfate $[-SO_4^{-2}]$ found in paper envelopes. Rubber out-gassing, along with human and animal digestion by-products, are common sources of indoor hydrogen sulfide pollutants. If there is a problem with silver tarnish in the collection, hydrogen sulfide is the probably source.

Tarnish (brown to colors) of silvering-out silver metal does not damage the film. The tarnish probably increases the density of the silvering somewhat, but not much. The negative image is obscured by the silvering-out deposits when either printing in the darkroom or scanning digitally.

7.1.4a Channeling is the mechanical resolution of the differences between the sizes of the two dominant layers making up film. The "channels" are tents formed by the larger top gelatin layer sitting on the smaller film base, shrunken by acetate radical loss. The significant layers are (1) silver-gelatin emulsion image layer, (2) cellulose acetate film and (3) anti-curl backing. Often there are subbing layer sitting between the gelatin and cellulose acetate, or other layers, as a very thin layer to enhance adhesion. They can have an influence on channel size and shape. Bubbling can precede and co-exist with channeling. Channeling defines the deterioration state L6, see [Table 5](#). Channeled film looks to be ruined, but the cellulose acetate film can be dissolved away in a solvent leaving the very thin gelatin pellicle, now flat, behind. While still floating on the solvent bath, the gelatin pellicle is transferred to the glass platen of a flatbed scanner for digital capture. This is a difficult process but manageable. Doug Munson, of the [Chicago Albumen Works](#) pioneered this process, when transferring to copy film; professional articles have been published by Munson and others.

7.1.4b Lifting Emulsion of a gelatin layer is beginning to peel from the edge of the film or glass plate, or the edges of islands of gelatin are lifting from the film or glass base. Often, the gelatin has suffered some form of water damage and has cracked. Sometimes the gelatin is not in direct contact with the film because there is a subbing (adhesive) layer. The subbing layer can be any commercially viable adhesive of the era when produced, but cellulose nitrate is often reported as a subbing layer through modern times. Cellulose nitrate fails in 25-40 years on its own; in a layered structure it could last many more years. Lifting gelatin can be set down (consolidated) with an adhesive such as conservation acrylics (Acryloid B-67 or B72) in non-swelling solvents. Not all lifting gelatin need be set down, wrinkling and other faults can result from consolidation.

7.1.4c Lost Emulsion follows lifting emulsion described above. In surveys there is generally a negative correlation between lifting and lost emulsion. If an edge has lifted, while still in place, it will be fairly stable given good storage condition. In poor storage or high handling conditions, the lifting gelatin layer will be in danger from physical damage. Low humidity will make the fragile gelatin layer more brittle and prone to damage. High humidity will tend to soften and swell the unattached gelatin layer. Above 82% RH, "unhardened" gelatin becomes very soft. Film gelatin is hardened, or crosslinked, thus it's not generally susceptible to excessive damage under high RH conditions.

7.1.5 Fading of Color, the exact rate of fading of color transparencies films is well known and documented in Wilhelm and Bower (1993) *The Permanence and Care of Photographs* <http://www.wilhelm-research.com>. Simple viewing of a transparency on a light box can be used to see gross fading and the fading loss of one dye. Slightly more consistent result will be achieved if one use

a more modern 5000K light box. Digitally scanned negative can be readily color corrected; after the scan, correction can be done at any time. Correction by hand using Photoshop and checking using Chromix's (Steve Upton) ColorThink software [3D plotter tool] is an ideal tool to return highly damaged film to a pristine color state.

Fading of color negatives is difficult to determine because of the orange masking layer. This makes judging color shift all but impossible from just an examination by direct viewing. To check for fading or dye shift in color negatives, the negative must be scanned and converted to a positive. It would be safe to assume there will be a color shift in color negatives over 20 years old, based on general color negatives in Wilhelm & Bower (1993). Test scanning color negatives during surveys is generally not done, thus, the degree of fading is not established for negative films.

8 - Cold Storage of Acetate Film

Most modern film (sheet, roll and MP camera original) is on acetate base. Acetate film is often marked Safety or Safety Film. All film will benefit from cold storage, by slowing base deterioration.

While some acetate film will reach the Vinegar Syndrome stage in 40-50 years, most will persist for 80-100 years before reaching the L3 stage, where they containing ≥ 0.5 free acid content; see Section 6 and [Table 5](#). Eventually all acetate base will degrade into a curled, bubbled and channeled state. The only solution is to get the film as soon as possible into temporary cold storage; Ziploc bags in an inexpensive upright freezer.

Cold storage is the only effective way to slow the deterioration process because it eliminates a major portion of the heat energy which drives the deterioration process forward. Decreasing the energy available for chemical reactions slows the process. At -25°F and 35% RH, the deterioration rate is decreased 2500 times (uncorrected for age and TOS) compared to storage at room conditions. Assuming a normal time-out-of-storage (TOS) the actual preservation advantage is more on the order of 40-times improvement; an excellent preservation outcome.

