THE PRESERVATION OF RECORDED SOUND MATERIALS[1]

By Gilles St. Laurent

Sound recordings are machine-readable artifacts; they are documents for which the integrity of the information they contain is directly related to the artifacts' physical well-being. Since the majority of sound recordings are made of plastic, conservation must be treated as a plastics degradation problem, requiring a different approach than paper conservation. It is important to understand the basic chemical degenerative processes and the principles of the retention of sound by the various media in order to ensure that proper action is taken to slow the rate of degradation.

SOUND AND HEARING

Sound can be defined as the change in air pressure above and below an equilibrium (usually the barometric pressure). For example, when a bass drum is struck, the skin vibrates back and forth. As the skin travels outward, away from the centre of the drum, the air pressure surrounding the drum rises above the barometric pressure; conversely as the drum skin travels inward, the air pressure lowers. This to-and-fro action occurs numerous times per second creating waves of compression and decompression in surrounding air.

As air pressure increases by the outward motion of the bass drum skin, the eardrum is pushed towards the centre of the head; conversely, as pressure decreases, the eardrum travels away from the centre of the head. Therefore, the eardrum physically moves in a parallel motion to the movement of the vibrating bass drum skin. The inner ear converts the change in air pressure into sound by translating the eardrum's mechanical motions into impulses that the brain will perceive as sound. The ear can detect changes in air pressure as slow as 20 cycles per second (a cycle being a complete to-and-fro motion) to as fast as 20,000 cycles per second. The higher the vibration speed, the higher the pitch; the larger the change in air pressure, the louder the sound.

THE RECORDING, RETENTION AND PLAYBACK OF SOUND

The Microphone

The interior of a microphone is comprised of a permanent magnet, a coil of wire and a diaphragm which, like the eardrum, vibrates to changes in air pressure. The vibration of the diaphragm in conjunction with the permanent magnet and the coil converts

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changes in air pressure into changes in electrical voltage. As air pressure increases, the diaphragm within the microphone is pushed towards the back of the microphone, inducing a voltage; as pressure decreases, the diaphragm travels outward inducing a voltage in the opposite direction. Like the eardrum, the diaphragm will move in a parallel motion to the movement of the example sound, the vibrating bass drum skin. The resulting voltage will be a continuous parallel voltage image of the movement of that bass drum skin.

If the bass drum were to be tuned at a higher pitch (the skin tightened) the skin would vibrate faster, causing the air pressure to compress and decompress faster, meaning that the diaphragm within the microphone will vibrate faster, consequently forcing the induced voltage to change direction more frequently. A higher pitch will thus be captured on the recording medium. If the drum were to be struck harder, producing a louder sound, the skin vibration would travel a greater distance, creating a higher compression of air, consequently forcing the microphone diaphragm to travel a greater distance thus inducing a larger voltage. The recording would thus be at a higher volume. This chain of events occurs with the recording of any sound. If an orchestra were to be recorded, the collective air pressure change surrounding the orchestra (caused by the mixture of vibrating strings, reeds, etc.) would be captured by the microphone.

The Speaker

Once sound has been converted to an electrical voltage, the "voltage image" can be amplified and then used to drive speakers. Like the skin of the bass drum, the movement of the speaker compresses and decompresses air to produce sound. If the voltage is going upwards, the speaker will travel outward; if the voltage is going downwards, the speaker will travel inward. The resulting movement of the speaker will be parallel to the movement of the skin on the bass drum, to the movement of an eardrum, to the movement of the diaphragm within the microphone, and to the induced voltage.

Discs

All records physically retain information in the same fashion and are recorded in a similar manner. Just as a speaker converts a change of voltage to a parallel mechanical motion, so with discs a cutting stylus converts a voltage change to a mechanical motion. When the voltage applied to the cutting stylus goes up, the stylus will move in one direction; when the voltage goes down, the cutting stylus will move in the opposite direction. The movement of the cutting stylus determines the pattern of the groove which, of course, moves in a parallel motion to the movement of the bass drum. Again, the resulting groove shape will be a continuous, identical physical image of the movement of that bass drum skin.

