2. Understanding Film and How It Decays

Since the 1890s, manufacturers have made countless varieties of motion picture stock to satisfy their many users. The first step in preserving film is understanding the shared traits of these materials and how their physical characteristics affect stability.[1]

2.1 Film Gauges

Film stock comes in different widths created for different markets. The width, generally called the gauge, is measured from edge to edge and expressed in millimeters —the most common in American collections being 35mm, 16mm, and 8mm.[2]

For each film gauge there is a family of like-gauged equipment and supplies designed to work together. Manufacturers make the film stock with holes (known as perforations), usually along the edges, to advance the film strip through the sprockets of same-gauged cameras and projectors.

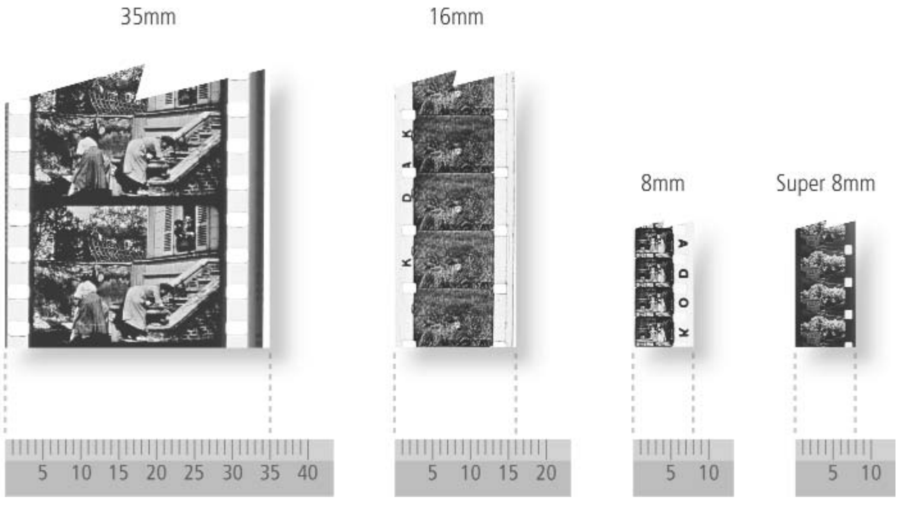
Smaller gauges are less expensive to use, making them more attractive for the amateur and educational markets. With larger gauges, however, the film frame has a greater area and projects a sharper image. This is why films created with the 70mm IMAX system appear so clear and crisp.

35mm. In 1893, the first commercially exhibited film in the United States used the 35mm gauge, and that remains the industry standard to this day.[3] As the new medium took hold, manufacturers improved camera and projection equipment, but for six decades they continued using flammable cellulose nitrate plastic (see 2.2) as a basic component of motion picture stock. The Eastman Kodak Company started phasing out cellulose nitrate film in 1948, and since the completion of the

1. Most of this chapter is drawn from the following sources: Steven Ascher and Edward Pincus, *The Filmmaker's Handbook: A Comprehensive Guide for the Digital Age*, rev. ed. (New York: Plume, 1999); Edward Blasko, Benjamin A. Luccitti, and Susan F. Morris, eds., *The Book of Film Care*, 2nd ed., Kodak Pub. H-23 (Rochester, NY: Eastman Kodak Company, 1992); Film Forever: The Home Film Preservation Guide, www.filmforever.org; Peter Z. Adelstein, *IPI Media Storage Quick Reference* (Rochester, NY: Image Permanence Institute, Rochester Institute of Technology, 2004); James M. Reilly, *Storage Guide for Color Photographic Materials: Caring for Color Slides, Prints, Negatives, and Movie Films* (Albany, NY: University of the State of New York, New York State Education Department, New York State Library, New York State Program for the Conservation and Preservation of Library Research Materials, 1998); and *IPI Storage Guide for Acetate Film: Instructions for Using the Wheel, Graphs, and Tables* (Rochester, NY: Image Permanence Institute, Rochester Institute of Technology, 1993).

2. *Film format* is a broader term that takes into account gauge; width, height, and position of the image; and sprocket hole size and placement.

3. Thomas Edison used strips of film 35mm wide for the kinetoscope, the personal film viewer that was unveiled in April 1893 at the Brooklyn Institute of Arts. The 35mm gauge was soon adapted for theatrical projection. See *Program Notes*, in *Treasures from American Film Archives: 50 Preserved Films* (San Francisco: National Film Preservation Foundation, 2000), 4.



