The Microscope and Forensic Identification of Hair, Fibers, and Paint

OBJECTIVES
In this chapter you should gain an understanding of:
- The parts of a compound microscope and how it works
- The use of a comparison microscope to compare two objects
- The large working distance and the larger depth of field afforded by the stereomicroscope
- Differentiation of amorphous and crystalline materials by use of a polarized light microscope
- The structure of hair and the microscopy techniques used to identify human hair
- The characteristics of natural fibers, human-made fibers, and the fabrics made with both types of fibers
- The composition of different types of paints and how paint samples are characterized
- The use of microspectrophotometers and scanning electron microscopes in the forensic lab

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Introduction

During the search of a crime scene, investigators will inevitably encounter many types of physical evidence. Although the search may initially focus on large objects that may prove to be evidence, trace evidence must not be overlooked. Trace evidence is a generic term used to describe small, often microscopic, objects that are readily transferred between people and places. The range of objects falling into the category of trace evidence is enormous and can include hair, fibers, glass, soil, feathers, pollen, dust, and paint.

In 1932, with a borrowed microscope and a few other pieces of basic equipment, the Federal Bureau of Investigation (FBI) established its technical laboratory in Washington, DC. The microscopic comparison of fibers and hairs was among the first examinations performed by this laboratory. Since then, forensic laboratories (including the FBI laboratory) have greatly expanded their capacity to handle trace evidence thanks to the development of modern analytical instruments. Forensic scientists often are confronted with the need to analyze many different types of materials obtained during criminal investigations. The identification or comparison of minuscule traces of a wide range of materials is a common occurrence in a modern crime lab. The earliest detectives—including the fictional Sherlock Holmes—used magnifying glasses to carefully examine evidence in the field and microscopes to study objects brought to their laboratories.

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Magnifying Small Details

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Refraction

A magnifying glass is a lens that is thicker in the middle than at the edge. It makes objects appear larger than they are by refracting (bending) light rays as they repeatedly pass through the air and back through the lens. When light passes at an angle through the interface between two transparent media (e.g., air and glass) that have different densities, an abrupt change in direction—that is, refraction—of the beam is observed as a consequence of
the difference in the velocity of the light in the two media.

The phenomenon of refraction is commonly observed with an object that is immersed in a glass of water. For example, when a glass of water contains a straw (Figure 4-1), refraction makes it appear that the straw is broken at the surface of the water. As the rays of light leave the water and enter the air, their velocity increases, causing them to be refracted. How much light bends (and thus the focal length) depends on the change in the refractive index ($\eta$) as the light enters and leaves the magnifying glass. The refractive index is a ratio of the velocity of light in a vacuum to its velocity in any other medium:

$$\text{Refractive Index} = \eta = \frac{\text{Velocity of light in a vacuum}}{\text{Velocity of light in a denser medium}}$$

The refractive index is 1.0 for air and 1.33 for water at 25°C. A typical glass has a refractive index of about 1.4 (a difference of 0.4 for light passing from air to glass).

To use a magnifying glass to examine an object, you look through the lens (Figure 4-2). The magnified image is called the virtual image. As the lens is moved closer to the eye, the virtual image increases in size by 5 to 10 times. Higher magnification requires two lenses that are at fixed distances from each other in a hollow tube, a setup known as a compound microscope.
Types of Microscopes

A microscope has at least two lenses: an objective lens and an ocular lens or eyepiece (FIGURE 4-3). The objective lens, which is the lower lens in the hollow tube, produces a “real” image—a magnified and inverted version of the object being examined. The real image is then viewed through the ocular lens (the smaller lens at the other end of the hollow tube in the eyepiece), producing a virtual image in the brain of the viewer. The virtual image is a magnified image produced in the viewer’s mind of the real image; it has the same orientation as the real image, but its magnification exceeds the magnification of the real image by the ocular lens (FIGURE 4-4). The magnification power of a microscope is greater than that of a magnifying glass because the former device has two lenses. The magnifying power of a microscope is determined by multiplying the power of the objective lens by the power of the ocular lens. A compound microscope can magnify objects up to 1,500 times.

A compound microscope—even one with perfect lenses using a tungsten light bulb to illuminate the object—has limitations, however. In particular, its ability to distinguish extremely small objects depends on the wavelength of the light used to illuminate the object. Wavelength is measured in units of micrometers (µm; also known as microns), where 1 µm is equal to 0.001 mm. The wavelength of white light (which is typically used to illuminate

![Diagram of a compound microscope](image)
objects in compound microscopes) is 0.55 µm, and a compound microscope can distinguish objects that are roughly one-half of that size (i.e., 0.275 µm). Smaller objects—if they are seen at all—may appear as a blur. To compensate for this shortcoming, some compound microscopes use blue light (which has a shorter wavelength than white light) to illuminate the object of interest.

Five types of microscopes are typically used for forensic examinations:

1. Compound microscope
2. Comparison microscope
3. Stereoscopic microscope
4. Polarizing microscope
5. Microspectrophotometer

Each of these microscopes has a specific function that makes it very effective for obtaining certain types of information. The scanning electron microscope (SEM), which can provide magnification of more than 100,000 times, also is occasionally used for forensic examination of evidence.

**Compound Microscopes**

The mechanical system of a compound microscope has six important parts:

- **Base:** The stand on which the microscope sits.
- **Arm:** A metal piece that supports the tube body of the microscope. It is also used as a handle to pick up the microscope.
- **Body tube:** A hollow tube that holds the objective lens at the lower end and the eyepiece lens at the upper end. Light passes from the objective lens through the body tube to the eyepiece, where it is observed by the eye.
- **Stage:** The platform that supports the specimen. The specimen is placed on a glass slide that is clipped into place on the stage. The x- and y-axis stage control knobs are used to move the slide back and forth under the objective lens.
- **Coarse adjustment:** A knob that focuses the microscope on the specimen by raising and lowering the body tube of the microscope.
- **Fine adjustment:** A knob that adjusts the height of the body tube in smaller increments so the specimen can be brought into fine focus.

The optical system has four fundamental parts: the illuminator, the condenser, the eyepiece, and the objective.