To retrieve information from a disc, a stylus is used to track the groove. The cartridge will convert the movement of the stylus to an electrical voltage (in the same fashion that a microphone converts mechanical motions to an electrical voltage) that can then be amplified and used to drive speakers. The movement of the speaker will be parallel to the movement of the stylus.

Tapes

The binder layer of magnetic tape contains a finite number of ferromagnetic particles whose permanent alignment within the binder records voltage (current) levels.

To record onto tape, the tape must first pass an erase head whose task is to arrange the particles completely randomly. If a small voltage is applied to the record head, then a small percentage of particles will become unidirectionally aligned. If a larger voltage is applied to the record head, then a larger percentage of particles will become aligned. Saturation occurs when there are no more particles available to align. The particles will remain aligned until exposed to a magnetic force.

At playback, the aligned particles will induce a voltage in the playback head. The voltage level will be proportional to the number of aligned particles.

Compact Discs (CDs)

Tapes and discs are analog recordings—the term "analog" referring to the transformation of sound into "parallel," or analogous grooves or particle alignments. Compact discs, on the other hand, are "digital" recordings. Rather than being a continuous physical image of changes in electrical voltage, digital recordings are based on a series of discrete electrical voltage measurements.

For the CD, the electrical voltage (produced by the microphone) is measured 44,100 times per second. At a certain period in time the voltage might be (for argument's sake) .5 volts out of a maximum 1 volt. 1/44,100th of a second later the voltage might be .5005 volts, the following 1/44,100th of a second .5009 volts, etc. As the skin of the bass drum travels outward, the resulting series of voltage readings get progressively larger; as the skin moves inward, the resulting series get progressively smaller.

Just as 2:00 p.m. can be expressed as 14:00 hrs, so any value can be expressed using binary digits—1s and 0s. Also, 1/3 can be expressed to .3, or more accurately .33, or better yet .333 etc. The greater the number of decimal places, the more precise the expression of the translation; hence the larger the number of digital bits used in a number, the more accurate the translation. For the compact disc, the number of digital bits used to translate or "digitize" a voltage reading is 16. Thus the compact disc stores one 16 bit number (in addition to other required information) every 44,100th of a second (per audio channel).

The CD stores information using pits and flat areas wound in a spiral starting at the centre of the disc. The edge of a pit (either the ascending edge or descending edge) indicates a one, a flat area either at the bottom of the pit or the land between the pits indicates 0. For example, a 5 bit number of 10001, using pits, would be an edge, a long flat area and another edge.

To play a CD, a laser beam is shone through the clear polycarbonate bottom to the aluminum layer. The light then reflects off the aluminum to a pickup which differentiates between the top and bottom of a pit and interprets these as 1s or 0s. The electronics then build a continuous voltage from these series of stored binary numbers representing the original voltage readings.

THE DEGRADATION MECHANISMS OF SOUND RECORDING

The life span of a plastic is largely determined at the manufacturing stage. Variables such as basic resin, the materials added to the basic resin to alter its properties, the lamination of materials with dissimilar properties, and the manufacturing process itself, all directly affect the life span of the plastic. Post-manufacture environmental factors such as storage conditions, temperature, humidity, and handling also contribute to the long-term stability of the plastics.

Acetate Discs

Prior to the advent of magnetic tape, instantaneous recordings were made chiefly on acetate discs. The chemical makeup of these discs, therefore, had to be a compromise between ease of engraving and the quality of the recording that resulted.

Since the 1930s, most acetate discs have been manufactured with a base, usually aluminum (although glass was used during the war years and cardboard for inexpensive home recordings), that was coated with nitrocellulose lacquer plasticized with castor oil. Because of the lacquer's inherent properties, acetate discs are the least stable type of sound recording.