Film comes in different widths, called gauges. The width is measured in millimeters.

changeover four years later, no nitrate film of any kind has been manufactured in the United States.[4] With minor exceptions, the expense and hazard of early 35mm limited the medium to professionals.

16MM. The film gauge most frequently found in American archives, libraries, and museums is 16mm. Kodak introduced 16mm in 1923 as a safe, nonflammable alternative for the home and educational markets. The cameras and projectors were portable, lightweight, and easy to operate. Amateurs embraced the new gauge and formed cine clubs where they could show their work and trade technical advice. Corporations adopted 16mm as a convenient gauge for employee training films. Soon an industry developed for producing 16mm instructional and educational films for businesses, schools, churches, and clubs. With the advent of portable video equipment in the 1970s, many 16mm users began switching to video. Thus, most 16mm films in archives, libraries, and museums date from the 1920s through the early 1980s.

REGULAR 8MM AND SUPER 8MM. Another common gauge in repositories is 8mm, often called Regular 8mm, which was introduced by Kodak in 1932 for home moviemakers. Many 8mm cameras use a spool or magazine containing 16mm film stock that is perforated with twice as many sprocket holes per foot as normal 16mm. When the film is sent to the laboratory for processing, it is slit to create two 8mm strips. Thus, 16mm and 8mm film have the same-size sprocket holes.

4. Most sources give 1951 as the last year of manufacture. Kodak reports that it began converting to safety film in 1948 and completely discontinued nitrate film production in 1952. Nitrate film stock remained in use through the early 1950s. Search "Chronology of Motion Picture Films—1940 to 1959," at www.kodak.com.

Super 8mm, first sold in 1965, brought an important innovation. It reduced the size of the sprocket holes, leaving more area for the picture. Super 8mm is used by amateurs and professionals and has won a following among avant-garde filmmakers.

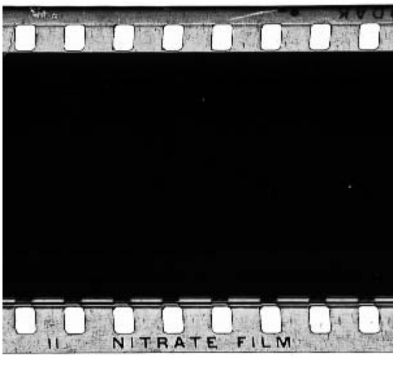
OTHER GAUGES. Many other gauges were tried in the early years of the nontheatrical market. Pathé, for example, introduced 28mm in 1912 and 9.5mm in 1922. Most did not survive the standardization brought largely by Kodak.[5]

2.2 INSIDE THE FILM STOCK

Regardless of the gauge, all motion picture films have the same basic structure. Film stock has two primary layers. The thicker layer, the transparent plastic base, provides support. The thinner layer, the emulsion, carries photosensitive materials in a gelatin binder. Both the base and the emulsion are subject to decay.

FILM BASES. Over the years manufacturers have used three types of transparent plastic for the film base: first cellulose nitrate, then cellulose acetate, and most recently polyester. Each has its own characteristics.

NITRATE. When motion picture film was introduced in the 1890s, cellulose nitrate was the only available transparent plastic durable enough for movie cameras and projectors. While strong and flexible, nitrate base film has a singular downside: It is highly flammable. Nitrate fires are virtually impossible to extinguish once they start burning.[6] (See 6.5 on the procedures for storing nitrate film.)



The words NITRATE FILM appear along the edge of many Kodak cellulose nitrate motion picture stocks.

Most 35mm film stock before the early 1950s had a cellulose nitrate base. Because of its flammability, nitrate base film stock was never used by American manufacturers for 16mm and 8mm film and was not sold by Kodak to the home market. As a precaution, from the mid 1920s on, Kodak labeled many of its nitrate stocks with the words NITRATE FILM along the edge to distinguish it from the materials intended for hobbyists.

5. For a detailed chronology chart breaking out motion picture films by brand name, manufacturer, and film base, see *Film Gauges* in the glossary of the ScreenSound Australia Web site, www.screensound.gov.au. For more on antique gauges, see Paolo Cherchi Usai, *Silent Cinema: An Introduction*, rev. ed. (London: BFI Publishing, 2000), and Brian Coe, *The History of Movie Photography* (Westfield, NJ: Eastview Editions, 1981).