There are several types of electric lighting (illuminators) for microscopes. Tungsten is the least expensive electric illumination; it is also hotter and less bright than the other kinds of illuminators. Fluorescent provides cooler and brighter light than tungsten. This is beneficial when you are viewing slides for long periods of time or when you are observing live specimens, such as protozoa. Halogen provides the very brightest illumination.

In the condenser, the light rays from the illuminator are focused through a lens in the center of the stage and onto the specimen. The condenser has an iris diaphragm that can be opened or closed to regulate the amount of light passing into the condenser.

The eyepiece is the part of the microscope that you look through. The objective is the second lens of the microscope. Compound microscopes have a "nosepiece" with a rotating objective turret, which allows you to change the objective lens and amplification power. The viewed image is magnified by both the objective and the eyepiece lens. Thus the total magnification is equal to the product of the magnifying power of the two lenses. For example, if the eyepiece lens has a magnification of 10× and the objective lens has a magnification of 40×, the total magnification will be the product of the two lenses’ magnifications: 10 × 40 = 400×. Forensic examiners typically use a 10× eyepiece with nosepiece that contains a 4×, 10×, 25×, or 40× objective lens, providing magnification of 40×, 100×, 250×, or 400×, respectively.

Each objective lens is stamped with a numerical aperture (NA). As the NA doubles, the lens is able to resolve details that are half as distant from each other (twice as close to each other). The NA is effectively an index of the ability of the objective lens to resolve fine detail. The higher the NA (up to about 1000× the NA), the more detail the microscope can discern. Anything beyond 1000×, however, is considered “empty magnification” that doesn’t add anything to the clarity of the image.

The forensic examiner must balance the microscope’s magnifying power with both the field of view and the depth of focus. The field of view is the area that the forensic examiner sees when looking through the eyepiece. As the magnifying power increases, the field of view shrinks. The examiner should start with a low magnification. After taking in this (relatively) “big picture,” the examiner should switch to a higher-power objective lens to scrutinize particular parts of the specimen more
A comparison microscope from a suspect, the forensic examiner often uses a comparison microscope to compare two specimens, such as evidence taken during an investigation. The microscope is used to examine the specimens under different magnifications, with the examinee viewing the images through a single eyepiece connected by an optical bridge to two compound microscopes placed side by side. The examiner should adjust the depth of focus (the thickness of the region in focus) to ensure the clarity of the image as necessary. As with the field of view, when the magnifying power increases, the depth of focus decreases. Thus both field of view and depth of focus decrease as magnifying power increases. As a consequence, high powers of magnification sacrifice detail within the region under examination and in focus. For this reason, a trade-off is necessary when using a compound microscope.

**Comparison Microscopes**

To compare two specimens, such as evidence taken during a crime scene with a reference sample taken from a suspect, the forensic examiner often uses a comparison microscope. A comparison microscope is essentially two compound microscopes that are connected by an optical bridge—that is, a series of mirrors and lenses that link the two microscopes’ objective lenses. The comparison microscope has a single eyepiece through which the forensic examiner views the images from both compound microscopes placed side by side.

Comparison microscopes that compare semi-transparent hairs and fibers are lighted from below the stage. Other comparison microscopes are designed to compare bullets, bullet cartridges, and other opaque objects (Figure 4-6). Because these specimens do not transmit light, illumination from below the stage is not possible; instead, optical microscopes for viewing these items are equipped with a vertical or reflected illumination system (Figure 4-6).

An experienced examiner will mount the evidence on the same side for all comparisons. For

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Serial Murderer Everett Bell Identified by “Nubs”

On August 22, 1995, the body of 8-year-old Sandra was discovered by police in a wooded area near her church in southern Michigan. The child had been brutally assaulted before she died of strangulation. Her bicycle was found near her partially hidden body. Police cordoned off the wooded area and the adjacent church parking lot to perform a detailed search of the area. Fingerprints were taken from the victim’s body and from the bicycle.

The coroner discovered material under Sandra’s fingernails, on her abdomen, and on her hands. Vaginal and rectal swabs and analysis of her clothing revealed no biological material other than her own. Furthermore, the bicycle provided no incriminating fingerprint evidence. However, hair and fibers were found on the victim.

The police launched a major investigation, canvassing the neighborhood around the church. They found that Everett Bell, a local resident and an employee of a Hardee’s® restaurant, was seen in the area around nighttime riding his bicycle. Bell’s employer revealed that Bell had been sent home early from work that day. The Hardee’s manager gave police Bell’s work pants, shirt, and cap.

The FBI laboratories found blue cotton fibers under Sandra’s fingernails. When they were examined under a microscope, it was clear that these fibers matched the blue cotton fibers from the suspect’s shirt. Blue and green fibers found on Sandra’s clothes also matched those from the shirt. In addition, a dark blue-gray polyester fiber matching the fibers of the suspect’s pants matched fibers found on the rectal swab. Of particular interest, the sample from the victim contained “nubs”; the end of the fiber was melted during manufacture into bulbs that are called nubs. The nubs that were lifted with tape from Bell’s shirt matched the nubs lifted from the surface of the victim’s shirt.

Hardee’s employees were given particular shirts manufactured by WestPoint Stevens Alamac Knits. Bell’s shirt was a short-sleeve polo shirt that Hardee’s had recently replaced with a striped shirt. Therefore, few of the solid shirts were still being worn by employees. Tape applied to the surface of Bell’s shirt removed a significant number of the nubs that proved to be identical to nubs found on the victim’s clothes, establishing physical contact between the victim and the suspect.

Bell later confessed to Sandra’s murder as well as to five other rapes and at least nine other murders.
The stereoscopic microscope has several features that make it particularly easy to use. This device has two eyepieces, which make it more comfortable for the viewer. It also produces a three-dimensional image that is presented in a right-side-up, frontward orientation (unlike the upside-down, backward orientation of the image produced by a compound microscope). Its large working distance, which is the distance between the objective lens and the specimen, means that the forensic examiner can use this device to view large items. Finally, the stereoscopic microscope can be lighted either from below, to illuminate semitransparent objects, or vertically from above, to illuminate opaque objects.