Shrinkage of the lacquer coating due to the loss of the castor oil plasticizer is the primary destructive force. The gradual loss of plasticizer causes progressive embrittlement and the irreversible loss of sound information. Because the coating is bonded to a core which cannot shrink, internal stresses result, which in turn cause cracking and peeling of the coating.

Nitrocellulose decomposes continuously and over time reacts with water vapour or oxygen to produce acids that act as a catalyst for several other chemical reactions. These reactions are accelerated with elevated temperature and humidity levels.

Shellac Discs

The first shellac discs date from the 1890s, and this format was used until the 1950s, when it was gradually replaced by vinyl discs.

Shellac discs are relatively stable. Determining the causes of shellac degradation is difficult because a very wide range of qualities of shellac and "fillers" have been used by manufacturers. For example, two separate chemical analyses of "typical" shellac discs showed the following:

Example I[1]

Flake Shellac	15.63%
Congo Gum	6.51%
Vinsol Resin	5.86%
Carbon Black (low oil content)	2.61%
Zinc Sterate	0.32%
Whiting (CaCO3)	52.13%
Aluminum Silicate	13.03%
Flock (long fibre)	3.91%

Example II

Shellac	22.0%
Copal Gum	7.0%
Silica	33.0%
Barytes	33.0%
Carbon Black	3.0%
Cotton Flock	2.0%

The average shellac content in these "shellac" discs is approximately 19 percent. The remaining aggregates are mostly "fillers" which were used to lower the cost of manufacturing. Unfortunately, storage stabilities of these fillers vary widely. Organic materials in the aggregates are susceptible to fungus attack, while shellac itself is said to be fungus-resistant.

The curing process during shellac manufacturing (wherein raw shellac undergoes chemical reactions under applied stress) generates a condensation reaction between its organic compounds. This reaction causes the shellac to shrink, increasing its density and brittleness. This condensation continues at a much slower rate after disc manufacturing and thus becomes the primary degenerative force. The internal reaction of the material and the rate at which the reaction occurs are related to storage temperature, storage humidity (moisture increases the condensation reaction rate) and completeness of the cured shellac.

In a proper storage environment, these discs suffer a slow, progressive embrittlement of the shellac. This embrittlement causes a fine powder to be shed from the disc after each playback. The behaviour of the other aggregate components is unpredictable, due to the wide combinations and variety of materials (and of material quality) that were used.

Vinyl Discs

Thus far, vinyl has proven to be the most stable of the materials that have been used in the manufacture of sound recordings.[2] However, although stable, its life is not indefinite. Pickett and Lemcoe, in *Preservation and Storage of Sound Recordings,* states that "failure by chemical degradation of a vinyl disc in ordinary library environments should not occur in less than a century."[3]

Vinyl discs are made of polyvinyl chloride (PVC) and a small percentage (usually less than 25 percent) of "fillers," stabilizer, pigment, anti-static substances, etc. Internal plasticization, through a copolymerizing of vinyl acetate with vinyl chloride, is needed to achieve the required properties for the desired application.

Polyvinyl chloride degrades chemically when exposed to ultraviolet light or to heat. Phonograph discs are exposed to high temperatures during moulding and pressing. Unless stopped, this heat would be a catalyst for ongoing dehydrochlorination, which is the release of hydrochloric acid (HCl) from the PVC as a result of thermo-degradation. Stabilization is therefore achieved by adding a chemical to the resin during manufacture. This does not prevent the degradation but controls it, mainly by consuming the free HCl. Sufficient effective stabilizer remains in a plastic phonograph disc to protect it for a long time after pressing.

Magnetic Tape

Magnetic tape first appeared in North America just after World War II. The National Library of Canada at present has approximately 21,000 items in open reel, cassette and 8-track formats.

Magnetic tape is made up of two layers: a "base" layer, and a thin "binder" layer which is bonded onto the base. The binder contains ferromagnetic particles whose permanent alignment within the binder produce the copy of sound waves.