A Sears' auto-defrost, 20 ft³ cu ft, upright freezer (\$800 delivered) can be used for storage at about 0°F . Appliance stores also a series of smaller chest-type manual-defrost freezers, ranging in size from 4 to 8 ft³ (large TV to the size of a desk) can be used for smaller collections, priced from \$180-350. The larger [20 ft³] upright will cost about \$50-100/yr ($\$3.75/\text{ft}^3$) and the smaller will cost about \$35-60/yr ($\$2.38/\text{ft}^3$).

Table 8: Effects of Cold Storage on Acetate Base Film

Lifetime for New Film, Years	Storage Conditions
45	70°F at 50%RH
175	55°F at 40%RH
1900	30°F at 30%RH
1600	30°F at 30%RH + 5 days-out-of-storage per year
31,500	0°F at 30%RH
1900	0°F at 30%RH + 5 days-out-of-storage per year
110,000	-15°F at 30%RH
1900	-15°F at 30%RH + 5 days-out-of-storage per year

Stand alone freezers have similar operating cost to the active humidity-controlled vaults, due to the lack of economy of scale for the freezers. A passive vault would run at about a third, to a quarter, of the cost to operate upright freezers or active vaults.

Certain upright freezers (low temp freezers) are capable of -25°F , but the affordable units are the smaller under counter size holding 4-6 ft³, rather than the 20 ft³ of the normal 0°F upright http://www.cooler-store.com/summit_upright_freezer_under_counter_1090_prd1.htm and http://www.cooler-store.com/summit_upright_freezer_low_temperature_1147_prd1.htm. The cost to purchase is about \$1000, and \$100-125/yr to operate. Larger, 20-70 ft³, low temperature upright freezers (-25°F) can be purchased for \$4-12K. Installing a walk-in low temperature freezer makes better sense if portability is not an issue. Passive type walk-in freezers capable of -15 to -25°F run about \$20-40K.

8.1 - Bags for Cold Storage

Average sized Ziploc bag will hold the following, with the inclusion of ample good quality matboard, blotters or quality cardboard as a moisture buffer

- 2-4 reels of film (500-1500 ft) per bag

- 50-200 sheets of 4 x 5 film in acid-free envelopes
- 25-100 sheets of 8 x 10 film in acid-free envelopes
- 200-400 slides in 10-20 slide protector pages
- 6-12 video cassettes per bag
- 4-8 boxes of microfilm per bag
- glass plates don't lend themselves to bag storage

See Gaylord Catalog (800-448-6160) and IMPAK Corp for ready-made bags and Metal Edge Inc. catalog (800-862-2228) for Freezer Kits.

Marvelseal 360 is a metalized polyethylene and polypropylene barrier film that is heat-sealable. It has a Nylon exterior that is slightly tougher than the Marvelseal 470. Escal bag material is a newer bag-making product that is clear. I have not used Escal, but it is getting favorable reviews. It is 4 times the cost of Marvelseal, but it's clear so you can see labeling inside; search online for sources.

A professional bag sealer should be chosen because the width of the seal is about ½", rather than the 1/8"-seam found in refrigerator bag sealers. The Futura Portable heat sealer, Barrier model, can be purchased for about \$65 from (a) Audion Packing Aids Corp, San Rafael (415-454-4868), (b) one of the online suppliers of bagging supplies such as IMPAC Corp. or <http://www.sorbentsystems.com/footsealer.html>; or (c) the conservation materials supplier selling the Marvelseal products.

Add 2-3 sheets of good-quality buffered 4-ply matboard (or 3/16" of buffered blotters, 4-5 sheets) to each bag as a moisture sink. See the University Products (800-336-4847) catalog for cut-sizes of matboard. Materials should be labeled on the exterior of the storage bags. A label with actual contents is very helpful, but a unique number that is referenced in a nearby paper cataloged or online database is more efficient. The materials should be held in a controlled room that has a stable relative humidity, such as 40-45% for about 1-2 weeks before they are sealed into the storage bags. This will increase the life over the average 65% RH conditions found in the Bay Area.

8.2 - Warm-Up Process

When photographic materials are taken out of cold storage they must be allowed to warm to room temperature in a sealed bag before they are exposed to the unlimited water content of a room. Allow 6-12 hours for the "average" bag to adjust back to room condition before cutting seal (or opening the Ziploc bag), when held in a thermal barrier holder such as a Styrofoam cooler. Longer is required if there is a great deal of air, or film, in the bag.

Warming-up in a "cooler" prevents temperature gradients, because the thermal barrier prevents rapid warming of the bagged materials.

Shorter warm-up times can be use for tightly-conforming bags holding relatively small amounts of materials. The bag will need to sit on a rack in a well ventilated room. There will always be concern about warming too fast, but a 2-4 hour warm-up can be used in critical situations. The Styrofoam cooler method is recommended and preferred.

8.3 - Time Out of Storage

Time out of storage (TOS) will decrease the useful life of materials in cold storage. IPI distributes written materials to figure TOS for (1) Color Film and (2) Acetate Base film. Basically, 5-days TOS per year (for sub-zero storage conditions) lowers life by 90% -- $0.1 \times \text{years} = \text{years with TOS}$. If the useful life starts at 1000 years it becomes 100 years, when using sub-zero cold storage.

