chapter 8

Hairs, Fibers, and Paint

Key Terms

anagen phase

catagen phase

cortex

cuticle

follicular tag

macromolecule

manufactured fibers

medulla

mitochondrial DNA

molecule

monomer

natural fibers

nuclear DNA

polymer

telogen phase

Learning Objectives

After studying this chapter you should be able to:

- Recognize and understand the cuticle, cortex, and medulla areas of hair
- List the three phases of hair growth
- Appreciate the distinction between animal and human hairs
- List hair features that are useful for the microscopic comparison of human hairs
- Explain the proper collection of forensic hair evidence
- Describe and understand the role of DNA typing in hair comparisons
- Understand the differences between natural and manufactured fibers
- List the properties of fibers that are most useful for forensic comparisons
- Describe the proper collection of fiber evidence
- List the most useful examinations for performing a forensic comparison of paint
- Describe the proper collection and preservation of forensic paint evidence

Jeffrey McDonald: Fatal Vision

The grisly murder scene that confronted police on February 17, 1970, is one that cannot be wiped from memory. Summoned to the Fort Bragg residence of Captain Jeffrey McDonald, a physician, police found the bludgeoned body of McDonald’s wife. She had been repeatedly knifed and her face was smashed to a pulp. McDonald’s two children, ages 2 and 5, had been brutally and repeatedly knifed and battered to death. Suspicion quickly fell on McDonald. To the eyes of investigators, the murder scene had a staged appearance.

McDonald described a frantic effort to subdue four intruders who had slashed at him with an ice pick. However, the confrontation left McDonald with minor wounds and no apparent defense wounds on his arms. McDonald then described how he had covered his slashed wife with his blue pajama top. Interestingly, when the body was removed blue threads were observed under the body. In fact, blue threads matching the pajama top turned up throughout the house—nineteen in one child's bedroom, including one beneath her fingernail, and two in the other child's bedroom. Eighty-one blue fibers were recovered from the master bedroom, and two were located on a bloodstained piece of wood outside the house. Later forensic examination showed that the forty-eight ice pick holes in the pajama top were smooth and cylindrical, a sign that the top was stationary when it was slashed. Also, folding the pajama top demonstrated that the forty-eight holes actually could have been made by twenty-one thrusts of an ice pick. This coincided with the number of wounds that McDonald's wife sustained. As described in the book *Fatal Vision,* which chronicled the murder investigation, when McDonald was confronted with adulterous conduct, he replied, "You guys are more thorough than I thought." McDonald is currently serving three consecutive life sentences.

The trace evidence transferred between individuals and objects during the commission of a crime, if recovered, often corroborates other evidence developed during the course of an investigation. Although in most cases physical evidence cannot by itself positively identify a suspect, laboratory examination may narrow the origin of such evidence to a group that includes the suspect. Using many of the instruments and techniques described in the previous three chapters, the crime laboratory has developed a variety of procedures for comparing and tracing the origins of physical evidence. This and the forthcoming chapters discuss how to apply these techniques to the analysis of the types of physical evidence most often encountered at crime scenes. We begin with a discussion of hairs, fibers, and paint.

MORPHOLOGY OF HAIR

Hair is encountered as physical evidence in a wide variety of crimes. However, any review of the forensic aspects of hair examination must start with the observation that it is not yet possible to individualize a human hair to any single head or body through its morphology. Over the years, criminalists have tried to isolate the physical and chemical properties of hair that could serve as individual characteristics of identity. Partial success has finally been achieved by isolating and characterizing the DNA present in hair. The importance of hair as physical evidence cannot be underemphasized. Its removal from the body often denotes physical contact between a victim and perpetrator and hence a crime of a serious or violent nature. When hair is properly collected at the crime scene and submitted to the laboratory along with enough standard/reference samples, it can provide strong corroborative evidence for placing an individual at a crime site.

The first step in the forensic examination of hair logically starts with its color and structure, or morphology, and, if warranted, progresses to the more detailed DNA extraction, isolation, and characterization.

Hair is an appendage of the skin that grows out of an organ known as the *hair follicle*. The length of a hair extends from its root or bulb embedded in the follicle, continues into the shaft, and terminates at the tip end. The shaft, which is composed of three layers—the **cuticle**, **cortex**, and **medulla**—is subjected to the most intense examination by the forensic scientist (see Figure 8–1).

Cuticle. Two features that make hair a good subject for establishing individual identity are its resistance to chemical decomposition and its ability to retain structural features over a long period of time. Much of this resistance and stability is attributed to the cuticle or outside covering of the hair. The cuticle is formed by overlapping scales that always point toward the tip end of each hair. The scales form from specialized cells that have hardened *(keratinized)* and flattened in progressing from the follicle. The scales of most animal hair can best be described as looking like shingles on a roof. Although the scale pattern is not a useful characteristic for individualizing human hair, the variety of patterns formed by animal hair makes it an important feature for species identification. Figure 8–2 shows the scale patterns of some animal hairs and of a human hair as viewed by the scanning electron microscope. Another method of studying the scale pattern of hair is to make a cast of its surface. This is done by embedding the hair in a soft medium, such as clear nail polish or softened vinyl. When the medium has hardened, the hair is removed, leaving a clear, distinct impression of the hair's cuticle, ideal for examination with a compound microscope.

Cortex. Contained within the protective layer of the cuticle is the cortex. The cortex is actually made up of spindle-shaped cortical cells aligned in a regular array, parallel to the length of the hair. The cortex derives its major forensic importance from the fact that it is embedded with the pigment granules that give hair its color. The color, shape, and distribution of these granules provide important points of comparison among the hairs of different individuals.

The structural features of the cortex are examined microscopically after the hair has been mounted in a liquid medium with a refractive index close to that of the hair. Under these conditions, the amount of light reflected off the hair's surface is minimized, and the amount of light penetrating the hair is optimized.

Medulla. The medulla is a collection of cells that looks like a central canal running through a hair. In many animals, this canal is a predominant feature, occupying more than half of the hair's diameter. The *medullary index* measures the diameter of the medulla relative to the diameter of the hair shaft and is normally expressed as a fraction. For humans, the index is generally less than one-third; for most other animals, the index is one-half or greater.

The presence and appearance of the medulla vary from individual to individual and even among the hairs of a given individual. Not all hairs have medullae, and when they do exist, the degree of medullation can vary. In this respect, medullae may be classified as being continuous, interrupted, fragmented, or absent (see Figure 8–3). Human head hairs generally exhibit no medullae or have fragmented ones; they rarely show continuous medullation. One noted exception is the Mongoloid race, whose members usually have head hairs with continuous medullae. Also, most animals have medullae that are either continuous or interrupted.

Another interesting feature of the medulla is its shape. Humans, as well as many animals, have medullae that give a nearly cylindrical appearance. Other animals exhibit medullae that have a patterned shape. For example, the medulla of a cat can best be described as resembling a string of pearls, whereas members of the deer family show a medullary structure consisting of spherical cells occupying the entire hair shaft. Figure 8–4 illustrates medullary sizes and forms for a number of common animal hairs and a human head hair.

A searchable database on CD-ROM of the thirty-five most common animal hairs encountered in forensic casework is commercially available.[1] This database allows an examiner to rapidly search for animal hairs based on scale patterns and/or medulla type using a PC. A typical screen presentation arising from such a data search is shown in Figure 8–5.

Root. The root and other surrounding cells within the hair follicle provide the tools necessary to produce hair and continue its growth. Human head hair grows in three developmental stages, and the shape and size of the hair root is determined by the growth phase in which the hair happens to be. The three phases of hair growth are the **anagen**, **catagen**, and **telogen phases**. In the anagen phase, which may last up to six years, the root is attached to the follicle for continued growth, giving the root bulb a flame-shaped appearance [Figure 8–6(a)]. When pulled from the root, some hairs in the anagen phase have a **follicular tag**. With the advent of DNA analysis, this follicular tag is important for individualizing hair. Hair continues to grow, but at a decreasing rate, during the catagen phase, which can last anywhere from two to three weeks. In the catagen phase, roots typically take on an elongated appearance [Figure 8–6(b)] as the root bulb shrinks and is pushed out of the hair follicle. Once hair growth ends, the telogen phase begins and the root takes on a club-shaped appearance [Figure 8–6(c)]. Over two to six months, the hair is pushed out of the follicle, causing the hair to be naturally shed.

IDENTIFICATION AND COMPARISON OF HAIR

Most often the prime purpose for examining hair evidence in a crime laboratory is to establish whether the hair is human or animal in origin or to determine whether human hair retrieved at a crime scene compares with hair from a particular individual. Although animal hair can normally be distinguished from human hair with little difficulty, human hair comparisons must be undertaken with extreme caution and with an awareness of hair's tendency to exhibit variable morphological characteristics, not only from one person to another but also within a single individual.

A careful microscopic examination of hair reveals morphological features that can distinguish human hair from animal hair. The hair of various animals also differs enough in structure that the examiner can often identify the species. Before reaching such a conclusion, however, the examiner must have access to a comprehensive collection of reference standards and the accumulated experience of hundreds of prior hair examinations. Scale structure, medullary index, and medullary shape are particularly important in hair identification.

The most common request when hair is used as forensic evidence is to determine whether hair recovered at the crime scene compares to hair removed from a suspect. In most cases, such a comparison relates to hair obtained from the scalp or pubic area. Ultimately, the evidential value of the comparison depends on the degree of probability with which the examiner can associate the hair in question with a particular individual.