1. Magnetic Tape Binder. Manufacturers are very secretive about the specific chemical makeup of their products. Binder chemical composition, uniformity and smoothness of application all affect audio quality, noise level, tape-to-head contact, and friction. These factors also affect the tape's aging properties.

The most common binder resin used today is polyester polyurethane. The most common ferromagnetic particle used is gamma ferric oxide (Fe3O2). Numerous additives may be used during the various manufacturing stages, including: solvents, used to obtain a suitable viscosity of emulsion and to improve the mixing and bonding operations; wetting agents, used to break binder/particle mixing tension to produce a more even ferromagnetic particle dispersion within the binder; plasticizer, used to add suppleness to plastic; stabilizers, used mostly as antioxidants to avoid chemical degradation that could lead to physical breakdown; lubricants, used to reduce drag so that speed deviation problems such as "wow" and "flutter" are diminished, and to minimize wear damage to heads; fine mineral powders, used to make polymers harder and more resistant to abrasion; conduction discharge (material such as carbon black), used to discharge electrical charges; and fungicides.

The most common and serious magnetic tape degradation occurs through hydrolysis, the chemical reaction wherein an ester such as the binder resin "consumes" water drawn from humidity in the air to liberate carboxylic acid and alcohol. Hydrolysis in magnetic tape results in the binder shedding a gummy and tacky material which causes tape layers to stick together and inhibits playback when it is deposited onto the tape recorder heads. The added friction increases tape stress and can cause machines to stop. Hydrolysis also causes a weakening in the bond holding the binder to the backing, which results in shedding or possible detachment.

Chromium dioxide (CrO_2) is used extensively as the ferromagnetic particles in cassette magnetic tape. It has been found that CrO_2 particles interact with the polyester polyurethane to accelerate hydrolytic degradation.

Other problems associated with binder manufacturing and deterioration are: incomplete dispersion of the ferromagnetic particles, causing momentary loss of signal ("dropout"); a weak bond that causes the binder to separate from the backing; lubricants that evaporate to the point where tapes are unplayable; fine oxide powders that shed from tapes and deposit onto heads, inhibiting playback.

2. Magnetic Tape Backing. The backing, which is the structural support of the tape, must resist stresses imposed by playback and storage without becoming permanently deformed (e.g., stretching), or losing dimensional stability (e.g., expanding through absorption of moisture or heat). Most magnetic tape backing has been made of either cellulose acetate or polyester, materials that have dissimilar physical and aging properties.

Cellulose acetate-backed tapes were manufactured from about 1935 until the early 1960s. These tapes rely heavily on plasticizer additives for suppleness, and these plasticizers are liable, over time, to evaporate and crystallize. These tapes have extremely low tensile strength and are easily broken. Cellulose acetate tapes are very susceptible to linear expansion in humid and/or warm conditions. Because of the different properties of the binder and the base, the absorption of humidity and heat result in tape curling and edge fluttering. These distortions greatly affect the tape-to-head contact, which in turn directly affects audio quality. Repeated dimensional changes due to environmental fluctuations grossly affect winding tension and can promote binder fatigue, cracking, and finally, catastrophic failure (i.e., the irreversible loss of sound information).

Polyester ("mylar") came into use in the early 1960s, and quickly replaced cellulose acetate for magnetic tape backing. Accelerated aging tests have found polyester to be a stable material which in fact undergoes hydrolysis degradation at a much slower rate than does the binder, polyester polyurethane, with which it is combined. However, polyester-based tape has a high tensile strength that can cause it to stretch irreparably (instead of breaking cleanly and repairably as does acetate-backed tape).

A third coating is now added to modern tape on the opposite side of the binder. Made of carbon black, it protects the backing from scratches, minimizes static electricity, and provides a more even wind.