Polarizing Microscopes

The compound microscope has been used to determine the types of minerals present in geological samples for more than 100 years. Minerals whose atoms are arranged in random order are classified as amorphous materials. Minerals whose atoms are arranged in a distinct order are classified as crystalline materials.
By observing how light interacts with thin sections of the minerals, the forensic examiner can classify minerals—and classification is the first step in forensic identification. The classification techniques described here rely on the fact that light traveling through the minerals in different directions will behave differently, but predictably. These differences can be detected with a polarizing microscope. To examine and classify a mineral, the sample must be dry and thin enough to be placed on a microscope slide under a cover slip. If the material is too thick, a portion can be shaved off with a scalpel.

Isotropic materials—such as gases, liquids, and cubic crystals—have the same optical properties when observed from any direction. Because isotropic materials have only one refractive index, they appear the same when light passes through them from different directions. By contrast, anisotropic (or birefringent) materials—such as quartz, calcite, and asbestos—are crystalline. In anisotropic minerals, the arrangement of atoms is not the same in all directions. Thus, when an anisotropic material is examined, the arrangement of atoms in the substance appears to change as the direction of observation changes. Photons of light passing through asbestos fibers from different directions will encounter different electrical neighborhoods, which in turn will affect the path and time of travel of the light beam in different ways.

Besides providing information on the shape, color, and size of different minerals, polarized light microscopy can distinguish between isotropic and anisotropic materials. This technique is used to identify the presence of certain minerals and their anisotropic properties.

**Plane-Polarized Light**

According to the wave theory of light, light waves oscillate (vibrate) at right angles to the direction in which the light is traveling through space. The oscillations occur in all planes that are perpendicular to the path traveled by the light. These oscillations may be produced by a light bulb and viewed by an observer looking directly into the beam (**FIGURE 4-8A**). If the beam of light is passed through a sheet of Polaroid® material, the light that is transmitted through the Polaroid sheet oscillates in one plane only. Such light is called plane-polarized light. If a second Polaroid lens is inserted before your eye, that lens must be aligned in a parallel plane so that plane-polarized light is passed. If the second Polaroid lens is rotated, less plane-polarized light is transmitted through the second lens, and, at a rotation of 90°, no light is transmitted (**FIGURE 4-8B**).

**Polarized Light Microscopy**

A polarizing microscope includes two polarizing filters: the polarizer lens, which is fixed in place below the specimen, and the analyzer lens, which is located above the specimen (**FIGURE 4-9**). The sample

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**FIGURE 4-8** (A) Light from a light bulb is polarized in one plane as it passes through the first polarizer, and it will reach the eye only if the second polarizer is in the same position. (B) When the second polarizer is rotated, it cuts off the light and stops its transmission.

**FIGURE 4-9** A polarizing microscope includes two polarizing filters: the polarizer lens and the analyzer lens.
stage, which is placed between the two filters, can be easily rotated.

Besides information about the gross fiber morphology and color of the sample, analysis of plane-polarized light can determine whether the sample exhibits pleochroism. Pleochroism is the property that causes a substance to show different absorption colors when it is exposed to polarized light coming from different directions. The observed colors change with the orientation of the crystal and can be seen only with plane-polarized light. As the sample stage is rotated, these substances change color.

Polarized light microscopy also is used to identify human-made fibers and paint. If a fiber is collected from a victim and placed on a microscope slide, it may be difficult to tell one type of fiber from another. If it is a glass fiber, however, its color will not change as the microscope stage is rotated. That is, because glass fibers are isotropic, they are unaffected by rotation under polarized light. Other human-made fibers are anisotropic and change colors as the stage is rotated. It is an easy matter to compare the pleochroism of a fiber found at a crime scene to a fiber taken from the suspect, thereby proving (or disproving) a link between the suspect and the scene.

**Microspectrophotometers**

The microscope allows the analyst to look over the general features of the object being investigated at low power. Once a general survey of the object is completed, the analyst can then hone in on small details at higher magnification. When an interesting characteristic is identified, its morphology can be compared with that of a reference material and its optical properties identified via a polarizing microscope.

In the past 2 decades, microscopes have also been attached to spectrophotometers. In a spectrophotometer, a lamp emits radiation—either ultraviolet (UV) or infrared (IR)—that passes through a sample. The sample absorbs some of this light, and the rest passes to the spectrophotometer. There, the light from the sample is separated according to its wavelength (the visible range light looks like a rainbow), and the spectrum formed is observed with a detector. Such analysis (spectroscopy) is used to elucidate the composition of unknown materials in many different fields. Spectroscopy can also be used to match compounds, measure concentrations, and determine physical structures.

A microspectrophotometer combines the capabilities of a spectrophotometer with those of a microscope. The microscope magnifies the image of the specimen for the spectrometer and allows the forensic examiner to analyze extremely small samples or a small region of a sample. The spectrophotometer then measures the intensity of light at each wavelength. Microspectrophotometers (also called microspectrometers, microscope spectrophotometers, and microphotometers) are extremely useful. In addition to measuring the light absorbed or transmitted by the sample, a microspectrophotometer can measure the intensity of light reflected...
from a sample, the intensity of light emitted when a sample fluoresces, or the intensity of polarized light after it has interacted with a sample.

Microspectrophotometers have numerous advantages over conventional spectrometers. For instance, they can easily take spectra of samples as small as 2.5 μm wide while viewing the sample directly. The latter feature allows for more precise measurements of the sample while eliminating interference from the surrounding material. Also, because many human-made substances—even colorless ones—absorb more in the UV region than in the visible light and IR regions, microspectrophotometers are very useful for analysis of synthetic fibers (discussed later in this chapter).

To see how this works, suppose that comparison of two fibers—one found at a crime scene and the other taken from a suspect—using a polarized light microscope indicates that the appearance and morphology of the two fibers are identical. When the fibers are analyzed in an IR microspectrophotometer, each produces an IR spectrum. At first glance, the two spectra appear very similar and indicate that both fibers are nylon. With a careful comparison of the two spectra, however, small differences become apparent. When these IR spectra are compared with the IR spectra of known reference fibers, one fiber is found to be nylon-6 and the other nylon-6,6. Although the word nylon is used to describe an entire class of fibers, there are actually five common nylons sold commercially in the United States: nylon-6,6; nylon-6,12; nylon-4,6; nylon-6; and nylon-12. All nylons share some physical properties (such as solubility in solvent), but some subgroups differ in appearance and absorption of dye due to differences in molecular structure. As this example shows, the microspectrophotometer has the ability to differentiate fibers that fall into the same generic class (nylon) but are structurally different (nylon-6 versus nylon-6,6).