In making a hair comparison, a comparison microscope is an invaluable tool that allows the examiner to view the questioned and known hair together, side by side. Any variations in the microscopic characteristics will thus be readily observed. Because hair from any part of the body exhibits a range of characteristics, it is necessary to have an adequate number of known hairs that are representative of all its features when making a comparison.

In comparing hair, the criminalist is particularly interested in matching the color, length, and diameter. Other important features are the presence or absence of a medulla and the distribution, shape, and color intensity of the pigment granules in the cortex. A microscopic examination may also distinguish dyed or bleached hair from natural hair. A dyed color is often present in the cuticle as well as throughout the cortex. Bleaching, on the other hand, tends to remove pigment from the hair and to give it a yellowish tint. If hair has grown since it was last bleached or dyed, the natural-end portion will be quite distinct in color. An estimate of the time since dyeing or bleaching can be made because *hair grows approximately one centimeter per month.* Other significant but less frequent features may be observed in hair. For example, morphological abnormalities may be present due to certain diseases or deficiencies. Also, the presence of fungal and nit infections can further link a hair specimen to a particular individual.

While microscopic comparison of hairs has long been accepted as an appropriate approach for including and excluding questioned hairs against standard/reference hairs, many forensic scientists have long recognized that this approach is very subjective and is highly dependent on the skills and integrity of the analyst, as well as the hair morphology being examined. However, until the advent of DNA analysis, the forensic science community had no choice but to rely on the microscope to carry out hair comparisons. Any lingering doubts about the necessity of augmenting microscopic hair examinations with DNA analysis evaporated with the publication of an FBI study describing significant error rates associated with microscopic comparison of hairs.[2] Hair evidence submitted to the FBI for DNA analysis between 1996 and 2000 was examined both microscopically and by DNA analysis. Approximately 11 percent of the hairs (9 out of 80) in which FBI hair examiners found a positive microscopic match between questioned and standard/reference hairs were found to be nonmatches when they were later subjected to DNA analysis. The course of events is clear; microscopic hair comparisons must be regarded by police and courts as presumptive in nature and all positive microscopic hair comparisons must be confirmed by DNA determinations.

A number of questions may be asked to further ascertain the present status of forensic hair examinations.

Forensics at Work

The Central Park Jogger Case Revisited

On April 19, 1989, a young lady left her apartment around nine p.m. to jog in New York's

Central Park. Nearly five hours later, she was found comatose lying in a puddle of mud in the park. She had been raped, her skull was fractured, and she had lost 75 percent of her blood. When the woman recovered, she had no memory of what happened to her. The brutality of the crime sent shock waves through the city and seemed to fuel a national perception that crime was running rampant and unchecked through the streets of New York.

Already in custody at the station house of the Central Park Precinct was a group of 14- and 15-year-old boys who had been rounded up leaving the park earlier in the night by police who suspected that they had been involved in a series of random attacks.

Over the next two days, four of the teenagers gave videotape statements, which they later recanted, admitting to participating in the attack. Ultimately, five of the teenagers were charged with the crime. Interestingly, none of the semen collected from the victim could be linked to any of the defendants. However, according to the testimony of a forensic analyst, two head hairs collected from the clothing of one of the defendants microscopically compared to those of the victim, and a third hair collected from the same defendant's T-shirt microscopically compared to the victim's pubic hair. Besides these three hairs, a fourth hair was found microscopically similar to the victim's. This hair was recovered from the clothing of Steven Lopez, who was originally charged with rape but not prosecuted for the crime. Hairs were the only pieces of physical evidence offered by the district attorney to directly link any of the teenagers to the crime. The hairs were cited by the district attorney as a way for the jury to know that the videotaped confessions of the teenagers were reliable. The five defendants were convicted and ultimately served from nine to thirteen years.

Matias Reyes was arrested in August 1989, more than three months after the jogger attack. He pleaded guilty to murdering a pregnant woman, raping three others, and committing a robbery.

He was sentenced to thirty-three years to life. In January 2002, Reyes confessed to the Central Park attack. Follow-up tests revealed that Reyes's DNA compared to semen recovered from the jogger's body and her sock. Other DNA tests showed that the hairs offered into evidence at the original trial did not come from the victim, and so could not be used to link the teenagers to the crime as the district attorney had argued.

After an eleven-month reinvestigation of the original charges, a New York State Supreme Court judge dismissed all the convictions against the five teenage suspects in the Central Park jogger case.

Can the Body Area from Which a Hair Originated Be Determined? Normally, it is easy to determine the body area from which a hair came. For example, scalp hairs generally show little diameter variation and have a more uniform distribution of pigment color when compared to other body hairs. Pubic hairs are short and curly, with wide variations in shaft diameter, and usually have continuous medullae. Beard hairs are coarse, are normally triangular in cross section, and have blunt tips acquired from cutting or shaving.

Can the Racial Origin of Hair Be Determined? In many instances, the examiner can distinguish hair originating from members of different races; this is especially true of Caucasian and Negroid head hair. Negroid hairs are normally kinky, containing dense, unevenly distributed pigments. Caucasian hairs are usually straight or wavy, with very fine to coarse pigments that are more evenly distributed when compared to Negroid hair. Sometimes a cross-sectional examination of hair may aid in the identification of race. Cross-sections of hair from Caucasians are oval to round in shape, whereas cross-sections of Negroid hair are flat to oval in shape. However, all of these observations are general in nature, with many possible exceptions. The criminalist must approach the determination of race from hair with caution and a good deal of experience.

Can the Age and Sex of an Individual Be Determined from a Hair Sample? The age of an individual cannot be learned from a hair examination with any degree of certainty except with infant hair. Infant hairs are fine, are short in length, have fine pigment, and are rudimentary in character. Although the presence of dye or bleach on the hair may offer some clue to sex, present hairstyles make these characteristics less valuable than they were in the past. The recovery of nuclear DNA either from tissue adhering to hair or from the root structure of the hair will allow a determination of whether the hair originated from a male or female (see p. 401).

Is It Possible to Determine Whether Hair Was Forcibly Removed from the Body? A microscopic examination of the hair root may establish whether the hair fell out or was pulled out of the skin. A hair root with follicular tissue (root sheath cells) adhering to it, as shown in Figure 8–7, indicates a hair that has been pulled out either by a person or by brushing or combing. Hair naturally falling off the body has a bulbous-shaped root free of any adhering tissue. However, the absence of sheath cells cannot always be relied on for correctly judging whether hair has been forcibly pulled from the body. In some cases the root of a hair is devoid of any adhering tissue even when it has been pulled from the body. Apparently, an important consideration is how quickly the hair is pulled out of the head. Hairs pulled quickly from the head are much more likely to have sheath cells compared to hairs that have been removed slowly from the scalp.[3]

Are Efforts Being Made to Individualize Human Hair? As we will learn in Chapter 13, forensic scientists are routinely isolating and characterizing individual variations in DNA. Forensic hair examiners can link human hair to a particular individual by characterizing the

nuclear DNA in the hair root or in follicular tissue adhering to the root (see Figure 8–7). Recall that the follicular tag is the richest source of DNA associated with hair. In the absence of follicular tissue, an examiner must extract DNA from the hair root. The growth phase of hair (see p. 211) is a useful predictor of the likelihood of successfully typing DNA in human hair.[4] Examiners have a higher rate of success in extracting DNA from hair roots in the anagen phase or from anagen-phase hairs entering the catagen phase of growth. Telogen-phase hairs have an inadequate amount of DNA for successfully typing. Because most hairs are naturally shed and are expected to be in the telogen stage, these observations do not portend well for hairs collected at crime scenes. However, some crime scenes are populated with forcibly removed hairs that are expected to be rich sources for nuclear DNA.

When a questioned hair does not have adhering tissue or a root structure amenable to the isolation of nuclear DNA, there is an alternative—**mitochondrial DNA**. Unlike the nuclear DNA described earlier, which is located in the nuclei of practically every cell in our body, mitochondrial DNA is found in cellular material outside the nucleus. Interestingly, unlike nuclear DNA, which is passed down to us from both parents, mitochondrial DNA is transmitted only from mother to child. Importantly, many more copies of mitochondrial DNA are located in our cells as compared to nuclear DNA. For this reason, the success rate of finding and typing mitochondrial DNA is much greater from samples, such as hair, that have limited quantities of nuclear DNA. Hairs 1–2 centimeters long can be subjected to mitochondrial analysis with extremely high odds of success. This subject is discussed in greater detail in Chapter 13.

Can DNA Individualize a Human Hair? In some cases, the answer is yes. As we will learn in Chapter 13, nuclear DNA produces frequency of occurrences as low as one in billions or trillions. On the other hand, mitochondrial DNA cannot individualize human hair, but its diversity within the human population often permits exclusion of a significant portion of a population as potential contributors of a hair sample. Ideally, the combination of a positive microscopic comparison and an association through nuclear or mitochondrial DNA analysis provides a strong and meaningful link between a questioned hair and standard/reference hairs. However, a word of caution: mitochondrial DNA cannot distinguish microscopically similar hairs from different individuals who are maternally related.

COLLECTION AND PRESERVATION OF HAIR EVIDENCE

When questioned hairs are submitted to a forensic laboratory for examination, they must always be accompanied by an adequate number of standard/ reference samples from the victim of the crime and from individuals suspected of having deposited hair at the crime scene. We have learned that hair from different parts of the body varies significantly in its physical characteristics. Likewise, hair from any one area of the body can also have a wide range of characteristics. For this reason, the questioned and standard/reference hairs must come from the same area of the body; one cannot, for instance, compare head hair to pubic hair. It is also important that the collection of standard/reference hair be carried out in a way to ensure a representative sampling of hair from any one area of the body.