6. Once started, the combustion of nitrate film liberates its own oxygen and is self-sustaining.

TABLE 1. FILM GAUGES AND THEIR SUPPORT MATERIAL

Support	Dates of Use	Gauge
Nitrate	1893–early 1950s	35mm
Acetate	1909–present*	35mm, 28mm, 16mm, 9.5mm, Regular 8mm, Super 8mm
Polyester	Mid 1950s–present	35mm, 16mm, some Super 8mm

*Cellulose diacetate motion picture film is thought to have been introduced in 1909. The first extant example dates from 1912. Diacetate was followed in the 1930s by cellulose acetate propionate and cellulose acetate butyrate, and in the late 1940s by cellulose triacetate.

ACETATE. Manufacturers found a safe substitute for cellulose nitrate by exploring plastics in the cellulose acetate family. Beginning in 1909, a number of new acetate bases were introduced, starting with cellulose diacetate,[7] then in the 1930s cellulose acetate propionate and cellulose acetate butyrate, and finally in the late 1940s cellulose triacetate.[8] Generally speaking, all relatively nonflammable substitutes for nitrate are called safety film. Every known American 16mm and 8mm film employs some type of safety film base. Kodak acetate film often has the words SAFETY FILM printed along the edge.

POLYESTER. In the mid 1950s, Kodak began selling a new type of safety film made of polyester. Polyester is the toughest and most chemically stable film base used today. Because it is so strong, polyester can be made thinner than other types of motion picture stock. In addition, its tensile strength makes it less vulnerable to physical damage caused by improper handling. Polyester is the film stock now generally used for new 35mm release prints shown in American theaters. Unlike nitrate or acetate film, polyester cannot be spliced with currently available film cement. It can, however, be spliced with splicing tape or an ultrasonic splicer.

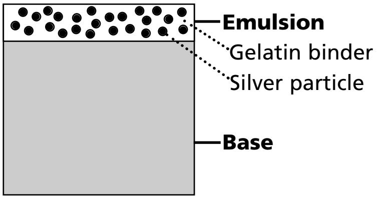
Under similar storage conditions, polyester far outlasts other types of film. Polyester is sold under various trade names, such as Cronar (Dupont) and ESTAR (Kodak).

EMULSION. The emulsion carries the photosensitive materials in a gelatin binder, forming the image-creating layer. The composition of this layer differs for black-and-white and color films.

The emulsion of raw black-and-white motion picture film contains silver salts that are converted to metallic silver particles during processing. With black-and-

7. For a discussion of 28mm diacetate film, see Anke Mebold and Charles Tepperman, "Resurrecting the Lost History of 28mm Film in North America," *Film History* 15 (2003): 137–51.
8. Each brought a technical improvement: Cellulose acetate propionate and cellulose acetate butyrate overcame the physical weakness of cellulose diacetate but were not as strong as cellulose triacetate.

white stock, the emulsion side of the film appears duller and more textured than the shiny and smoother base side. When properly processed and stored, silver images are very stable.

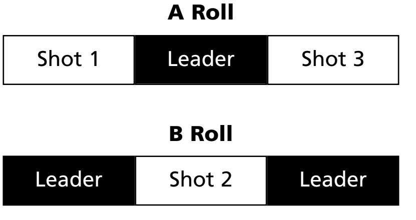


Cross section of black-and-white film.

The emulsion of color motion picture film, on the other hand, contains three layers of dyes—yellow, cyan, and magenta. The emulsion and base sides are difficult to distinguish, but it is possible to identify the emulsion side by holding the film to the light and checking for the side on which the image appears slightly raised or textured.

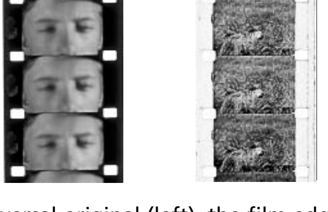
2.3 Negative, Print, and Reversal Films

In the photographic process that creates moving pictures, the film element that captures the image in the camera is the negative. The negative is developed and printed to make a positive for projection. Sometimes two rolls of negative or positive—A and B rolls—are run in succession through the printer, allowing the filmmaker to alternate between them to hide the splices between scenes and to create fades and dissolves. Where one carries the picture, the other has black or blank leader. Collections acquired from filmmakers and film-producing organizations may have 16mm negatives or positives in the form of A and B rolls.