**Scanning Electron Microscopes**

When the evidence available is very small and more magnification is needed, an SEM is often used as part of the forensic analysis (FIGURE 4-10A). An SEM can magnify an image 100,000 times and has a depth of focus that is more than 300 times that available with an optical microscope.

An SEM operates on the same basic principle as the polarizing microscope but uses electrons rather than light to identify properties of the object. Electrons, which are produced in the electron source found in the SEM, travel through a specimen in a way that is similar to a beam of light passing through a sample in an optical microscope. Instead of glass lenses directing light wavelengths through a specimen, however, the electron microscope’s electromagnetic lenses direct electrons through a specimen (FIGURE 4-10B). Because the wavelength of electrons is much smaller than the wavelength of light, the resolution achieved by the SEM is many times greater than the resolution possible with the light microscope. Thus the SEM can reveal the finest details of structure and the complex surface of synthetic fibers (FIGURE 4-11).

Some of the electrons striking the surface of the sample are immediately reflected back toward the electron source; these are called backscattered electrons. An electron detector can be placed above the sample to scan the surface and produce an image from the backscattered electrons. Other electrons that strike the surface of the sample penetrate it; they can be measured by an electron detector that is placed beneath the sample. In addition, some of the electrons striking the surface cause X-rays to be emitted. By measuring the energy of the emitted X-ray, the elemental composition of the surface can be determined through a technique called energy dispersive X-ray spectroscopy (EDX). If a fiber is coated with a dulling agent, such as titanium dioxide, the EDX will detect its presence.

**Forensic Applications of Microscopy: Hair**

Hair is frequently the subject of forensic examination. This analysis has some limitations, however—namely, forensic examination of an individual hair will not result in definitive identification of the person from whom the hair was shed, unless the hair has a tag attached that can be analyzed for DNA. At best, a hair’s morphology (when compared with a reference hair) may be consistent with the reference hair; it cannot be said definitively to be a perfect match. Hair does not possess a sufficient number of unique, individual characteristics to be positively associated with a particular person to the exclusion of all others. Although hair samples are commonly used to exclude a suspect, they can be considered only as contributing evidence—to connect the suspect to the crime scene, for example, or to connect multiple crime scene areas to each other through transfer of evidence.
FIGURE 4-10 (A) A scanning electron microscope (SEM). (B) A schematic diagram of an SEM.
The cuticle consists of scales of hardened, flattened, keratinized tissue that overlie the cortex. These scales have a shape and pattern that are unique to the animal species from which they came—for example, the cuticle of a cat hair differs from the cuticle of a human hair (FIGURE 4-13). In addition, the acidity of modern shampoos can be adjusted to make these scales stand up or lie down. When the scales lie flat, hair reflects light and has an attractive luster—think of the attractive model’s hair in a shampoo commercial.

One way to observe the scale pattern is to make a cast of the surface. To do so, the forensic examiner presses the hair into a soft material, such as clear nail polish or soft vinyl. Later, when the material hardens and the hair is removed, the impression of the cuticle is left behind in the clear plastic. This plastic will transmit light, so the impression of the cuticle can be examined on the plastic’s surface with a compound microscope under high magnification.

Cortex

The cortex consists of an orderly array of spindle-shaped cortical cells, which is aligned parallel to the length of the hair. The cortex contains pigment bodies, which contain the natural dye melanin, and cortical fusi, which are irregular-shaped air spaces of varying sizes. Cortical fusi are commonly found near the root of a mature human hair, although they may be present throughout the length of the hair. As part of a side-by-side comparison of evidentiary hair samples and reference hair samples,
medium that has about the same index of refraction as the hair. This choice minimizes the amount of reflected light and optimizes the amount of light that penetrates the hair, facilitating the observation of the cortex.

**Medulla**

The medulla consists of one or more rows of dark-colored cells that run lengthwise through the center of the hair shaft. The shape of the medulla may be cylindrical (human) or patterned (animals). The pattern observed is specific to the particular species from which the hair came.

The medulla may be a continuous, fragmented, or interrupted line of dark cells. The medullar ratio (the ratio of the medullar diameter to the hair diameter) for animal hair is generally greater than 0.5; the medullar ratio for human head hair is generally less than 0.33.

**Hair Growth**

The root of the hair (refer to Figure 4-12) is surrounded by cells that provide all the necessary ingredients to generate hair and to sustain its growth. Human hair goes through three developmental stages: the anagenic phase, catagenic phase, and telogenic phase. The size and shape of the hair root are different in each of these phases (Figure 4-14).

The anagenic phase is the initial growth phase, during which the hair follicle is actively producing the hair. During this phase, which may last as long as 6 years, the follicle is attached to the root by the dermal papilla. During the anagenic phase, the hair must be “pulled” to be lost, in which case it may have a follicular tag. The follicular tag includes cells from the root that contain DNA (Figure 4-15). Although a human hair itself has no genomic DNA, it does contain mitochondrial DNA. The follicular tag can be used for DNA typing for either genomic or mitochondrial DNA.

The catagenic phase is a short period of transition between the anagenic and telogenic phases. It lasts only 2 to 3 weeks. During this phase, hair continues to grow, but the root bulb shrinks, takes on a club shape, and is pushed out of the follicle.

During the telogenic (final) phase, hair naturally becomes loose and falls out. Over a 2- to 6-month period, the hair is pushed out of the follicle, causing the hair to be naturally shed. The forensic examiner may compare the samples on the basis of the color, shape, and distribution of their pigment bodies and cortical fusi.

If hair has been dyed, dye may sometimes be observed in the cuticle and the cortex. If the hair has been bleached, the cortex will be devoid of pigment granules (though it may have a yellow tint). The cortex can be observed with a compound microscope. The hair is usually mounted in a liquid.
former connection, the dermal papilla, is no longer attached to the hair but is assimilated by the follicle.

Hair grows at a constant rate of approximately 1 cm per month. If the shed hair has grown after bleaching or coloring, an estimate of the time since chemical treatment can be established by assessing the presence (or absence) of color pigment or dye in the cuticle and cortex.