Forensic Brief

The murder of Ennis Cosby, son of entertainer Bill Cosby, at first appeared unsolvable. It was a random act. When his car tire went flat, he pulled off the road and called a friend on his cellular phone to ask for assistance. Shortly thereafter, an assailant demanded money and, when Cosby didn’t respond quickly enough, shot him once in the temple. Acting on a tip from a friend of the assailant, police investigators later found a .38 revolver wrapped in a blue cap miles from the crime scene. Mikail Markhasev was arrested and charged with murder. At trial, the district attorney introduced firearms evidence to show that the recovered gun had fired the bullet aimed at Cosby. However, a single hair also recovered from the hat dramatically linked Markhasev to the crime. Los Angeles Police Department forensic analyst Harry Klann identified six DNA markers from the follicular tissue adhering to the hair root that matched Markhasev's DNA. This particular DNA profile is found in one out of 15,500 members of the general population. Upon hearing all the evidence, the jury deliberated and convicted Markhasev of murder.

Forensic hair comparisons generally involve either head hair or pubic hair. Collecting fifty full-length hairs from all areas of the scalp normally ensures a representative sampling of head hair. Likewise, a minimum collection of twenty-four full-length pubic hairs should cover the range of characteristics present in this type of hair. In rape cases, care must first be taken to comb the pubic area with a clean comb to remove all loose foreign hair present before the victim is sampled for standard/reference hair. The comb should then be packaged in a separate envelope.

Because a hair may show variation in color and other morphological features over its entire length, the entire hair length is collected. This requirement is best accomplished by either pulling the hair out of the skin or clipping it at the skin line. During an autopsy, hair samples are collected from a victim of suspicious death as a matter of routine. Because the autopsy may occur early in an investigation, the need for hair standard/ reference samples may not always be apparent. However, one should never rule out the possible involvement of hair evidence in subsequent investigative findings. Failure to make this simple collection at an opportune time may result in complicated legal problems at a later date.

TYPES OF FIBERS

Just as hair left at a crime scene can serve as identification, the same logic can reasonably be extended to the fibers that compose our fabrics and garments. Fibers may become important evidence in incidents that involve personal contact—such as homicide, assault, or sexual offenses—in which cross-transfers may occur between the clothing of suspect and victim. Similarly, the force of impact between a hit-and-run victim and a vehicle often leaves fibers, threads, or even whole pieces of clothing adhering to parts of the vehicle. Fibers may also become fixed in screens or glass broken in the course of a breaking-and-entering attempt.

Regardless of where and under what conditions fibers are recovered, their ultimate value as forensic evidence depends on the criminalist's ability to narrow their origin to a limited number of sources or even to a single source. Unfortunately, mass production of garments and fabrics has limited the value of fiber evidence in this respect, and only under the most unusual circumstances does the recovery of fibers at a crime scene provide individual identification with a high degree of certainty.

For centuries, humans depended on natural sources derived from plants and animals for textile fibers. Early in the twentieth century, the first manufactured fiber—rayon—became a practical reality, followed in the 1920s by the introduction of cellulose acetate. Since the late 1930s, scientists have produced dozens of new fibers. In fact, the development of fibers, fabrics, finishes, and other textile-processing techniques has made greater advances since 1900 than in the five thousand years of recorded history before the twentieth century. Today, such varied items as clothing, carpeting, drapes, wigs, and even artificial turf attest to the predominant role that manufactured fibers have come to play in our culture and environment.

For the purpose of discussing the forensic examination of fibers, it is convenient to classify them into two broad groups: *natural* and *manufactured.*

Natural Fibers

Natural fibers are wholly derived from animal or plant sources. Animal fibers comprise the majority of the natural fibers encountered in crime laboratory examinations. These include hair coverings from such animals as sheep (wool), goats (mohair, cashmere), camels, llamas, alpacas, and vicuñas; fur fibers include those obtained from animals such as mink, rabbit, beaver, and muskrat.

Forensic examination of animal fibers uses the same procedures discussed in the previous section for the forensic examination of animal hairs. Identification and comparison of such fibers relies solely on a microscopic examination of color and morphological characteristics. Again, a sufficient number of standard/reference specimens must be examined to establish the range of fiber characteristics that comprise the suspect fabric.

By far the most prevalent plant fiber is cotton. The wide use of undyed white cotton fibers in clothing and other fabrics has made its evidential value almost meaningless, although the presence of dyed cotton in a combination of colors has, in some cases, enhanced its evidential significance. The microscopic view of cotton fiber shown in Figure 8–8 reveals its most distinguishing feature—a ribbonlike shape with twists at irregular intervals.

Manufactured Fibers

Beginning with the introduction of rayon in 1911 and the development of nylon in 1939, **manufactured fibers** have increasingly replaced natural fibers in garments and fabrics. Today, such fibers are marketed under hundreds of different trade names. To reduce consumer confusion, the U.S. Federal Trade Commission has approved "generic" or family names for the grouping of all manufactured fibers. Many of these generic classes are produced by several manufacturers and are sold under a confusing variety of trade names. For example, in the United States, polyesters are marketed under names that include Dacron, Fortrel, and Kodel. In England, polyesters are called Terylene. Table 8–1 lists major generic fibers, along with common trade names and their characteristics and applications.

The first machine-made fibers were manufactured from raw materials derived from cotton or wood pulp. These materials are processed, and pure cellulose is extracted from them. Depending on the type of fiber desired, the cellulose may be chemically treated and dissolved in an appropriate solvent before it is forced through the small holes of a spinning jet or spinneret to produce the fiber. Fibers manufactured from natural raw materials in this manner are classified as *regenerated fibers* and commonly include rayon, acetate, and triacetate, all of which are produced from regenerated cellulose.

Table 8–1 Major Generic Fibers

Major Generic Fiber	Characteristics	Major Domestic and Industrial Uses
ACETATE	• Luxurious feel and appearance • Wide range of colors and lusters • Excellent drapability and softness	***Apparel:*** Blouses, dresses, foundation garments, lingerie, linings, shirts, slacks, sportswear ***Fabrics:*** Brocade, crepe, double knits, faille, knitted jerseys, lace, satin, taffeta, tricot

	• Relatively fast-drying • Shrink-, moth-, and mildew-resistant	***Home Furnishings:*** Draperies, upholstery ***Other:*** Cigarette filters, fiberfill for pillows, quilted products
ACRYLIC	• Soft and warm • Wool-like • Retains shape • Resilient • Quick-drying • Resistant to moths, sunlight, oil, and chemicals	***Apparel:*** Dresses, infant wear, knitted garments, skiwear, socks, sportswear, sweaters ***Fabrics:*** Fleece and pile fabrics, face fabrics in bonded fabrics, simulated furs, jerseys ***Home Furnishings*** Blankets. carpets, draperies, upholstery ***Other:*** Auto tops, awnings, hand-knitting and craft yarns, industrial and geotextile fabrics
ARAMID	• Does not melt • Highly flame-resistant • Great strength • Great resistance to stretch	Hot-gas filtration fabrics, protective clothing, military helmets, protective vests, structural composites for aircraft and boats, sailcloth, tires, ropes and cables, mechanical rubber goods, marine and sporting goods

	• Maintains shape and form at high temperatures	
BICOMPONENT	• Thermal bonding • Self-bulking • Very fine fibers • Unique cross-sections • The functionality of special polymers or additives at reduced cost	Uniform distribution of adhesive; fiber remains a part of structure and adds integrity; customized sheath materials to bond various materials; wide range of bonding temperatures; cleaner, environmentally friendly (*no effluent*); recyclable; lamination / molding / densification of composites
LYOCELL	• Soft, strong, absorbent • Good dyeability • Fibrillates during wet processing to produce special textures	Dresses, slacks, and coats
MELAMINE	• White and dyeable • Flame resistance and low thermal conductivity • High-heat dimensional	***Fire-Blocking Fabrics:*** Aircraft seating, fire blockers for upholstered furniture in high-risk occupancies (e.g., to meet California TB 133 requirements)

	stability • Processable on standard textile equipment	***Protective Clothing:*** Firefighters' turnout gear, insulating thermal liners, knit hoods, molten metal splash apparel, heat-resistant gloves ***Filter Media:*** High-capacity, high-efficiency, high-temperature baghouse air filters
MODACRYLIC	• Soft • Resilient • Abrasion- and flame-resistant • Quick-drying • Resists acids and alkalies • Retains shape	***Apparel:*** Deep-pile coats, trims, linings, simulated fur, wigs, and hairpieces ***Fabrics:*** Fleece fabrics, industrial fabrics, knit-pile fabric backings, nonwoven fabrics ***Home Furnishings:*** Awnings, blankets, carpets, flame-resistant draperies and curtains, scatter rugs ***Other:*** Filters, paint rollers, stuffed toys
NYLON	• Exceptionally strong • Supple • Abrasion-resistant	***Apparel:*** Blouses, dresses, foundation garments, hosiery, lingerie and underwear, raincoats, ski and snow