PRESERVATION OF SOUND RECORDINGS

A good definition of preservation put forward by the International Institute for Conservation—Canadian Group and the Canadian Association of Professional Conservators is that preservation encompasses "all actions taken to retard deterioration of, or to prevent damage to, cultural property. Preservation involves controlling the environment and conditions of use, and may include treatment in order to maintain a cultural property, as nearly as possible, in an unchanging state."[4]

There are essentially only three concerns to consider when handling and storing sound recordings:

1) that they be kept free of any foreign matter deposits;
2) that they be kept free of any pressure that might cause deformations; and
3) that they be stored in a stable, controlled environment.

1. FOREIGN MATTER DEPOSITS

General

In conservation terms, dirt can be classified into two categories: (1) foreign matter deposits which are not part of the original object, such as grease from fingerprints, soot, stains, adhesives, etc., and (2) alterations of original object material through chemical reactions (whether internal reactions or reactions with environmental agents). Metal corrosion products, palmitic acid from acetate discs, or a gummy substance on tapes are examples of alteration in the state of the original.[5]

Dust is commonly a mixture of fragments of human skin, minute particles of mineral or plant material, textile fibres, industrial smoke, grease from fingerprints, and other organic and inorganic materials. There are often salts such as sodium chloride (carried in from sea spray or on skin fragments), and sharp gritty silica crystals. In this chemical mixture are the spore of countless moulds, fungi and micro-organisms which live on the organic material in the dust (fingerprints, for example, serve as good culture media). Much of the dirt is hygroscopic (water-attracting) and this tendency can encourage the growth of moulds, as well as increase the corrosiveness of salts, hydrolysis in tapes and the release of palmitic acids from acetate discs.[6]

Dust (including fingerprints) will negatively affect sound recording preservation in a number of ways:

Discs

Dust is abrasive, and combined with the pressure exerted on the groove walls by the stylus, can permanently etch the walls worse, dust also can be imbedded permanently into the plastic. Only a small point of the stylus is actually making contact with the groove walls. One and a half grams of stylus pressure on such a minute surface translates to several tons of pressure per square inch. The resulting drag generates enough heat that the plastic partially melts (though not enough to deform), causing a microscopic flow around the stylus into which dust can be embedded permanently.

Tapes

Dust attracts and traps moisture and will precipitate hydrolysis, a common and serious cause of long-term magnetic tape degradation. Also, dust will cause permanent damage to the tape when the abrasiveness of the dust along with the pressure exerted between the tape surface and the tape recorder heads will scratch the oxide layer and the tape recorder heads.

CDs

Since there is no physical contact at playback, there is virtually no chance of physical damage occurring during playback due to dust deposits. Nevertheless, dust will impede proper playback by obstructing the reading of the information, while it may also affect the long-term preservation. Currently, the precise, long-term degradation mechanisms for the CD are still unknown. If dust is improperly removed, permanent physical damage will occur owing to the scratching of the protective layer.

To minimize foreign matter deposits:

General:

- Never touch the surface of a recording. Use white lintless cotton gloves and handle by the edges.
- Recordings should not, unnecessarily, be left exposed to air. Return items to their containers when not in use and never leave storage containers open.
- Do not place recordings near sources of paper or cardboard dust.

- Keep the surrounding area clean. Do not consume food or beverages in the area in which recordings are handled.
- Keep storage facilities as dust-free as possible.
- The air conditioning system should be equipped with dust filtering equipment.
- Keep labelling to a minimum, but limit the placement of labels, especially pressure sensitive labels, to the container.
- Keep equipment clean, well adjusted and in good working condition.

Discs

- Do not use paper or cardboard inner sleeves and do not store records without inner sleeves.
- Use soft polyethylene inner sleeves. Do not use record sleeves made of PVC.
- Remove LPs from the jacket (with the inner sleeve) by bowing the jacket open by holding it against the body and applying a slight pressure with a hand. Pull the disc out by holding a corner of the inner sleeve. Avoid pressing down onto the disc with the fingers as any dust caught between the sleeve and the disc will be pressed into the grooves.
- Remove LPs from the inner sleeve by bowing the inner sleeve and letting it slip gradually into an open hand so that the edge falls on the inside of the thumb knuckle. The middle finger should reach for the centre label. Never reach into the sleeve.
- To hold a disc, place the thumb on the edge, and the rest of the fingers of the same hand on the centre label for balance. Use both hands on the edge to place disc on turntable.