**Comparison of Hair by Microscopy**

When hair evidence is found at the scene of a crime, the forensic examiner must first answer two questions: (1) Is the hair human? and (2) does it match the hair of the suspect?

If the victim is covered with pet hair, a trained forensic examiner should be able to distinguish an animal hair from a human hair with little difficulty. To do so, the examiner will look for matches in published reference photos and use microscopy to reveal details of the sample's cuticle (i.e., scales), medullar ratio, and medullar pattern. As mentioned earlier, these characteristics are often unique to a particular species.

Human hair comparison is a much more difficult task. An examiner typically uses a comparison microscope to view the evidence hair and the known hair side by side. First, the examiner assesses the samples' color, length, and diameter. Next, the examiner compares features such as the shape of the medulla (if present) and the distribution, color, and shape of the pigment granules (including whether the hair has been colored or bleached). Other abnormalities due to disease, fungal infections, or physical damage can also be used as a basis for comparison if found in a specimen.

The microscopic comparison of human hair has been long accepted by the forensic community as a valid way to include and exclude suspect hairs against reference hairs—but only if the examiner has the proper training to make this determination. In 2002, a study by the FBI reported that significant error rates were associated with the microscopic comparison of human hairs (Houck & Budlowe, 2002). As part of this study, human hair evidence submitted to the FBI over a 4-year period was subjected to both standard microscopic examination and DNA analysis. Of the 80 hairs compared, only 9 (approximately 11%) for which the FBI examiners found a positive microscopic match between the questioned sample and a reference hair were found not to match by DNA
The search for hair evidence should begin as soon as it is possible. Hair evidence is easily transferred to and from the crime scene, perpetrator, and victim. Waiting too long to begin the search will bring into question the actual relationship of the evidence to the crime.

### Information Obtained by Microscopic Comparison of Hair

A microscopic examination of the hair sample may enable the examiner to determine the area of the body from which the hair originated. Scalp hairs, for example, tend to have a consistent diameter and a relatively uniform distribution of pigment; in some cases, they may also be dyed, bleached, or damaged. By contrast, beard hairs may be relatively coarse due to constant trimming and tend to have blunt tips from cutting or shaving; an examination of a cross section of such a hair may reveal that it is triangular in nature. Pubic hairs, by comparison, have widely variable cross-sections and shaft diameters; these short, curly hairs also may feature continuous medullae.

Microscopic examination cannot reveal the age or sex of the individual who was the source of a particular hair. The exception is infant hair; it tends to be short, with fine pigment granules. Sometimes, microscopic analysis may be able to suggest the race of the hair's owner. **Table 4-1** lists the characteristics of human hair that are associated with particular racial groups. Head hairs are usually the best samples for determining race, although hairs from other body areas can prove useful as well. Racial determination from the microscopic examination of head hairs from infants can be difficult, however, given the rudimentary nature of hair in young children. Hairs from individuals of mixed racial ancestry may possess microscopic characteristics attributed to more than one racial group. DNA studies have shown that many people have DNA from multiple racial groups; thus race cannot be divided into clearly defined categories, as many people falsely believe. The identification of race is

<table>
<thead>
<tr>
<th>Race</th>
<th>Diameter</th>
<th>Cross Section</th>
<th>Pigmentation</th>
<th>Cuticle</th>
<th>Undulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negroid</td>
<td>69–90 µm</td>
<td>Flat</td>
<td>Dense and clumped</td>
<td>—</td>
<td>Prevalent</td>
</tr>
<tr>
<td>Caucasian</td>
<td>70–100 µm</td>
<td>Oval</td>
<td>Evenly distributed</td>
<td>Medium</td>
<td>Uncommon</td>
</tr>
<tr>
<td>Mongolian</td>
<td>90–120 µm</td>
<td>Round</td>
<td>Dense auburn</td>
<td>Thick</td>
<td>Never</td>
</tr>
</tbody>
</table>

**Table 4-1** Characteristics of Human Hair
An investigator must, therefore, be extremely careful to secure all fiber evidence so it will not be accidentally lost and make certain to avoid any cross-contamination.

Most fiber evidence allows the examiner only to place it within a class. Not until a suspect has been identified and reference fibers collected from this individual will fiber evidence be individualized. The forensic examiner should begin the examination of fiber evidence with a low-power stereoscopic microscope. This technique allows the specific fibers in question to be selected and isolated for more detailed analysis.

Natural Fibers

Items of clothing, remnants of cloth, thread or yarn, and pieces of rope are all commonly found at crime scenes, and many are made from natural fibers. Natural fibers, which are derived from plant or animal sources, include materials such as cotton, flax, silk, wool, and kapok. In most textile materials, the natural fibers are twisted or spun together to form threads or yarns that are woven or knitted into fabric. When examined under magnification, a thread made from natural fibers appears to be a collection of many small twisted hairs (FIGURE 4-18).

Cotton (a plant fiber) is the most widely used natural fiber. In fact, undyed white cotton is so most useful as an investigative tool, but it also can be an associative tool when an individual’s hairs exhibit unusual racial characteristics.

Forensic Applications of Microscopy: Fibers

The term fiber is used to designate any long, thin, solid object. In scientific terms, a fiber is said to have a high aspect ratio; that is, the ratio of its length to its cross-section diameter is large. Fibers of forensic interest are classified based on their origin and composition (FIGURE 4-17). Most fibers of forensic interest are very common and are encountered daily in homes and workplaces.

Investigators do not have to worry about the composition of fibers being altered over time because the vast majority of fibers do not undergo physical, biological, or chemical degradation while at a crime scene. If one part of the fiber in question has been damaged, microscopic measurements can usually be taken at many other points along the fiber. Because fibers are so small and light, they are easily transferred from one object to another. As a consequence, they often provide evidence of association between a suspect and a crime scene. Of course, if a fiber was transferred once during a crime, it may be easily transferred a second time—such as during the investigation of the crime scene.

An investigator must, therefore, be extremely careful to secure all fiber evidence so it will not be accidentally lost and make certain to avoid any cross-contamination.