	• Lustrous • Easy to wash • Resists damage from oil and many chemicals • Resilient • Low in moisture absorbency	apparel, suits, windbreakers ***Home Furnishings:*** Bedspreads, carpets, draperies, curtains, upholstery ***Other:*** Air hoses, conveyor and seat belts, parachutes, racket strings, ropes and nets, sleeping bags, tarpaulins, tents, thread, tire cord, geotextiles
OLEFIN	• Unique wicking properties that make it very comfortable • Abrasion-resistant • Quick-drying • Resistant to deterioration from chemicals, mildew, perspiration, rot, and weather • Sensitive to heat • Soil resistant • Strong; very lightweight	***Apparel:*** Pantyhose, underwear, knitted sports shirts, men's half-hose, men's knitted sportswear, sweaters ***Home Furnishings:*** Carpet and carpet backing, slipcovers, upholstery ***Other:*** Dye nets, filter fabrics, laundry and sandbags, geotextiles, automotive interiors, cordage, doll hair, industrial sewing thread

	• Excellent colorfastness	
POLYESTER	• Strong • Resistant to stretching and shrinking • Resistant to most chemicals • Quick-drying • Crisp and resilient when wet or dry • Wrinkle- and abrasion-resistant • Retains heat-set pleats and creases • Easy to wash	***Apparel:*** Blouses, shirts, career apparel, children's wear, dresses, half-hose, insulated garments, ties, lingerie and underwear, permanent press garments, slacks, suits ***Home Furnishings:*** Carpets, curtains, draperies, sheets and pillowcases ***Other:*** Fiberfill for various products, fire hose, power belting, ropes and nets, tire cord, sail, V-belts
PBI	• Extremely flame resistant • Outstanding comfort factor combined with thermal and chemical stability properties	Suitable for high-performance protective apparel such as firefighters' turnout coats, astronaut space suits, and applications in which fire resistance is important

	• Will not burn or melt • Low shrinkage when exposed to flame	
RAYON	• Highly absorbent • Soft and comfortable • Easy to dye • Versatile • Good drapability	***Apparel:*** Blouses, coats, dresses, jackets, lingerie, linings, millinery. rainwear, slacks, sports shirts, sportswear, suits, ties, work clothes ***Home Furnishings:*** Bedspreads, blankets, carpets, curtains, draperies, sheets, slipcovers, tablecloths, upholstery ***Other:*** Industrial products, medical-surgical products, nonwoven products, tire cord
SPANDEX	• Can be stretched 500 percent without breaking • Can be stretched repeatedly and recover original length • Lightweight	***Articles*** (in which stretch is desired): Athletic apparel, bathing suits, delicate laces, foundation garments, golf jackets, ski pants, slacks, support and surgical hose

	• Stronger and more durable than rubber • Resistant to body oils

Source: American Fiber Manufacturers Assoc. Inc., Washington, D.C., http://www.fibersource.com/f-tutor/q-guide.htm.

Most of the fibers currently manufactured are produced solely from synthetic chemicals and are therefore classified as *synthetic fibers.* These include nylons, polyesters, and acrylics. The creation of synthetic fibers became a reality only when scientists developed a method of synthesizing long-chained molecules called **polymers**.

In 1930, chemists discovered an unusual characteristic of one of the polymers under investigation. When a glass rod in contact with viscous material in a beaker was slowly pulled away, the substance adhered to the rod and formed a fine filament that hardened as soon as it entered the cool air. Furthermore, the cold filaments could be stretched several times their extended length to produce a flexible, strong, and attractive fiber. The first synthetic fiber was improved and then marketed as nylon. Since then, fiber chemists have successfully synthesized new polymers and have developed more efficient methods for manufacturing them. These efforts have produced a multitude of synthetic fibers.

Polymers

The polymer is the basic chemical substance of all synthetic fibers. Indeed, an almost unbelievable array of household, industrial, and recreational products is manufactured from polymers; these include plastics, paints, adhesives, and synthetic rubber. Polymers exist in countless forms and varieties and with the proper treatment can be made to assume different chemical and physical properties.

As we have already observed, chemical substances are composed from basic structural units called **molecules**. The molecules of most materials are composed of just a few atoms; for example, water, H_2O, has 2 atoms of hydrogen and 1 atom of oxygen. The heroin molecule, $C_{21}H_{23}O_5N$, contains 21 atoms of carbon, 23 atoms of hydrogen, 5 atoms of oxygen, and 1 atom of nitrogen. Polymers, on the other hand, are formed by linking a large number of molecules, so that it is not unusual for a polymer to contain thousands or even millions of atoms. This is why polymers are often referred to as **macromolecules**, or “big” molecules.

Simply, a polymer can be pictured as resembling a long, repeating chain, with each link representing the basic structure of the polymer (see Figure 8–9). The repeating molecular units in the polymer, called **monomers**, are joined end to end, so that thousands are linked to form a long chain. What makes polymer chemistry so fascinating is the countless possibilities for linking different molecules. By simply varying the chemical structure of the basic molecules, or monomers, and by devising numerous ways to weave them together, chemists have created polymers that exhibit different properties. This versatility enables polymer chemists to synthesize glues, plastics, paints, and fibers.

It would be a mistake to give the impression that all polymers are synthesized in the chemical laboratory. Indeed, this is far from true, for nature has produced polymers that humans have not yet been able to copy. For example, the proteins that form the basic structure of animal hairs, as well as of all living matter, are polymers, composed of thousands of amino acids linked in a highly organized arrangement and sequence. Similarly, cellulose, the basic ingredient of wood and cotton, and starch are both natural polymers built by the combination of several thousand carbohydrate monomers, as shown in Figure 8–10. Hence, the synthesis of manufactured fibers merely represents an extension of chemical principles that nature has successfully used to produce hair and vegetable fibers.

IDENTIFICATION AND COMPARISON OF MANUFACTURED FIBERS

The evidential value of fibers lies in the criminalist's ability to trace their origin. Obviously, if the examiner is presented with fabrics that can be exactly fitted together at their torn edges, it is a virtual certainty that the fabrics were of common origin. Such a fit is demonstrated in Figure 8–11 for a piece of fabric that was removed from a vehicle suspected of involvement in a hit-and-run fatality. The exact fit with the remains of the victim's trousers resulted in the direct implication of the car's driver in the incident.

However, more often the criminalist obtains a limited number of fibers for identification and comparison. Generally, in these situations, the possibilities for obtaining a physical match are nonexistent, and the examiner must resort to a side-by-side comparison of the standard/reference and crime-scene fibers.

The first and most important step in the examination is a microscopic comparison for color and diameter using a comparison microscope. Unless these two characteristics agree, there is little reason to suspect a match. Other morphological features that could be present to aid in the comparison are lengthwise striations on the surface of some fibers and the pitting of the fiber's surface with delustering particles (usually titanium dioxide) added in the manufacturing process to reduce shine (Figure 8–12). The cross-sectional shape of a fiber may also help characterize the fiber.[5] In the Wayne Williams case (see Chapter 3), unusually shaped yellow-green fibers discovered on a number of the murder victims were ultimately linked to a carpet in the Williams home. This fiber was a key element in proving Williams's guilt. A photomicrograph of this unusually shaped fiber is shown in Figure 8–13.

Although two fibers may seem to have the same color when viewed under the microscope, compositional differences may actually exist in the dyes that were applied to them during their manufacture. In fact, most textile fibers are impregnated with a mixture of dyes selected to obtain a desired shade or color. The significance of a fiber comparison is enhanced when the forensic examiner can show that the questioned and standard/ reference fibers have the same dye composition. The visible-light microspectrophotometer (pp. 189–192) is a convenient way for analysts to compare the colors of fibers through spectral patterns. This technique is not limited by sample size—a fiber as small as one millimeter or less in length can be examined by this type of microscope. The examination is nondestructive and is carried out on fibers simply mounted on a microscope slide. A more detailed analysis of the fiber's dye composition can be obtained through a chromatographic separation of the dye constituents. To accomplish this, small strands of fibers are compared for dye content by first extracting the dye off each fiber with a suitable solvent and then spotting the dye solution onto a thin-layer chromatography plate. The dye components of the questioned and standard/reference fibers are separated on the thin-layer plate and compared side by side for similarity.[6]

Once this phase of the analysis is complete, and before any conclusion can be reached that two or more fibers compare, they must be shown to have the same chemical composition. In this respect, tests are performed to confirm that all of the fibers involved belong to the same broad generic class. Additionally, the comparison will be substantially enhanced if it can be demonstrated that all of the fibers belong to the same subclassification within their generic class. For example, at least four different types of nylon are available in commercial and consumer markets, including nylon 6, nylon 6–10, nylon 11, and nylon 6–6. Although all types of nylon have many properties in common, each may differ in physical shape, appearance, and dyeability because of modifications in basic chemical structure. Similarly, a study of more than two hundred different samples of acrylic fibers revealed that they could actually be divided into twenty-four distinguishable groups on the basis of their polymeric structure and microscopic characteristics.[7]

Textile chemists have devised numerous tests for determining the class of a fiber. However, unlike the textile chemist, the criminalist frequently does not have the luxury of having a substantial quantity of fabric to work with and must therefore select tests that will yield the most information with the least amount of material. Only a single fiber may be available for analysis, and often this may amount to no more than a minute strand recovered from a fingernail scraping of a homicide or rape victim.

A most useful physical property of fibers, from the criminalist's point of view, is that many manufactured fibers exhibit double refraction or birefringence (see pp. 110–111). Synthetic fibers are manufactured by melting a polymeric substance or dissolving it in a solvent and then forcing it through the very fine holes of a spinneret. The polymer emerges as a very fine filament, with its molecules aligned parallel to the length of the filament (see Figure 8–14). Just as the regular arrangement of atoms produces a crystal, so will the regular arrangement of the fiber's polymers cause crystallinity in the finished fiber. This crystallinity makes a fiber stiff and strong and gives it the optical property of double refraction.