Tapes

- Do not store paper inside the reel-to-reel tape box.
- After removing the end tab from the virgin reel-to-reel tape, cut off one-and-one-half wraps of the tape. This is to avoid any adhesive, left by the end tab, from being transferred to the machine or causing layer-to-layer adhesion of the tape.

CDs

- Remove CDs from their case by pressing thumb and third finger on edges near the top and bottom of the case and pressing on the plastic clasp in the centre with the other hand.

Cleaning[7]

Since dust is usually held in place by electrostatic attraction, dry wiping on its own does not work effectively. The added friction created by the duster will cause the dust to jump back to the charged surface.

Distilled water is used for cleaning records and CDs for many reasons. Its precise chemical makeup is known, it will not leave any residue behind, is safe to use, and is inexpensive. Water disperses static charges and counteracts the increase in conductivity from the pick-up of salt deposits from fingerprints. However, water alone cannot dissolve grease, thus surfactants are used as additives to enable water to be a grease solvent. Surfactants break grease surface bonds and allow water to penetrate grease solids, causing swelling and then random dispersion.

General

- The Canadian Conservation Institute (CCI) recommends the use of nonionic, ethelyne oxide condensates surfactants to clean sound recordings. The CCI does not foresee long-term problems associated with the use of nonionic surfactants such as Tergitol. Tergitol 15-S-3 is an oil soluble surfactant and 15-S-9 is a water soluble surfactant. Combined they remove a wide range of dirt and greases and can safely be used on sound recordings. Use 0.5 parts of Tergitol 15-S-3 and 0.5 parts of Tergitol 15-S-9 per 100 parts of distilled water. These products are available in small quantities from TALAS (Division of Technical Library Service Inc.), 213 West 35th Street, New York, N.Y. (212)465-8722.

- Keep an air gun handy to blow off light surface dust.

Discs

- Records are best cleaned using a record cleaning machine such as the Keith Monks, VPI, Nitty Gritty using 0.5 part of Tergitol 15-S-3 and 0.5 parts of Tergitol 15-S-9 per 100 parts of distilled water. These machines allow for an even dispersion of fluid and then can vacuum the liquid leaving a clean, dry surface. Records should be cleaned before each playback.
- Clean acetate discs showing signs of palmitic acid deposits (white greasy substance on acetate disc surface) as if cleaning LPs, except add 2 parts ammonia per 100 to the Tergitol cleaning solution.

Tapes

- Vacuum the reel-to-reel tape pack if dusty. Use a vacuum which has a hose, and keep the motor away from the tape in order to reduce the risk of magnetizing the tapes.
- Clean tape surfaces using a product such as 3M "Tape Cleaning Fabric" (610-1-150). This soft fabric product will pick up loose debris commonly found on tape surfaces after being dislodged by the fabric fibres.

CDs

- An air gun should be used to blow off any light surface dust.
- If fingerprints or other stains must be removed, 0.5 part of Tergitol 15-S-3 and 0.5 parts of Tergitol 15-S-9 per 100 parts of distilled water can be utilized safely. Carefully blot the area of the disc needing washing with a soft cloth (preferably a soft cotton that has been washed several times) imbued with a concentration of Tergitol and distilled water. Rinse well using a second cloth soaked in distilled water. Blot dry using a soft cotton cloth. Use an air gun to blow off any lint left over.
- Avoid rubbing in any direction.

2. SURFACE DEFORMATIONS

Since the surface of a sound recording is the information carrier, it is critical that the surface be well cared for. Physical deformations such as warping of discs, stretching of tape or shock from dropping them, will directly affect sound information integrity. One must develop a respect for the integrity of the artifact.