Most fiber evidence allows the examiner only to place it within a class. Not until a suspect has been identified and reference fibers collected from this individual will fiber evidence be individualized. The forensic examiner should begin the examination of fiber evidence with a low-power stereoscopic microscope. This technique allows the specific fibers in question to be selected and isolated for more detailed analysis.

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Cotton (a plant fiber) is the most widely used natural fiber. In fact, undyed white cotton is so
widely used in clothing and other fabrics that it has almost no evidentiary value. Animal fibers include hair from sheep (wool), goats (cashmere), llamas, and alpacas as well as fur from animals such as rabbits and mink. Identification of animal fur follows the same procedure as the microscopic examination of animal hair described previously.

Yarn

Yarns are categorized into two primary groups: filament and spun. Filament yarns are made of a continuous length of a human-made fiber. Spun yarns are made of short lengths of fibers that are twisted or spun together so they adhere to each other to form a thread or yarn. Whether the thread is a filament or a spun yarn can be determined simply by untwisting the yarn. Filament yarns unravel into long strands of fibers, whereas spun yarns unravel into short lengths of fiber that can be easily pulled apart. Because yarn is made by twisting parallel fibers together, the twist direction is another factor that allows for comparison. Other physical properties used to compare yarn samples include their texture, the number of twists per inch, the number of fibers making up each strand, the blend of fibers (if more than one is present), the color, and piling characteristics (i.e., tufts of fiber sticking out of the main bundle).

The examination of threads of yarn is normally done under a stereomicroscope using fine tweezers. The specimen is unraveled slowly and its features noted while being viewed under low power.

Woven Fabrics

Woven fabrics are made by intertwining two sets of yarns that are placed at a 90° angle to each other on a loom. The lengthwise strand, which is known as the warp, runs the length of the fabric. The weft strands are interlaced at right angles to the warp strands. The device used to weave fabrics is called a loom (Figure 4-19). A loom can produce a variety of distinctive patterns, known as weave structure.

The basic weave patterns, which can be seen in Figure 4-20, are plain, satin, basket, twill, and leno. The plain weave is the most common weave structure (Figure 4-21); each weft yarn goes alternately...
over and under the warp yarns to produce a durable “checkerboard” fabric. The twill weave creates a fabric with a diagonally oriented pattern because two or more warp threads are interlaced with two or more weft threads (FIGURE 4-22). Denim fabric is one of the most common twill weaves. Twill fabric is distinctive because the two sides of the fabric look different. The satin weave produces a smooth fabric because four or more warp threads are allowed to “float” over the weft threads before

FIGURE 4-19 A loom is used to weave fabric.

FIGURE 4-20 The most common weave structures: plain, basket, satin, twill, and leno.

FIGURE 4-21 In this graphic representation of a plain weave, the red squares are the warp yarn, and the purple squares are the weft yarn.
being tied down with one thread. In the satin weave, the front of the fabric is composed almost entirely of warp threads produced by repeating the weave. The satin weave is used for satin fabric, cotton bed linens, and lingerie. Satin weave is very flexible, which makes it useful for garments that need to drape.

Fabric analysis is usually performed under a stereomicroscope in conjunction with tweezers, a ruler for counting threads, and a protractor for measuring angles. The forensic examiner records the colors of the threads and number of threads per inch and determines the type of weave present in the cloth. The questioned fabric then is compared to known textile samples.

**Synthetic Fibers**

Rayon, the first human-made fiber, was introduced in the United States in 1910. The "wash and wear" revolution in the 1950s found Americans replacing their clotheslines with electric clothes dryers. The new wash-and-wear garments were made of acrylic and polyester fibers, which ensured that they dried wrinkle free. Since then, a wide variety of synthetic fibers have replaced natural fibers in many fabrics, garments, rugs, and other domestic products. Today, the U.S. fiber industry produces more than 9 billion pounds of fiber each year and has annual domestic sales that exceed $10 billion.

Modern manufactured fibers are classified into two categories: cellulosic fibers and synthetic fibers. Cellulosic fibers are produced from cellulose-containing raw materials, such as trees and other plants. Synthetic fibers are produced from chemicals made from refined petroleum or natural gas.

The U.S. Federal Trade Commission (FTC) has approved generic names for each fiber type. For example, generic names for cellulosic fibers include rayon, acetate, and lyocell; generic names for synthetic fibers include polyester, nylon, acrylic, polyolefin, and spandex. Table 4-2 lists generic fiber types, the most common trademarked names, and the major uses for each fiber type. Under the Textile Products Identification Act, the FTC imposes criminal sanctions against anyone who sells a textile fiber product that is misbranded or falsely or deceptively advertised.

The earliest synthetic fibers were made by treating cotton or wood with a variety of chemicals to produce regenerated fibers. In these processes, cellulose is extracted from the cellulosic fiber, and the resulting material is immersed in a solvent. This thick liquid is then forced through a small hole, causing the solvent to evaporate and a fiber to form.

In 1940, only 10% of the fibers used in the United States were synthetic. After World War II, however, chemists at DuPont learned how to create synthetic fibers using chemicals that are by-products of petroleum refinement. Their discoveries led to an explosion of new development in this area. The evolution of the technology to make these new fibers proceeded hand in hand with the development of the plastics industry.

**Polymers**

Plastics are malleable materials that can be easily formed into a wide variety of products—sheets of
sandwich wrap, door panels of cars, food containers, or flexible threads. Chemists call plastics polymers because these huge molecules are formed by chemically linking together many smaller molecules. Polymer is derived from a combination of the Greek words polý (meaning “many”) and meros (meaning “parts”). The individual parts that combine to form the polymer are known as monomers (from the Greek monos, meaning “single”). In homopolymers (from the Greek homos, meaning “same”), one type of molecule is joined to other molecules of the same type to form an enormously long linear thread; an example is polyethylene (FIGURE 4-23A). By changing the chemical structure of the monomer, different types of polymer chains can be easily assembled, each of which has different physical properties. Copolymers are formed by the reaction of two different monomers (FIGURE 4-23B).

### Forming Synthetic Fibers

Most synthetic fibers are produced by the melt spinning process. First, the polymer is melted. The molten material is then forced (extruded) through a spinneret, a mold containing a variable number of holes (FIGURE 4-24). As it cools, the polymer hardens into a solid.