Polarized white light passing through a synthetic fiber is split into two rays that are perpendicular to each other, causing the fiber to display polarization or interference colors when viewed under a polarizing microscope (see Figure 8–15). Depending on the class of fiber, each polarized plane of light has a characteristic index of refraction. This value can be determined by immersing the fiber in a fluid with a comparable refractive index and observing the disappearance of the Becke line under a polarizing microscope. Table 8–2 lists the two refractive indices of some common classes of fibers, along with their birefringence. The virtue of this technique is that a single fiber, microscopic in size, can be analyzed in a nondestructive manner.

The polymers that compose a manufactured fiber, just as in any other organic substance, selectively absorb infrared light in a characteristic pattern. Infrared spectrophotometry thus provides a rapid and reliable method for identifying the generic class, and in some cases the subclasses, of fibers. The infrared microspectrophotometer combines a microscope with an infrared spectrophotometer (see p. 192). Such a combination makes possible the infrared analysis of a small single-strand fiber while it is being viewed under a microscope.[8]

Table 8–2 Refractive Indices of Common Textile Fibers

	Refractive Index		
Fiber	**Parallel**	**Perpendicular**	**Birefringence**
Acetate	1.478	1.477	0.001
Triacetate	1.472	1.471	0.001
Acrylic	1.524	1.520	0.004
Nylon			
Nylon 6	1.568	1.515	0.053
Nylon 6–6	1.582	1.519	0.063

Polyester			
Dacron	1.710	1.535	0.175
Kodel	1.642	1.540	0.102
Modacrylic	1.536	1.531	0.005
Rayon			
Cuprammonium rayon	1.552	1.520	0.032
Viscose rayon	1.544	1.520	0.024

Note: The listed values are for specific fibers, which explains the highly precise values given. In identification work, such precision is not practical; values within 0.02 or 0.03 of those listed will suffice.

Once a fiber match has been determined, the question of the significance of such a finding is bound to be raised. In reality, no analytical technique permits the criminalist to associate a fiber strand definitively to any single garment. Furthermore, except in the most unusual circumstances, no statistical databases are available for determining the probability of a fiber's origin. Considering the mass distribution of synthetic fibers and the constantly changing fashion tastes of our society, it is highly unlikely that such data will be available in the foreseeable future. Nevertheless, one should not discount or minimize the significance of a fiber association. An enormous variety of fibers exists in our society. By simply looking at the random individuals we meet every day, we can see how unlikely it is to find two different people wearing identically colored fabrics (with the exception of blue denims or white cottons). There are thousands of different-colored fibers in our environment. Combine this with the fact that forensic scientists compare not only the color of fibers but also their size, shape, microscopic appearance, chemical composition, and dye content, and one can now begin to appreciate how unlikely it is to find two indistinguishable colored fibers emanating from randomly selected sources. Furthermore, the significance of a fiber association increases dramatically if the analyst can link two or more distinctly different fibers to the same object. Likewise, the associative value of fiber evidence is dramatically enhanced if it is accompanied by other types of physical evidence linking a person or object to a crime.

Forensics at Work

Fatal Vision Revisited

Dr. Jeffrey MacDonald was convicted in 1979 of murdering his wife and two young daughters. The events surrounding the crime and the subsequent trial were recounted in Joe McGinniss's best-selling book *Fatal Vision*. The focus of MacDonald's defense was that intruders entered his home and committed these violent acts. Eleven years after this conviction, MacDonald's attorneys filed a petition for a new trial, claiming the existence of "critical new" evidence.

The defense asserted that wig fibers found on a hairbrush in the MacDonald residence were evidence that an intruder dressed in a wig entered the MacDonald home on the day of the murder. Subsequent examination of this claim by the FBI Laboratory focused on a blond fall frequently worn by MacDonald's wife. Fibers removed from the fall were shown to clearly match fibers on the hairbrush. The examination included the use of infrared microspectrophotometry to demonstrate that the suspect wig fibers were chemically identical to fibers found in the composition of the MacDonald fall (see Figure 8–16). Hence, although wig fibers were found at the crime scene, the source of these fibers could be accounted for—they came from Mrs. MacDonald’s fall.

Another piece of evidence cited by MacDonald’s lawyers was a bluish-black woolen fiber found on the body of Mrs. MacDonald. They claimed that this fiber compared to a bluish-black woolen fiber recovered from the club used to assault her. These wool fibers were central to MacDonald’s defense that the “intruders” wore dark-colored clothing. Initial examination showed that the fibers were microscopically indistinguishable. However, the FBI also compared the two wool fibers by visible-light microspectrophotometry. Comparison of their spectra clearly showed that their dye compositions differed, providing no evidence of outside intruders (see Figure 8–17). Ultimately, the U.S. Supreme Court denied the merits of MacDonald’s petition for a new trial.

Source: B. M. Murtagh and M. P. Malone, “Fatal Vision Revisited,” *The Police Chief* (June 1993): 15.

As with most class evidence, the significance of a fiber comparison is dictated by the circumstances of the case; by the location, number, and nature of the fibers examined; and, most important, by the judgment of an experienced examiner.

COLLECTION AND PRESERVATION OF FIBER EVIDENCE

As criminal investigators have become more aware of the potential contribution of trace physical evidence to the success of their investigations, they have placed greater emphasis on conducting thorough crime-scene searches for evidence of forensic value. Their skill and determination at carrying out these tasks is tested when it comes to the collection of fiber-related evidence. Fiber evidence can be associated with virtually any type of crime. It cannot usually be seen with the naked eye and thus can be easily overlooked by someone not specifically looking for it. An investigator committed to optimizing the laboratory’s chances for locating minute strands of fibers seeks to identify and preserve potential “carriers” of fiber evidence. Relevant articles of clothing should be packaged carefully in paper bags. Each article must be placed in a separate bag to avoid cross-contamination of evidence. Scrupulous care must be taken to prevent articles of clothing from different people or from different locations from coming into contact. Such articles must not even be placed on the same surface prior to packaging. Likewise, carpets, rugs, and bedding are to be folded carefully to protect areas suspected of containing fibers. Car seats should be carefully covered with polyethylene sheets to protect fiber evidence, and knife blades should be covered to protect adhering fibers. If a body is thought to have been wrapped at one time in a blanket or carpet, adhesive tape lifts of exposed body areas may reveal fiber strands.

Occasionally the field investigator may need to remove a fiber from an object, particularly if loosely adhering fibrous material may be lost in transit to the laboratory. These fibers must be removed with a clean forceps and placed in a small sheet of paper, which, after folding and labeling, can be placed inside another container. Again, scrupulous care must be taken to prevent contact between fibers collected from different objects or from different locations.

In the laboratory, the search for fiber evidence on clothing and other relevant objects, as well as in debris, is time consuming and tedious, and will test the skill and patience of the examiner. The crime-scene investigator can reduce this task to manageable proportions by collecting only relevant items for examination. It is essential from the onset of an investigation that the crime-scene investigator pinpoint areas where a likely transfer of fiber evidence occurred and then take necessary measures to ensure proper collection and preservation of these materials.

FORENSIC EXAMINATION OF PAINT

Our environment contains millions of objects whose surfaces are painted. Thus, it is not surprising to observe that paint, in one form or another, is one of the most prevalent types of physical evidence received by the crime laboratory. Paint as physical evidence is perhaps most frequently encountered in hit-and-run and burglary cases. For example, a chip of dried paint or a paint smear may be transferred to the clothing of a hit-and-run victim on impact with an automobile, or paint smears could be transferred onto a tool during the commission of a burglary. Obviously, in many situations a transfer of paint from one surface to another could impart an object with an identifiable forensic characteristic.

In most circumstances, the criminalist must compare two or more paints to establish their common origin. For example, such a comparison may associate an individual or a vehicle with the crime site. However, the criminalist need not be confined to comparisons alone. Crime laboratories often help identify the color, make, and model of an automobile by examining small quantities of paint recovered at an accident scene. Such requests, normally made in connection with hit-and-run cases, can lead to the apprehension of the responsible vehicle.

Paint spread onto a surface dries into a hard film consisting of pigments and additives suspended in a binder. Pigments impart color and hiding (or opacity) to paint and are usually mixtures of different inorganic and organic compounds added to the paint by the manufacturer to produce specific colors and properties. The binder provides the support medium for the pigments and additives and is a polymeric substance. Paint is thus composed of a binder and pigments, as well as other additives, all dissolved or dispersed in a suitable solvent. After the paint has been applied to a surface, the solvent evaporates, leaving behind a hard polymeric binder and any pigments that were suspended in it.

The Telltale Rabbit

On a cold winter's day … a female was found in the alleyway of an East Harlem tenement. In close proximity to the body was a California florist flower box and a plastic liner. The decedent was identified as a member of a well-known church. She was known to have been selling church literature in the buildings that surround the alley in which the body was discovered. The detectives investigating the case forwarded the flower box, plastic liner, and the decedent's clothing to the forensic science laboratory. On the box and liner were found tan wool fibers, red acrylic fibers, and navy blue wool fibers (all identified by polarized light microscopy). The three types of questioned fibers were compared microscopically with the decedent's clothing. All three were found to be consistent in all respects to the textile fibers composing the decedent's clothing (tan wool overcoat, navy blue wool/polyester blend slacks, and red acrylic sweater), thereby associating the woman with the flower box and liner. In addition, light blue nylon rug fibers and several brown-colored rabbit hairs were found on the box and liner. Similar light blue nylon rug fibers and rabbit hairs, as well as red-colored nylon rug fibers, were found on the decedent's tan wool overcoat. Neither the rabbit hairs nor the nylon rug fibers could be associated with the victim's environment (her clothing or residence).