With 16mm A and B rolls, the shots are divided between two rolls of film and separated by leader.

Reversal film is a special case. The same film that runs through the camera is processed to become a positive image. Thus, with reversal film, the camera original can become the projection print without use of an intervening negative.



In a reversal original (left), the film edge is black; in a print made from a negative, the edge is usually clear.

Often cost-conscious amateur and independent filmmakers favor reversal film. Because it shortcuts the traditional negative-positive printing process, reversal stock is cheaper to use. Reversal film may be color or black and white.

A good portion of the 16mm and virtually all Regular 8mm and Super 8mm prints found in American collections are reversal originals. They can be identified by examining the film edge near the sprocket holes. If the edge appears clear, the print was produced from a negative; if black, it is probably reversal film.

2.4 Color in Film

While the first exhibited films were in black and white, filmmakers soon found ways to add color to their works. During the early years of the motion picture, color was sometimes painted on prints by hand, often with a stencil. The more common technique in the United States was to dye black-and-white prints with tints. Though tinting was largely confined to 35mm commercial releases, Kodak added amber and occasionally other colors to 16mm prints of theatrical films that were sold to consumers over-the-counter. These are found today in some collections.

Experiments in capturing natural color with the camera led to the development of various color film stocks and printing processes in the 1920s and 1930s for the lucrative 35mm commercial market. The remarkably stable Technicolor prints gained primacy in the late 1930s, but cheaper, more convenient systems eventually won out.

For amateurs, Kodak introduced the celebrated Kodachrome reversal film in 1935. While the film stock was initially prone to fading, Kodak made improvements and by 1938 had a film with notable stability. With 16mm and 8mm Kodachrome, color can remain vivid decades later, particularly if the film has been stored under cold and dry conditions.

After World War II, other brands of color film reached the 16mm and 8mm market, each with its own characteristics. Manufacturers have significantly improved the stability of photographic dyes, but fading is still a major preservation problem with older color films.

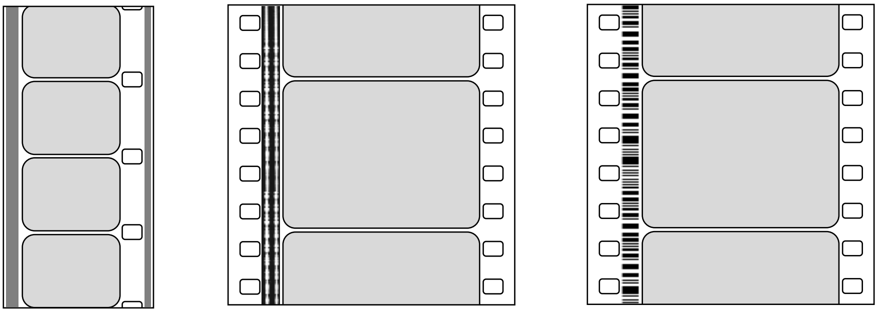
Lenticular film: black and white or "color"?

Before introducing Kodachrome, Kodak sold an unusual type of 16mm black-and-white film that projects as a color image when shown through a customized projector with a three-color lens. The film base is embossed lengthwise with ridges, called lenticules, that act as semicylindrical lenses. When light is projected through these lenticules and the three-color projector lens, a color image is created on the screen.

It is easy to mistake lenticular color film for black and white. For identification, first check for the word KODACOLOR printed on the film edge (see 3.3 on edge codes). Then examine the base side of the film under magnification, and look for raised cylindrical bands running parallel to the film edge.

Specialist laboratories can verify identification and make modern color copies from lenticular prints.*

*See the Film Technology Company Inc. Web site, www.filmtech.com.



Composite prints (from left): 16mm print with magnetic sound track and balance stripe, 35mm print with variable area optical sound track, and 35mm print with variable density optical sound track.

2.5 Sound Tracks

Early innovators strove to integrate sound, like color, in the motion picture viewing experience. Hollywood had converted to sound by 1929. The high-end amateur market followed, with RCA introducing the first 16mm sound camera in 1934. Sound tracks can be found on 35mm, 16mm, Super 8mm, and occasionally 8mm prints. A viewing positive with a sound track is called a composite print.