To minimize deformations

General

- Never leave recordings near sources of heat or light (especially ultraviolet light) as plastics are adversely affected by both.
- Do not place heavy objects on top of recordings. Recordings should never be placed on top of each other.
- Shelve recordings vertically; do not stack "off vertical" or horizontally.
- Do not use shelving units where supports put more pressure on one area of the recording or where supports are more than four to six inches apart.

- Do not interfile recordings of different sizes as smaller items may get lost or damaged, while larger items may be subjected to uneven pressure.

Discs

- Remove shrink-wrap on LPs completely. Shrink-wrap can continue to shrink, thus warping the disc.

Tapes

- Do not drop tapes. The shock could partially rearrange the ferromagnetic particles, effectively attenuating high frequencies.
- Store tapes away from any sources of magnetic fields.
- Do not store reel-to-reel tapes in a plastic bag within tape box. The plastic bag will trap moisture.
- Handle reel-to-reel tapes by the hub rather than the flanges as the pressure on the flanges will damage them and ultimately damage the tape edges.
- Ten-inch reels should have supports in their boxes so that the hub bears the weight of the tapes rather than the flanges.
- Rewind (exercise) reel-to-reel tapes every 3.5 years.
- Store reel-to-reel tapes with an "archival wind." Wind tapes slowly so that air pockets between layers do not form causing successive layers to be placed unevenly on top of each other. The unevenness will cause stress, expose binder to air and exposes edges to possible physical damage by the flanges.
- A reel-to-reel tape deck with the heads removed can be used to rewind tape in the regular play mode. The tape tension might have to be readjusted to compensate for the removal of the heads.

3. ENVIRONMENT

A proper environment for the storage of sound recordings is essential to retard degradation mechanisms. Elevated temperature and humidity can affect certain chemical properties of the plastics that make up recording media and can also create an environment that encourages the growth of fungus. Wide or rapid fluctuations of the environment are equally detrimental to the long-term preservation of sound artifacts.

Acetate discs

Shrinkage of the lacquer coating due to the loss of plasticizer is the primary destructive force of these discs. Excess moisture will accelerate plasticizer loss. Acetate discs decompose continuously, and over time react with water vapour or oxygen to produce acids that in turn act as catalysts for several other chemical reactions. One of these is the release of palmitic acid, a white waxy substance. Acetate discs are very susceptible to fungus growth. Excess heat will probably accelerate the loss of the coating adhesion.

Shellac discs

High humidity levels accelerate the embrittlement of shellac discs. This embrittlement causes a fine powder to be shed from the disc after each playback, effectively scraping away groove information. The severity of the embrittlement is unpredictable, due to the wide combinations and variety of materials (and of material quality) that were used during their production. The average shellac content in shellac discs is approximately 19 percent with the remaining 81% composed of aggregates. Organic materials in the aggregates are susceptible to fungus attack, while shellac itself is said to be fungus-resistant.

Vinyl discs

Vinyl discs are adversely affected by ultraviolet light and thermal cycling (heat fluctuation). The consequence of thermal cycling is that each cycle of temperature results in a small irreversible deformation, and these deformations are cumulative.[8] Vinyl discs are resistant to fungal growth and are unaffected by high humidity levels.

Tapes

Hydrolysis is the chemical reaction whereby the binder resin "consumes" water drawn from humidity in the air to liberate carboxylic acid and alcohol. Hydrolysis in magnetic tape results in the binder shedding a gummy and tacky material which causes tape layers to stick together and inhibits playback when it is deposited onto the tape recorder heads. Hydrolysis also causes a weakening in the bond holding the binder to the backing, which results in shedding or possible detachment.

Cellulose acetate backed tapes are very susceptible to linear expansion in humid and/or warm conditions. Because of the different properties of the binder and the base, the absorption of humidity and heat result in tape curling and edge fluttering. Repeated dimensional changes due to environmental fluctuations grossly affect winding tension (hence the need for periodic rewinding) and can promote binder fatigue, cracking, and finally, the irreversible loss of sound information (known as catastrophic failure). Tape binder is somewhat susceptible to fungi growth though less so with modern tapes as fungicides are currently incorporated into the binder.