All of this information was conveyed to the field investigators. Upon further inquiry in the neighborhood, the investigating officers learned the identification of a man who had, the day after the body was discovered, sold a full-length, brown-colored rabbit hair coat to a local man. The investigators obtained the rabbit hair coat from the purchaser. The hair composing the coat was compared microscopically to the questioned rabbit hairs found on the victim's wool coat and the flower box liner. The specimens of questioned rabbit hair were found to be consistent in all physical and microscopic characteristics to the rabbit hair composing the suspect's coat. Armed with this information, the police now had probable cause to obtain a search warrant for the suspect's apartment.

In the suspect's apartment two rugs were found. One was colored light blue and the other was red in color; both rugs were composed of nylon fibers. Samples of each rug were collected by the crime-scene unit and forwarded to the forensic science laboratory for comparison with the questioned rug fibers found on the victim's clothing, the flower box, and plastic liner. Both the questioned and known rug fibers were found to be consistent in all respects. The presence of light blue nylon rug fibers, red nylon rug fibers, and brown-colored rabbit hairs on the flower box, plastic liner, and woman's clothing enabled the author to make associations between the woman, flower box, and liner found in the alleyway with the suspect and his apartment. . . .

Further inquiry about the suspect was made in the neighborhood by the investigating officers. A witness was located who stated he saw the suspect carrying a large California flower box a day or two before the body was discovered.

From the evidence it was theorized that the woman was killed in the suspect's apartment, placed in the flower box, brought up to the roof of the building in which the defendant resided, and thrown off the building into the alley below. On the basis of all of this evidence, the suspect was arrested, indicted, and tried for murder in the second degree. After two trials, at which extensive testimony (three days) about the trace evidence was given by the author, the defendant was found guilty of murder in the second degree and subsequently sentenced to life imprisonment.

Source: Reprinted in part by permission of the American Society of Testing and Materials from N. Petraco, "Trace Evidence—The Invisible Witness," ***Journal of Forensic Sciences,*** **31 (1986): 321. Copyright 1986.**

One of the most common types of paint examined in the crime laboratory is finishes from automobiles. One interesting fact that is helpful in forensic characterization of automotive paint is that manufacturers apply a variety of coatings to the body of an automobile. This adds significant diversity to automobile paint and contributes to the forensic significance of automobile paint comparisons. The automotive finishing system for steel usually consists of at least four organic coatings:

Electrocoat primer. The first layer applied to the steel body of a car is the electrocoat primer. The primer, consisting of epoxy-based resins, is electroplated onto the steel body of the automobile to provide corrosion resistance. The resulting coating is uniform in appearance and thickness. The color of these electrodeposition primers ranges from black to gray.

Primer surfacer. Originally responsible for corrosion control, the surfacer usually follows the electrocoat layer and is applied before the basecoat. Primer surfacers are epoxy-modified polyesters or urethanes. The function of this layer is to completely smooth out and hide any seams or imperfections, because the colorcoat will be applied on this surface. This layer is highly pigmented. Color pigments are used to minimize color contrast between primer and topcoats. For example, a light gray primer may be used under pastel shades of a colored topcoat; a red oxide may be used under a dark-colored topcoat.

Basecoat. The next layer of paint on a car is the basecoat or colorcoat. This layer provides the color and aesthetics of the finish and represents the “eye appeal” of the finished automobile. The integrity of this layer depends on its ability to resist weather, UV radiation, and acid rain. Most commonly, an acrylic-based polymer comprises the binder system of basecoats. Interestingly, the choice of automotive pigments is dictated by toxic and environmental concerns. Thus, the use of lead, chrome, and other heavy-metal pigments has been abandoned in favor of organic-based pigments. There is also a growing trend toward pearl luster or mica pigments. Mica pigments are coated with layers of metal oxide to generate interference colors. Also, the addition of aluminum flakes to automotive paint imparts a metallic look to the paint's finish.

Clearcoat. An unpigmented clearcoat is applied to improve gloss, durability, and appearance. Most clearcoats are acrylic based, but polyurethane clearcoats are increasing in popularity. These topcoats provide outstanding etch resistance and appearance.

The microscope has traditionally been and remains the most important instrument for locating and comparing paint specimens. Considering the thousands of paint colors and shades, it is quite understandable why color, more than any other property, imparts paint with its most distinctive forensic characteristics. Questioned and known specimens are best compared side by side under a stereoscopic microscope for color, surface texture, and color layer sequence. See Figure 8–18.

The importance of layer structure for evaluating the evidential significance of paint evidence cannot be overemphasized. When paint specimens possess colored layers that match in number and sequence of colors, the examiner can begin to relate the paints to a common origin. How many layers must be matched before the criminalist can conclude that the paints come from the same source? There is no one accepted criterion. Much depends on the uniqueness of each layer's color and texture, as well as the frequency with which the particular combination of colors under investigation is observed to occur. Because no books or journals have compiled this type of information, the criminalist is left to his or her own experience and knowledge when making this decision.

Unfortunately, most paint specimens presented to the criminalist do not have a layer structure of sufficient complexity to allow them to be individualized to a single source, nor is it common to have paint chips that can be physically fitted together to prove common origin, as shown in Figure 8–19. However, the diverse chemical composition of modern paints provides additional points of comparison between specimens. Specifically, a thorough comparison of paint must include a chemical analysis of the paint's pigments, its binder composition, or both.

The wide variation in binder formulations in automobile finishes provides particularly significant information. More important, paint manufacturers make automobile finishes in hundreds of varieties; this knowledge is most helpful to the criminalist who is trying to associate a paint chip with one car as distinguished from the thousands of similar models that have been produced in any one year. For instance, there are more than a hundred automobile production plants in the United States. Each can use one paint supplier for a particular color or vary suppliers during a model year. Although a paint supplier must maintain strict quality control over a paint's color, the batch formulation of any paint binder can vary, depending on the availability and cost of basic ingredients.

Pyrolysis gas chromatography has proven to be a particularly invaluable technique for distinguishing most paint formulations. In this process, paint chips as small as 20 micrograms are decomposed by heat into numerous gaseous products and are sent through a gas chromatograph. As shown in Figure 8–20, the polymer chain is decomposed by a heated filament, and the resultant products are swept into and through a gas chromatograph column. The separated decomposition products of the polymer emerge and are recorded. The pattern of this chromatogram or "pyrogram" distinguishes one polymer from another. The result is a pyrogram that is sufficiently detailed to reflect the chemical makeup of the binder. Figure 8–21 illustrates how the patterns produced by paint pyrograms can differentiate acrylic enamel paints removed from two different automobiles. Infrared spectrophotometry is still another analytical technique that provides information about the binder composition of paint.[9] Binders selectively absorb infrared radiation to yield a spectrum that is highly characteristic of a paint specimen.

The elements that constitute the inorganic pigments of paints can be identified by a variety of techniques—emission spectroscopy, neutron activation analysis, X-ray diffraction, and X-ray spectroscopy (pp. 192–194). The emission spectrograph, for instance, can simultaneously detect fifteen to twenty elements in most automobile paints. Some of these elements are relatively common to all paints and have little forensic value; others are less frequently encountered and provide excellent points of comparison between paint specimens (see Figure 6–3).

Once a paint comparison is completed, the task of assessing the significance of the finding begins. How certain can one be that two similar paints came from the same surface? For instance, a casual observer sees countless identically colored automobiles on our roads and streets. If this is the case, what value is a comparison of a paint chip from a hit-and-run scene to paint removed from a suspect car? From previous discussions it should be apparent that far more is involved in paint comparison than matching surface paint colors. Paint layers present beneath a surface layer offer valuable points of comparison. Furthermore, forensic analysts can detect subtle differences in paint binder formulations, as well as major or minor differences in the elemental composition of paint. Obviously, these properties cannot be discerned by the naked eye.

The significance of a paint comparison was convincingly demonstrated from data gathered at the Centre of Forensic Science, Toronto, Canada.[10] Paint chips randomly taken from 260 vehicles located in a local wreck yard were compared by color, layer structure, and, when required, by infrared spectroscopy. All were distinguishable except for one pair. In statistical terms, these results signify that if a crime-scene paint sample and a paint standard/reference sample removed from a suspect car compare by the previously discussed tests, the odds against the crime-scene paint originating from another randomly chosen vehicle are approximately 33,000 to one. Obviously, this type of evidence is bound to forge a strong link between the suspect car and the crime scene.

Crime laboratories are often asked to identify the make and model of a car from a very small amount of paint left behind at a crime scene. Such information is frequently of use in a search for an unknown car involved in a hit-and-run incident. Often, the questioned paint can be identified when its color is compared to color chips representing the various makes and models of manufactured cars. However, in many cases it is not possible to state the exact make or model of the car in question, since any one paint color can be found on more than one car model. For instance, General Motors may use the same paint color for several production years on cars in their Cadillac, Buick, Oldsmobile, Pontiac, and Chevrolet lines.