Before the advent of digital technology, sound tracks came in two types: optical and magnetic. Most optical tracks are photographically exposed directly onto the film during printing. In projection, light passing through the track is read and translated as sound. Optical tracks appear along the edge of the film as either high-contrast wavy lines (variable area) or a gray stripe of varying darkness (variable density).

Magnetic tracks, or mag tracks, work on a different principle from optical tracks. The mag track operates like a magnetic audiotape affixed to the film. During projection the track is read by the projector's playback head. Mag tracks appear as a dull brown stripe, usually along the edge of the film's base side. Particularly on small gauge films, a second stripe is often added along the opposite film edge for physical balance; with a stripe along both edges, the film produces a more even roll when wound. This balance stripe may be used to carry a second audio track.

Sound tracks usually precede their matching images on the motion picture film. This offset is necessary so that the projector reads the sound at a point in the film path at which the movement is smooth and steady.[9] The separation between sound and picture varies with format, as shown in table 2. It is important to remember this principle when making film repairs (see 3.5) so that sound is not lost.

In commercial filmmaking, before sound is added to the print it is often stored as a separate film element, tape, or electronic file. Collections acquired from film-

9. Film moves intermittently through the projection gate, where image projection occurs, so the sound track must be read either before or after the film passes through this gate.

Table 2. Number of Frames Usually Separating Sound and Image

	35mm*	16mm	8mm	Super 8mm
Magnetic track	28	28	56	18
Optical track	20	26	Not used	22

* 35mm mag and some early 35mm optical tracks follow the picture instead of preceding it.

makers and film-producing organizations may include 35mm or 16mm mag films used in production. These elements, sometimes called full-coat mags, have a dull-brown magnetic recording layer covering one side of the film surface. Similarly, filmmakers and preservationists may put the optical sound track on separate track-only reels.[10] With amateur and avant-garde films in particular, preservationists should watch for commentary, dialogue, or music recorded on a separate audio-tape reel or cassette intended to be played with the film during screening.

2.6 Common Types of Decay and Damage

Early motion pictures were assumed to have little value after their initial commercial release. Film was intended as an exhibition medium.

While base and emulsion are both prone to chemical decay, some film stocks or batches may be more vulnerable than others. Poor storage and handling take a further toll. The following are common types of film decay and damage found in library, museum, and archive collections.

Mechanical damage. When film is mishandled, inevitably there is physical damage. Films unspooled on a dirty worktable or passed through worn rollers can pick up dust, dirt, scratches, and abrasions. Tears can occur if the film is stressed during winding (see 3.2) or projection. When the film is incorrectly threaded in the projector, perforations can be stretched, ripped, or torn apart. Improper shipping procedures are another major cause of damage (see 5.8). The physical evidence of past abuse remains with the film print.

Preservationists can repair tears, damaged splices, and broken sprocket holes. But scratches are permanent, though they sometimes can be minimized in the laboratory during duplication.

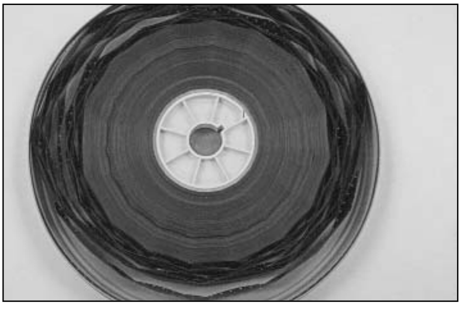
Mold, mildew, and fungus. A film stored under humid conditions can become a host for mold, mildew, and fungus. Generally the organisms start the attack from the outside edge and make their way into the film roll. These biological agents can cause significant damage to the emulsion.

10. With optical track elements, the film area that would ordinarily carry the picture is blank.

The growth initially appears in the form of matte-white spots and eventually grows into a lacy, weblike pattern. The invasion can be stopped by cleaning the film (see 3.6) and then moving it to a cold and dry environment. Once the organisms have eaten into the emulsion, however, the image loss is irreversible.

Mold growing on film.

ACETATE DECAY (VINEGAR SYNDROME). Water, high humidity, and heat can destroy the plastic base of acetate film. In the early stage of decay the plastic releases acetic acid, which is chemically identical to vinegar, hence the name "vinegar syndrome." As the decomposition advances, the chemical reaction accelerates.



As acetate film decays, it shrinks, loses flexibility, curls, and warps.