The shapes of the holes in the spinneret determine the cross-sectional shape of the polymer—for example, round, trilobal, flat, or dumbbell (FIGURE 4-25). Round (hollow) fibers trap air, creating insulation (e.g., in synthetic down comforters). Trilobed fibers reflect more light, so they are often used to give an attractive sparkle to textiles. Pentagonal-shaped fibers, when used in carpet, show less soil and dirt. Octagonal-shaped fibers offer glitter-free effects. Not surprisingly, the forensic examiner may be able to use these characteristics to place a synthetic fiber within a particular class.

Companies may use a variety of techniques to dye fibers—sometimes even using different dyeing shades of the same color. Some fibers may appear to be a solid color but actually consist of two or more different fibers that have been chemically linked together, making them incompatible with other fibers.

### TABLE 4-2

<table>
<thead>
<tr>
<th>Generic Fiber Type</th>
<th>Common Trademark Names</th>
<th>Major Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetate</td>
<td>Celanese Acetate®</td>
<td>Sportswear, lingerie, draperies, and upholstery</td>
</tr>
<tr>
<td>Acrylic</td>
<td>Creslan®, Dralon®, Acrilan®, Duraspun®, Wear-Dated®</td>
<td>Sportswear, sweaters, socks, blankets, carpets, draperies, and upholstery</td>
</tr>
<tr>
<td>Lyocell</td>
<td>Tencel®, Lyocell by Lenzing®</td>
<td>Men’s and women’s dress clothing</td>
</tr>
<tr>
<td>Nylon</td>
<td>Condura®, Supplex®, Tactel®, Antlon®, Zeftron®, Vivana®, Caprolan®, Capima®</td>
<td>Ski apparel, windbreakers, luggage, rope, tents, and thread</td>
</tr>
<tr>
<td>Polyester</td>
<td>Dacron®, CoolMax®, Thermax®, Hollofil®, Thermoloft®, Fortrel®, ESP®, Polarguard®</td>
<td>Permanent-press garments, ties, dress apparel, lingerie, draperies, sheets, and pillow cases</td>
</tr>
<tr>
<td>Polyolefin</td>
<td>Herculan®, Innovaa®, Marvess®, Salus®, Telar®, Alpha Olefin®, Essera®, Kermel®</td>
<td>Pantyhose, knitted sportswear, carpets, upholstery, furniture, and slipcovers</td>
</tr>
<tr>
<td>Rayon</td>
<td>Modal®</td>
<td>Coat linings, lingerie, ties, bedspreads, and tablecloths</td>
</tr>
<tr>
<td>Spandex</td>
<td>Lycra®, Doralstan®</td>
<td>Bathing suits, lingerie, and stretch pants</td>
</tr>
</tbody>
</table>

Data from American Fiber Manufacturers Association, Fabric University (www.fabriclink.com).
Comparison and Identification of Synthetic Fibers

The first step in the comparison of synthetic fibers is an examination of the fibers with a comparison microscope, paying special attention to features such as color, diameter, cross-section shape, pitting or striations, and the presence of dulling agents (Figure 4.26). The main advantages of microscopic comparison are as follows:

- This technique does not destroy the fiber, unlike other analysis techniques.
- Microscopic comparison is not limited by the sample size; a fiber 1 mm in length can be easily examined.
- Every forensic laboratory has a comparison microscope readily available.

If pigments are used to color the fiber, they will be attached to the surface as granules. In contrast, dyes will penetrate farther into the fiber. Many fibers have treated surfaces. For example, shiny fibers may be treated with dulling agents, such as titanium dioxide, to make the fibers appear less lustrous.
The Microscope and Forensic Identification of Hair, Fibers, and Paint

Man-Made Fibers

- Round
- Trilobal
- Flat
- Dumbbell

**FIGURE 4-25** The spinneret can be replaced with different-shaped holes to make fibers with different cross sections.

Once the microscopic comparison has shown that the gross morphology of the two fibers is the same, the chemical composition of the samples is compared. Additional tests should be performed to determine whether the fibers belong to the same generic class. Additionally, the analyst should try to place the fiber into a specific polymer subclass. (Recall the earlier example, in which a fiber was first classified as a nylon, and then further classified as nylon-6 versus nylon-6.6.)

The refractive index is another useful physical property that can be used for the identification of synthetic fibers. As mentioned earlier, synthetic fibers are manufactured by drawing a molten polymeric substance through a spinneret to create a fiber. The force exerted during this extrusion process causes the molecules in the polymer to align along the length of the fiber, which gives the fiber not only strength but also the ability to refract light. Synthetic fibers, which tend to be thicker in the center and thinner toward the edges, may therefore act as lenses. If the fiber's refractive index is higher than that of the surrounding medium, the rays converge toward the center of the fiber; if its refractive index is lower than that of the surrounding medium, the rays diverge toward the edge of the fiber. The internal reflection of light within the fiber is due to the presence of minute differences in the solid state of the fiber. The forensic examiner can identify the refractive index of a fiber by immersing the fiber in a fluid with a comparable refractive index and observing the disappearance of the Becke line (the bright line that develops as the objective lens is moved out of focus) under a polarizing microscope. This technique is not limited by sample size, and it is nondestructive.

**Paint**

Crime labs analyze a large number of paint chips. Paint is transfer evidence, and it can provide important clues in investigations, especially in burglaries and vehicular crimes. Paints are applied to many surfaces in our modern society, either because they protect the underlying material or for aesthetic purposes where a beautiful surface is desired. Water-based and oil-based paints are composed of three major ingredients: (1) a pigment, (2) a solvent, and (3) a binder.

The pigment, either organic or inorganic, provides the desired color. The primary pigment in white paint is inorganic, usually titanium oxide (TiO₂) or zinc oxide (ZnO). These compounds are white or opaque, and they serve to cover any previous color on the surface to be painted. White lead [2 PbCO₃ ∑ Pb(OH)₂] was used extensively as a primary pigment until 1977, when it was banned for interior use because of its toxicity. Pigments—such as carbon black, iron oxide (Fe₂O₃, brown and red), cadmium sulfide (CdS, orange), chromium oxide (Cr₂O₃, green), and various organic compounds—are mixed with the primary pigment to obtain the desired color. Blue and green colors are made by adding organic pigments.