CDs

The compact disc is a laminate of 4 different materials. The bottom of the disc is made of polycarbonate onto which the pits containing the digitized sound information are stamped. A thin layer of aluminum is then applied, covering the pits. A thin lacquer coating (which becomes the top of the disc) is then applied to cover the aluminum layer, and finally the ink for the labelling.

As with any laminated products, one must wonder how the aging characteristics of each material will interact with, and affect adjacent layers.

Proper storage environment

- Store recordings at a maintained temperature of between no more than 15-20°C. Fluctuation of temperature should not vary more than 2°C in a 24-hour period.
- Maintain a relative humidity of 25-45%. Fluctuation of relative humidity should not vary more than 5% in a 24-hour period.[9]
- Maintain proper ventilation and air circulation of stacks at all times to avoid any microclimates.
- Keep sound recordings in dark storage when not being consulted. Fit light fixtures with fluorescent tubes which do not produce ultraviolet radiation in excess of 75 w/lm (microwatts per lumen).

CONCLUSION

Over the past century, recorded sound has become an intrinsic part of our culture. Upon hearing an early sound recording device in 1888, Sir Arthur Sullivan stated that he was "astonished and somewhat terrified at the result of this evening's experiments—astonished at the wonderful power you have developed, and terrified at the thought that so much hideous and bad music may be put on record forever."[10] Unfortunately, sound recordings are not "forever." These are ephemeral documents, both in their physical composition and consequently in the means by which the sound is ultimately retained. They can have their life span shortened considerably by both internal and external forces. By undertaking certain precautionary measures, custodians of the heritage of sound can lengthen considerably their collection's life span thus preserving a rich, invaluable world of sound.

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Bob Barclay and Scott Williams, Canadian Conservation Institute; Morgan Cundiff, International Piano Archives, University of Maryland; Gerald Gibson, Larry Miller, William Nugent, Library of Congress; Dr. R. Pisipati, Mobay Chemical Company; David Williams, Nimbus Records; Dietrich Schuller, Phonogrammarchiv, Vienna; Paul Toraka, Stanton Magnetics Incorporated; Jean-Marc Fontaine, Ministère de la Culture et de la Communication, France; Michel Bourbonnais, National Archives of Canada; Dr. Floyd Tool, National Research Council; Dr. Frank Ma, Union Carbide Canada Limited.

Notes:

1. Pickett, A.G.; Lemcoe, M.M., *Preservation and Storage of Sound Recordings.* Washington, D.C.: Library of Congress, 1959.
2. The stability of the newest format, the compact disc, has not yet been determined.
3. Pickett, A.G.; Lemcoe, M.M., *Preservation and Storage.* Washington, D.C.: Library of Congress, 1959. Reprinted by ARSC, 1991.
4. International Institute for Conservation—Canadian Group and the Canadian Association of Professional Conservators. *Code of Ethics and Guidance for Practice: for Those Involved in the Conservation of Cultural Property in Canada.* The International Institute for Conservation of Historic and Artistic Works-Canadian Group/The Canadian Association of Professional Conservators (CAPC). Ottawa: 1989, second edition. Page 19.
5. Moncrieff, Anne; Weaver, Graham. *Science for Conservators: Cleaning.* London: Crafts Council, 1983. Page 14.
6. *Ibid.* Page 14.
7. Please Note: Refer to manufacturer safety data sheets for the use of any chemicals mentioned herein.
8. Pickett, A.G.; Lemcoe, M.M., *Preservation and Storage.* Washington, D.C.: Library of Congress, 1959. Reprinted by ARSC, 1991.
9. N.B. ANSI/AES are preparing a report entitled Environment Storage Conditions which will deal with the proper storage environment for tapes. It is to be completed by the fall of 1991.
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