Typically the decay process follows this pattern:

1. The film begins to smell like vinegar.
2. The film base begins to shrink. As the base shrinks irregularly, the film resists being laid flat. It curls and warps along both length and width.
3. The film loses flexibility.
4. The emulsion may crack and eventually flake off.
5. White powder may appear along the edges and surface of the film.

The acetic acid vapor released by films with vinegar syndrome can infect other acetate base materials stored nearby, particularly in a poorly ventilated storage area. The Image Permanence Institute (IPI) at the Rochester Institute of Technology advises freezing films in advanced acetate decay (A-D Strip level 2 or above).

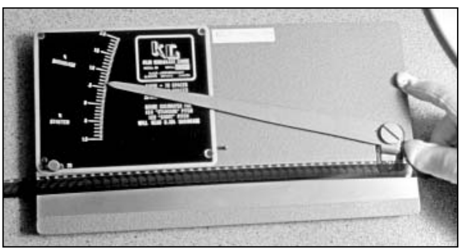
MEASURING ACETATE DECAY WITH A-D STRIPS

IPI's A-D Strips are an easy way to check for acetate decay. Just put a strip with the film in the can or box and close the lid. After at least 24 hours—exposure time varies with temperature and relative humidity—the strip will turn color on a scale from blue (0, the lowest acidity) to yellow (3, the highest). To assess the overall level of acetate decay in a film collection, IPI recommends testing a random sample of materials. Instructions are found in IPI's *User's Guide for A-D Strips*, which can be downloaded from www.rit.edu/ipi.

A-D Strips are not designed for use with nitrate or polyester film.

Acetate decay cannot be reversed, but it can be slowed by improving storage conditions (see chapter 6). At the early decay stages, the film content can be rescued by transferring it to new film stock. Generally once the film becomes too brittle, it cannot be copied in its entirety, although less damaged sections may be salvageable.

SHRINKAGE. Although shrinkage is a major symptom of acetate decay, it also affects nitrate and can be aggravated by overly dry storage conditions. If the relative humidity falls below 15% for extended periods, the film loses moisture, contracts, and may become brittle.



Using a shrinkage gauge.

Shrinkage is a particular problem for small gauge films because of the smaller size of the film frame and the mechanical precision required of the equipment. Once a 16mm or 8mm film has shrunk beyond 0.8% (1% for 35mm), it may be damaged in projection. Beyond 2%, even skilled laboratories can have trouble copying the film. At this point the film generally exhibits additional decay problems beyond shrinkage.

USING A SHRINKAGE GAUGE

A shrinkage gauge is a tool for measuring the degree of shrinkage in motion picture film. As the film shrinks, the distance between its sprocket holes decreases correspondingly. The instrument applies this fact in measuring shrinkage.

To obtain a shrinkage reading, lay your film flat along the device and engage the sprocket holes in the two pins, one of which is fixed and the other movable. The instrument compares the standardized distance between perforations with that of your film and expresses the difference in terms of a percentage. Depending on the design, the tool can be adjusted to accommodate different film gauges. Illustrated instructions are provided on the Association of Moving Image Archivists (AMIA) Web site, www.amianet.org.

Recognizing the diagnostic importance of measuring shrinkage, the AMIA provides a shrinkage-gauge lending service for members.

ESTIMATING SHRINKAGE: THE LOW-TECH APPROACH

While not as precise as a shrinkage gauge, another method for estimating shrinkage is to compare your film against new film stock of the same gauge.

Take a strip of fresh film 100 frames long and line it up with 100 frames of test film; if the older film is one-half a frame shorter, the shrinkage is 0.5%.

COLOR FADING. While varying in stability, all types and brands of color motion picture film will fade over time. The three dye layers lose their original color at different rates. In some film stocks, yellow is the first to go; in others it is cyan. As dyes break down, the color balance changes. Contrast is lost, and the film begins to acquire a pinkish brown cast. Eventually the film takes on a washed-out monochromatic look. Prints and negatives can experience fading at different rates.