Color charts for automobile finishes are available from various paint manufacturers and refinishers. Starting with the 1974 model year, the Law Enforcement Standards Laboratory at the National Institute of Standards and Technology collected and disseminated to crime laboratories auto paint color samples from U.S. domestic passenger cars. This collection was distributed by Collaborative Testing Services, McLean, Virginia, through 1991. Since 1975, the Royal Canadian Mounted Police Forensic Laboratories have been systematically gathering color and chemical information on automotive paints. This computerized database, known as PDQ (Paint Data Query), allows an analyst to obtain information on paints related to automobile make, model, and year. The database contains such parameters as automotive paint layer colors, primer colors, and binder composition. A number of U.S. laboratories have access to PDQ.[11]

COLLECTION AND PRESERVATION OF PAINT EVIDENCE

As has already been noted, paint chips are most likely to be found on or near people or objects involved in hit-and-run incidents. The recovery of loose paint chips from a garment or from the road surface must be done with the utmost care to keep the paint chip intact. Paint chips may be picked up with a tweezers or scooped up with a piece of paper. Paper druggist folds and glass or plastic vials make excellent containers for paint. If the paint is smeared on or embedded in garments or objects, the investigator should not attempt to remove it; instead, it is best to package the whole item carefully and send it to the laboratory for examination.

When a transfer of paint occurs in hit-and-run situations, such as to the clothing of a pedestrian victim, uncontaminated standard/reference paint must always be collected from an undamaged area of the vehicle for comparison in the laboratory. It is particularly important that the collected paint be close to the area of the car that was suspected of being in contact with the victim. This is necessary because other portions of the car may have faded or been repainted. Standard/reference samples are always removed so as to include all the paint layers down to the bare metal. This is best accomplished by removing a painted section with a clean scalpel or knife blade. Samples 1/4 inch square are sufficient for laboratory examination. Each paint sample should be separately packaged and marked with the exact location of its recovery. When a cross-transfer of paint occurs between two vehicles, again all of the layers, including the foreign as well as the underlying original paints, must be removed from each vehicle. A standard/reference sample from an adjacent undamaged area of each vehicle must also be taken in such cases. Carefully wipe the blade of any knife or scraping tool used before collecting each sample, to avoid cross-contamination of paints.

Forensics at Work

The CBS Murders

In the early morning hours … atop a lonely roof garage on the west side of Manhattan, three men were found murdered. Each man had been shot once in the back of the head. A light-colored van was seen speeding away from the scene. Hours later, in a secluded alley street on the lower east side of Manhattan, the body of a fully clothed woman was found lying face down by two dog walkers. The woman had been killed in the same manner as the men on the roof garage. The condition of the woman's body, and other evidence, made it apparent that she had been shot at the garage, and then transported to the alley.

An eyewitness to the incident stated that he saw a man shoot a woman and place her in a light-colored van. The gunman then chased down the three men who were coming to the woman's aid, and shot each one of them. Days later, the prime suspect to the killings was arrested in Kentucky, in a black-colored van.

Numerous items of evidence (over 100) were collected from the van, and forwarded to the New York City police laboratory for examination. Among the items of evidence forwarded were three sets of vacuum sweepings from the van's interior.

An autopsy of the woman produced several items of trace evidence that were removed from the victim and forwarded to the author for microscopic examination. The woman's clothing was also received by the author for trace analysis.

A prime question that arose during the investigation was: could the woman's body, which had been placed in a light-colored van at the garage, and later left in an alley on the lower east side, be associated with the black van recovered over 1000 km (600 miles) away from the scene? Microscopic analysis and comparison of the trace evidential materials found on the victim and inside the van made this association possible.

Listed in Table 1 are all the items of similar trace materials that both the victim and the van had in common.

Microscopic comparisons of the questioned human head hair present on the victim’s clothing were made with known samples. Ten of the brown-colored and gray-colored Caucasian head hairs from the victim’s blazer were consistent in microscopic characteristics to the defendant’s known head hair sample. One chemically treated head hair found on the victim was consistent in microscopic characteristics to the known head hair sample obtained from the defendant’s wife. One forcibly removed, brown-colored, Caucasian head hair that was found on the rear door of the van’s interior by the Kentucky state police was found to be consistent in all characteristics with the decedent’s known head hair sample.

Microscopic comparisons of the white- and brown/white-colored dog hair from the victim’s clothing, and the van’s interior, were made with known samples of dog hair obtained from a dog owned by the defendant’s nephew, the van’s previous owner. The questioned dog hairs were found to be consistent with the hair from the nephew’s dog.

The white seed that was recovered from the victim’s mouth by the medical examiner, and the white seed that was found in the van’s sweepings by the author, were forwarded to an internationally known botanist for identification and comparison. During the trial, the botanist testified that the two seeds were identical in all respects, and that although he could not identify the seed, both were either from the same species of plant, if not the same plant, probably a rare wild flower.

Sixteen gray metallic/black-colored paint chips from the victim and her clothing were compared to the gray metallic/black-colored paint removed from the van. Samples from the questioned and known sources were examined and compared by microscopic, chemical, and instrumental means. All of the paint specimens from the van and from the victim were found to be similar in all respects.

The remaining items of trace evidence from the victim and the van were examined and compared microscopically, and where necessary, by chemical and instrumental methods. Each of the remaining types of trace evidence from the victim was found to be similar to its counterpart from the van.

Blue- and black-colored flakes of acrylic paint were found in the van's sweepings, and on the suspect's sneakers. No blue- or black-colored paint flakes were found on the victim and her clothing. During a crime scene search of the defendant's residence in New Jersey, a large quantity of blue- and black-colored acrylic paint was found in the garage. It was apparent from the evidence present in the defendant's garage that a large rectangular shaped object had recently been painted with blue- and black-colored paint. The blue and black paint flakes from all the sources and the known blue (undercoat) and black (topcoat) paint from the van were compared by microscopic, chemical, and instrumental means. All the samples of paint were found to be consistent in every respect.

Table 1 Items of Similar Trace Evidence That Were Recovered from Both the Victim and the Van's Interior

	Source	
Trace Evidence	Victim	Van
White seed	mouth	sweepings
Paint chips	hair and wool blazer	sweepings and floor
gray metallic/black		
Sawdust	hair, blazer, and sheet	sweepings and misc. items
Glass fragments	wool blazer and sheet	sweepings and misc. items
clear		
amber		
green		
Cellophane	wool blazer	floor
Urethane foam	wool blazer	sweepings, misc. items, and foam mattress
foam mattress		
Blue olefin	skirt	floor
plastic		
Dog hair	wool blazer	sweepings and misc. items
brown/white		
white		
Human hair	wool blazer	hairbrush, sweepings, and

brown	misc. items
gray	

At the trial, extensive testimony concerning the collection, examination, identification, and comparison of the trace evidence from the victim and the van was given by the author, over a two-day period. When questioned about the source of the trace evidence found on the victim and her clothing, the author stated unequivocally that the trace evidence on the victim was from the defendant's van. On the basis of this evidence and other circumstantial evidence, the defendant was found guilty of all charges and sentenced to 100 years in prison.

This case takes its title from the fact that the three male victims were employees of CBS-TV.

Source: Reprinted by permission of the American Society of Testing and Materials from N. Petraco, "Trace Evidence—The Invisible Witness," ***Journal of Forensic Sciences,*** **31 (1986): 321. Copyright 1986.**

Tools used to enter buildings or safes often contain traces of paints as well as other substances such as wood and safe insulation. Care must be taken not to lose this type of trace evidence. The scene investigator should not try to remove the paint; instead, he or she should package the tool for laboratory examination. Standard/reference paint should be collected from all surfaces suspected of having been in contact with the tool. Again, all layers of paint must be included in the sample.

When the tool has left its impression on a surface, standard/reference paint is collected from an uncontaminated area adjacent to the impression. No attempt should be made to collect the paint from the impression itself. If this is done, the impression may be permanently altered and its evidential value lost.

Chapter Summary

Hair is an appendage of the skin that grows out of an organ known as the hair follicle. The length of a hair extends from its root or bulb embedded in the follicle, continues into a shaft, and terminates at a tip end. The shaft, which is composed of three layers—the cuticle, cortex, and medulla—is subjected to the most intense examination by the forensic scientist. The comparison microscope is an indispensable tool for comparing these morphological characteristics. When comparing strands of hair, the criminalist is particularly interested in matching the color, length, and diameter. A careful microscopic examination of hair reveals morphological features that can distinguish human hair from the hair of animals. Scale structure, medullary index, and medullary shape are particularly important in hair identification. Other important features for comparing hair are the presence or absence of a medulla and the distribution, shape, and color intensity of the pigment granules present in the cortex. However, microscopic hair examinations tend to be subjective and highly dependent on the skills and integrity of the analyst. Recent major breakthroughs in DNA profiling have extended this technology to the individualization of human hair. The probability of detecting DNA in hair roots is more likely for hair being examined in its anagen or early growth phase as opposed to its catagen or telogen phases. Often, when hair is forcibly removed a follicular tag, a translucent piece of tissue surrounding the hair's shaft near the root, may be present. This has proven to be a rich source of DNA associated with hair. Also, mitochondrial DNA can be extracted from the hair shaft. As a rule, all positive microscopic hair comparisons must be confirmed by DNA analysis.

The quality of fiber evidence depends on the ability of the criminalist to identify the origin of the fiber or at least to narrow the possibilities to a limited number of sources. Microscopic comparisons between questioned and standard/reference fibers are initially undertaken for color and diameter characteristics. Other morphological features that could be important in comparing fibers are striations on the surface of the fiber, the presence of delustering particles, and the cross-sectional shape of the fiber. The visible-light microspectrophotometer provides a convenient way to compare the colors of fibers through spectral patterns. Infrared spectrophotometry is a rapid and reliable tool for identifying the generic class of fibers, as is the polarizing microscope.