Time-out-of-storage (TOS) for 5 days suggests the following 6-steps:

- (1) Someone requests a slide on Monday
- (2) Taken out of the freezer for the 6-12 hour warm Monday evening
- (3) The user gets back to the slide Tuesday
- (4) They copy or use it on Wednesday
- (5) They give it back to the operator on Thursday
- (6) Sometime on Friday the operator reseals the package and gets it back into the freezer

All this assumes that the work area has consistent temperature and humidity, not requiring a preconditioning period.

8.4 - Storage Materials and Solutions

Devices for storage (low use-priority artifacts can be held in groups with interleaving):

- acid-free folders (Metal Edge)

- oversized folders made from acid-free/buffered paper (Permalife in Gaylord)
- oversized folders made from acid-free/buffered Tan Barrier Board (Gaylord)
- standard-sized large folders made from acid-free/buffered paper (Metal Edge)
- L-sealed Mylar folders of various sizes (Metal Edge)
- Mylar Document Protectors (Gaylord)
- Self-made Mylar folders made from Mylar (0.003-0.005" thick) on the roll
- Bulk in acid-free/buffered Archival Record Cartons (gray corrugated, Gaylord)
- Bulk in Standard Record Storage Boxes (Metal Edge, Tan, buffered)
- Within intellectual groups in Archival Document Cases (Tan, Lignin-free, Gaylord)

Foldered paper-base materials can be held in boxes such as

- Acid-free/buffered Archival Record Storage Cartons (gray corrugated, Gaylord)
- Archival Document Cases (Tan, Lignin-free, Gaylord)
- Drop Front Storage Boxes (Metal Edge, Tan)

Books, pamphlets and notebooks can be held in

- Archival Document Cases of various sizes (tan, lignin-free, Gaylord) within Document Preservation Binders (Gaylord)
- within Case Binders (Gaylord) using Glue-in attachment
- Individual Book Boxes (Metal Edge)
- Corrugated Book Storage Boxes (Metal Edge)

8.5 - Inner Housing – sleeves or interleaving

Inner housings protect the surface of a print or negative from damage when in a storage container. All historic images need surface protection such as sleeves, four-flap folders, page protectors (virgin polyethylene or poly propylene), or, single folders made from acid-free unbuffered paper, Permalife™ paper (with low buffering level), acid-free glassine or polyester (Mylar).

Sleeves: All the existing glassine and clear sleeves (Kodak triacetate) should be replaced with acid free paper envelopes, polyester sleeves or 4-flap paper folders.

Interleaving: Original prints held in groups within a single folder should be interleaved with some sort of acid free material such as acid-free glassine, Permalife™ paper or unbuffered acid-free tissue. Glassine is generally my choice because it has minimal texture, is easy to handle, is translucent and is now acid free (started about 20 years ago). Older glassine can be very acidic and should be eliminated from all collections. Buffered material are often not recommended for photographic materials, in a flood the extra alkalinity can soften gelatin.

9 - Other Resources

- Library Preservation at Harvard services has a succinct document (2 pp) on **Acetate Film Deterioration: Diagnosis and Storage** at <http://preserve.harvard.edu/pubs/acetatefilm.pdf>.
- David Horvath **The Acetate Negative Survey** (1987) final report to the National Museum Act can be found at <http://library.louisville.edu/library/ekstrom/special/AcetateNegativeSurvey.pdf>
- Manual on MP Film **Washington State Film Preservation Manual**, 2003, 37 pp, by Nicolette Bromberg, Hannah Palin and Libby Burke, presented by the Washington Preservation Initiative and the University <http://www.lib.washington.edu/specialcoll/film/preservationmanual.pdf>.
- Collection of **Images of Kodak Edge Printing** through 1967 by Brian Prichard <http://www.brianprichard.com/KODAK%20Edge%20Printing.htm>
- Extensive information on **Film Date Codes** by Brian Prichard, including Kodak, Fuji, Agfa, Selo and Ilford <http://www.brianprichard.com/Date%20Codes.htm>
- Henry Wilhelm and Carol Bower **The Permanence and Care of Photographs** (1993) 758 pp http://www.wilhelm-research.com/pdf/HW_Book_758_Pages_HiRes_v1a.pdf also individual chapter downloads.

Tim Vitale
Paper, Photographs &
Electronic Media Conservator
Digital Imaging & Facsimiles
Film [Still] Migration to Digital Format
Preservation & Imaging Consulting
Vitale Art Conservation
1500 Park Avenue
132
Emeryville, CA 94608

510-594-8277
Fx 510-594-8799
Mail to: tjvitale@ix.netcom.com

See: <http://vitaleartconservation.com>

Albumen Photography Website in 2000) <http://albumen.conservation-us.org>
VideoPreservation Website in 2007 <http://videopreservation.conservation-us.org>