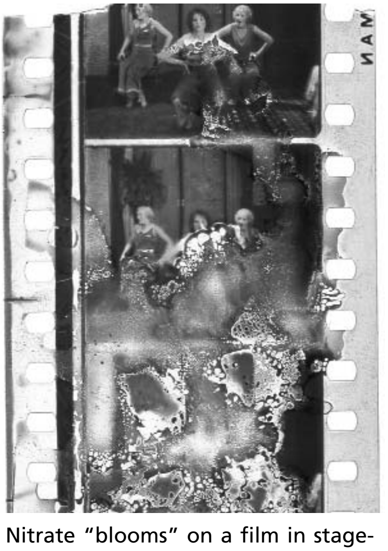
Heat and high relative humidity are the main culprits in color fading. The process can be slowed by cool and dry storage (see chapter 6) but not reversed.

For many years motion picture laboratories have sought methods to correct faded Hollywood film. Recently several proprietary photochemical processes have attracted interest. Digital techniques are also gaining ground. But for the present both approaches are far beyond the budget of noncommercial film collections.

NITRATE DECAY. The best-known form of film deterioration is nitrate decay. Nitrate degradation is a chemical process that occurs because of two factors: the nature of cellulose nitrate plastic itself and the way that the film is stored.

Nitrate decay follows a pattern. The International Federation of Film Archives (FIAF) defines the telltale criteria that distinguish the five-stage process.[11] Generally once nitrate film reaches the third stage, it cannot be duplicated. Severely deteriorated nitrate film is a hazardous waste and should be transferred to an authorized facility for disposal.

Like other forms of chemical film decay, nitrate deterioration cannot be reversed but can be retarded by improving storage (see chapter 6). Nitrate film should be copied before degradation affects the image.



Nitrate "blooms" on a film in stage-two nitrate decay.

FIVE STAGES OF NITRATE DECAY

1. Image fading. Brownish discoloration of emulsion. Faint noxious odor.
2. Sticky emulsion. Faint noxious odor.
3. Emulsion softens and blisters with gas bubbles. More pungent odor.
4. Film congeals into a solid mass. Strong noxious odor.
5. Film disintegrates into brownish powder.

11. See Eileen Bowser and John Kuiper, eds., *A Handbook for Film Archives* (New York: Garland Publishing, 1991), 18–19.

Magnetic track deterioration. Preservationists have observed that acetate films with magnetic sound tracks are especially vulnerable to vinegar syndrome, leading scientists to speculate that the iron oxide in the magnetic track may act as a catalyst in acetate decay. As the film base shrinks and becomes brittle, it compromises support of the magnetic sound strip. The magnetic coating can shed oxide, become sticky, or completely separate from the base.

As with the other chemical decay problems, improved storage slows the process. To prevent sound loss, it is important to copy the sound as soon as decay is detected.

Table 3. Film Damage and Decay: Summary

Problem	Detection Method	Symptoms	Remedy
Mechanical damage *(All film gauges)*	Visual inspection	• Tears • Torn or broken perforations • Broken splices	Physical repair
Careless handling *(All film gauges)*	Visual inspection	• Dirt • Scratches and abrasions on the film surface	• Cleaning • Scratches can be minimized during preservation copying
Mold, mildew, and fungus *(All film gauges)*	Visual inspection	• Matte-white spots on exterior of film roll • Growth into lacy, white web	• Cleaning • Improved storage
Acetate decay *(All acetate base film)*	• A-D Strips • Smell • Shrinkage • Visual inspection	• Vinegar odor • Shrinkage • Loss of flexibility; curling • Cracked emulsion • White powder on edge • A-D Strip level greater than 0	• Slow by improving storage • Isolate infected films • Copy content before decay is too advanced
Color fading	Visual inspection	• Shift in color • Loss of contrast and color balance • Film appears washed out	• Slow by improving storage • Copy content before decay is too advanced
Nitrate decay *(Not relevant to acetate or polyester film)*	• Visual inspection • Smell • Rusty metal cans	1. Image fading. Brownish discolor-ation of emulsion. 2. Sticky emulsion. Faint noxious odor. 3. Emulsion softens and blisters with gas bub-bles. Stronger odor. 4. Film congeals in solid mass. Strong noxious odor. 5. Film disintegrates into brownish powder.	• Slow by improving storage • Copy content before decay is too advanced • Dispose films in advanced decay as hazardous waste
Decay of mag-netic sound track on acetate film	• A-D Strips • Smell • Shrinkage • Visual inspection	• Film base loses flexibility • Mag track sheds, sticks, and separates • Vinegar odor • A-D Strip level greater than 0	• Slow by improving storage • Copy sound as soon as possible