Paint spread onto a surface dries into a hard film consisting of pigments and additives suspended in the binder. One of the most common types of paint examined in the crime laboratory is finishes from automobiles. Automobile manufacturers normally apply a variety of coatings to the body of an automobile. Hence, the wide diversity of automotive paint contributes to the forensic significance of an automobile paint comparison. Questioned and known specimens are best compared side by side under a stereoscopic microscope for color, surface texture, and color layer sequence. Pyrolysis gas chromatography and infrared spectrophotometry are invaluable techniques for distinguishing most paint binder formulations, adding further significance to a forensic paint comparison.

Review Questions

1. Hair is an appendage of the skin, growing out of an organ known as the ___________.
2. The three layers of the hair shaft are the ___________, the ___________, and the ___________.
3. True or False: The scales of most animal hairs can be described as looking like shingles on a

roof. ___________

4. The ___________ contains the pigment granules that impart color to hair.

5. The central canal running through many hairs is known as the ___________.

6. The diameter of the medulla relative to the diameter of the hair shaft is the ___________.

7. Human hair generally has a medullary index of less than ___________; the hair of most animals has an index of ___________ or greater.

8. Human head hairs generally exhibit (continuous, absent) medullae.

9. If a medulla exhibits a patterned shape, the hair is (human, animal) in origin.

10. The three stages of hair growth are the ___________, ___________, and ___________ phases.

11. A single hair (can, cannot) be individualized to one person by microscopic examination.

12. In making hair comparisons, it is best to view the hairs side by side under a(n) ___________ microscope.

13. ___________ hairs are short and curly, with wide variation in shaft diameter.

14. It (is, is not) possible to determine when hair was last bleached or dyed.

15. True or False: The age and sex of the individual from whom a hair sample has been taken can be determined through an examination of the hair's morphological features. ___________

16. Hair forcibly removed from the body (always, often) has follicular tissue adhering to its root.

17. Microscopic hair comparisons must be regarded by police and courts as presumptive in nature, and all positive microscopical hair comparisons must be confirmed by ___________

typing.

18. True or False: Currently, DNA typing can individualize a single hair. ___________

19. A(n) ___________ hair root is a likely candidate for DNA typing.

20. A minimum collection of ___________ full-length hairs normally ensures a representative sampling of head hair.

21. A minimum collection of ___________ full-length pubic hairs is recommended to cover the range of characteristics present in this region of the body.

22. ___________ fibers are derived totally from animal or plant sources.

23. The most prevalent natural plant fiber is ___________.

24. True or False: Regenerated fibers, such as rayon and acetate, are manufactured by chemically treating cellulose and passing it through a spinneret. ___________

25. Fibers manufactured solely from synthetic chemicals are classified as ___________.

26. True or False: Polyester was the first synthetic fiber. ___________

27. ___________ are composed of a large number of atoms arranged in repeating units.

28. The basic unit of the polymer is called the ___________.

29. ___________ are polymers composed of thousands of amino acids linked in a highly organized arrangement and sequence.

30. True or False: A first step in the forensic examination of fibers is to compare color and diameter. ___________

31. The microspectrophotometer employing ___________ light is a convenient way for analysts

to compare the colors of fibers through spectral patterns.

32. The dye components removed from fibers can be separated and compared by ____________ chromatography.

33. Synthetic fibers possess the physical property of ____________ because they are crystalline.

34. The microspectrophotometer employing ____________ light provides a rapid and reliable method for identifying the generic class of a single fiber.

35. Normally, fibers possess (individual, class) characteristics.

36. The two most important components of dried paint from the criminalist's point of view are the ____________ and the ____________.

37. The most important physical property of paint in a forensic comparison is ____________.

38. Paints can be individualized to a single source only when they have a sufficiently detailed ____________.

39. The ____________ layer provides corrosion resistance for the automobile.

40. "Eye appeal" of the automobile comes from the ____________ layer.

41. Pyrolysis gas chromatography is a particularly valuable technique for characterizing paint's (binder, pigments).

42. Emission spectroscopy can be used to identify the (inorganic, organic) components of paint's pigments.

43. True or False: Paint samples removed for examination must always include all of the paint layers. ____________

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Cuticle

The scale structure covering the exterior of the hair.

Cortex

The main body of the hair shaft.

Medulla

A cellular column running through the center of the hair.

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Anagen Phase

The initial growth phase during which the hair follicle actively produces hair.

Catagen Phase

A transition stage between the anagen and telogen phases of hair growth.

Telogen Phase

The final growth phase in which hair naturally falls out of the skin.

Follicular Tag

A translucent piece of tissue surrounding the hair's shaft near the root. It contains the richest source of DNA associated with hair.

Nuclear DNA

DNA present within the nucleus of a cell. This form of DNA is inherited from both parents.

Mitochondrial DNA

DNA present in small structures (mitochondria) outside the nucleus of a cell. Mitochondria supply energy to the cell. This form of DNA is inherited maternally (from the mother).

Natural Fibers

Fibers derived entirely from animal or plant sources.

Manufactured Fibers

Fibers derived from either natural or synthetic polymers; the fibers are typically made by forcing the polymeric material through the holes of a spinneret.

Polymer

A substance composed of a large number of atoms. These atoms are usually arranged in repeating units or monomers.

Molecule

Two or more atoms held together by chemical bonds.

Macromolecule

A molecule with a high molecular mass.

Monomer

The basic unit of structure from which a polymer is constructed.

Battery Park at night. *Courtesy of Hans Deumling, Getty Images Inc. Image Bank*

Bill Cosby and his son Ennis Cosby. *Courtesy of George Kalinsky, People/In Style Syndication*

Jeffrey McDonald in 1995 at Sheridan, Oregon, Federal Correctional Institution. *Courtesy AP Wide World Photos*

Figure 8–1 Cross section of skin showing hair growing out of a tubelike structure called the follicle.

Figure 8–2 Scale patterns of various types of hair. (a) Human head hair (600×), (b) dog (1250×), (c) deer (120×), (d) rabbit (300×), (e) cat (2000×), and (f) horse (450×). *Courtesy International Scientific Instruments, Mountain View, Calif., and New Jersey State Police*

Figure 8–3 Medulla patterns.

Figure 8–4 Medulla patterns for various types of hair. (a) Human head hair (400×), (b) dog (400×), (c) deer (500×), (d) rabbit (450×), (e) cat (400×), and (f) mouse (500×).

Figure 8–5 Information on rabbit hair contained within the *Forensic Animal Hair Atlas.* *Courtesy RJ Lee Group, Inc. Monroeville, Pa.*

Figure 8–6 Hair roots in the (a) anagen phase, (b) catagen phase, and (c) telogen phase (100×). *Courtesy Charles A. Linch*

Figure 8–7 Forcibly removed head hair, with follicular tissue attached. *Courtesy New*

Jersey State Police

Figure 8–8 Photomicrograph of cotton fiber (450×).

Figure 8–9 The chain-link model of a segment of a polymer molecule. The actual molecule may contain as many as several million monomer units or links.

Figure 8–10 Starch and cellulose are natural carbohydrate polymers consisting of a large number of repeating units or monomers.

Figure 8–11 A piece of fabric found on a suspect hit-and-run vehicle inserted into the torn trousers of the victim. *Courtesy New Jersey State Police*

Figure 8–12 Photomicrographs of synthetic fibers: (a) cellulose triacetate (450×) and (b) olefin fiber embedded with titanium dioxide particles (450×).

Figure 8–13 A scanning electron photomicrograph of the cross-section of a nylon fiber removed from a sheet used to transport the body of a murder victim. The fiber, associated with a carpet in Wayne Williams's home, was manufactured in 1971 in relatively small quantities. *Courtesy Federal Bureau of Investigation, Washington, D.C.*

Figure 8–14 In the production of manufactured fibers, the bulk polymer is forced through small holes to form a filament in which all the polymers are aligned in the same direction.

Figure 8–15 A photomicrograph of nylon fibers displaying interference colors when observed between the crossed polars of a polarizing microscope (50×). *Courtesy William Randle, Missouri State Highway Patrol Crime Laboratory, Jefferson City, Mo.*

Figure 8–16 A fiber comparison made with an infrared spectrophotometer. The infrared spectrum of a fiber from Mrs. MacDonald's fall compares to a fiber recovered from a

hairbrush in the MacDonald home. These fibers were identified as modacrylics, the most common type of synthetic fiber used in the manufacture of human hair goods. *Courtesy S. A. Michael Malone, FBI Laboratory, Washington, D.C.*

Figure 8–17 The visible-light spectrum for the woolen fiber recovered from Mrs. MacDonald's body is clearly different from that of the fiber recovered from the club used to assault her. *Courtesy S. A. Michael Malone, FBI Laboratory, Washington, D.C.*

Figure 8–18 A stereoscopic microscope comparison of two automotive paints. The questioned paint on the left has a layer structure consistent with the contol paint on the right. *Courtesy Leica Microsystems, Inc., Buffalo, N.Y., www.leica-microsystems.com*

Figure 8–19 Paint chip 1 was recovered from the scene of a hit-and-run. Paint chip 2 was obtained from the suspect vehicle. *Courtesy New Jersey State Police*

Figure 8–20 Schematic diagram of pyrolysis gas chromatography.

Figure 8–21 Paint pyrograms of acrylic enamel paints. (a) Paint from a Ford model and (b) paint from a Chrysler model. *Courtesy Varian Inc., Palo Alto, Calif.*

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