The solvent in a paint is the liquid in which the pigment, binder, and other ingredients are suspended, usually in the form of an emulsion. Once the paint has been spread, the solvent evaporates...
and the paint dries. In oil-based paints, the solvent is usually a mixture of hydrocarbons obtained from petroleum. A compatible organic solvent must be used for thinning the paint and cleaning up after painting. This is usually turpentine, which, like most other suitable solvents, gives off hazardous fumes. In water-based paints, the solvent is water, which can be used both for thinning and for cleaning up.

The binder is a material that polymerizes and hardens as the paint dries, forming a continuous film that holds the paint to the painted surface. The pigment becomes trapped within the polymer network. In older oil-based paints, the binder was usually linseed oil. As the solvent evaporates and the paint hardens, the linseed oil chemically reacts with atmospheric oxygen to form a cross-linked polymeric material.

The latex binder in water-based paint is dispersed into the paint and starts to coalesce and form a solid film as water evaporates. The slightly rubbery nature of the partially polymerized material explains why water-based paints are called latex paints. As the water evaporates, further polymerization occurs, and the paint hardens.

Several synthetic polymers are used as binders in latex and acrylic paints. Paints with poly (vinyl acetate) binders now account for about 50% of the paint used for interior work. Those with poly-styrene-butadiene binders are less expensive but do not adhere quite as well and have a tendency to yellow. Acrylic paints, made with acrylonitrile binders, are considerably more expensive than other types of paints, but they are excellent for exterior work. They adhere well and are washable, very durable, and resistant to damage by sunlight. In most respects, they are superior to oil-based paints, which they have now largely replaced.

Automobile Paint

Automobile paint is much more complicated. During the manufacturing of automobiles, several different layers of paint are applied (Figure 4-27). Each layer has its own unique function. The electrocoat primer is an epoxy resin that is applied to the steel body of the car for corrosion resistance. This primer is black or gray in color. Next, the primer surfacer is applied to hide any minor imperfections in the surface. This primer is an epoxy—modified polyester or polyurethane. Pigment is added to this primer to cover and hide the electrocoat primer. The next layer of paint is called the basecoat. This layer, which is an acrylic-based polymer, gives the automobile its beautiful color. The basecoat might also contain aluminum or metal oxide powders to give the paint a metallic look. Finally, an unpigmented acrylic clearcoat is applied to provide resistance to scratches, solar radiation, and acid rain. Not only is each layer a different color, but the organic resin and pigment in each layer are different. A careful analysis that reveals the layer structure will allow an examiner to individualize the paint chip.

Collection of Paint Evidence

Paint evidence is most likely to be found in crimes involving burglary or involving a vehicle. When a paint chip is located, the investigator must be extremely careful to keep the paint chip intact. Paint chips can be handled with forceps or picked up by sliding a thin piece of paper under the chip. It is best not to attempt to remove paint that is smeared on clothing or other objects. The object should be carefully packaged and sent to the laboratory.

A reference sample must be collected for comparison. This sample should always be collected from an undamaged area for comparison in the laboratory. When collecting a sample from a vehicle involved in an accident, it is very important that the collected paint be as close to the point of impact as possible. Remember that not all surfaces of an automobile fade at the same rate, and parts of the car may have been repainted. When collecting
In automotive standard the investigator must be careful to remove all the layers of paint (including the undercoat layers) down to the metal (or plastic) body surface. This is easily accomplished by using a sharp scalpel to remove the paint reference sample. If there was a cross-transfer of paint between two vehicles, all layers of paint need to be removed from each vehicle.

In cases of burglary, tools used by the burglar may have trace paint evidence attached. If such a tool is found, the investigator should package it and send it to the laboratory for examination. A reference paint sample should be collected from an area that has been in contact with the tool, such as a window sash or a doorjamb. Care must be taken to remove all the layers of paint down to the base material (e.g., wood, plastic, aluminum). If there are many coats of paint on the window or door that was the point of entry for the burglar, these paint chips may have unique layers.

An investigator needs to be very careful when handling paint evidence. A physical “jigsaw” match (Figure 4-28) of a questioned paint chip and an area where the reference paint is being collected are conclusive evidence. The fit of the edges of the two (questioned and reference chips), any surface markings, and the layer structure will establish the uniqueness of the match and will individualize the match.

**Forensic Analysis of Paint**

Forensic paint analysis begins with a comparison of the paint chip in question and the paint chip from a known source. Considering that there are thousands of paint colors, it is not surprising that color is the most important forensic characteristic. The color, texture, and layer sequence can be easily observed by placing the questioned and known samples under a stereomicroscope (Figure 4-29) or an illuminated desk magnifier. The layer structure order, color, thickness, and other details should be recorded. It may be necessary to cut the paint chip so that necessary information can be collected. Using a scalpel to cut through the chip can help reveal the layer structure. Sometimes the chip is cast into a block of epoxy, and microtome is used to cut the chip and reveal its layer structure. Samples embedded in epoxy make it possible to grind and polish the edge so that physical details such as pigment size and distribution can be determined.

If the paint chips are big enough, destructive chemical tests on a part of the chip can provide additional data. The application of solvent to a paint chip will cause swelling or the generation of colors. This information may help to identify resins and pigments in the chip. These tests can be performed in a porcelain spot plate with very small paint chips under a stereomicroscope. By comparing the reaction of the questioned and known samples to different solvents, trained microscopists can determine if the two came from a common source. Infrared microspectrophotometry is routinely used for paint analysis. Any infrared beam is reflected from the surface of the paint chip to produce an infrared spectrum of the surface. The infrared spectra are then interpreted and compared with the infrared spectra of known organic materials.
this way, the identity of the major organic components present in the paint chip can be determined (FIGURE 4-30).

An SEM with an energy-dispersive X-ray (EDX) can be used to identify the inorganic pigments in a paint sample. The layer structure can be studied in more detail by using the high magnifying power of the SEM, and the identity of the pigment can be determined by the EDX. The chip is cast into an epoxy block and a side is cut away with a microtome. FIGURE 4-31 shows a chip standing on end, with its layer structure exposed, giving a picture of not only the layers but also their elemental composition.
1. The black ski mask is the same color as the ski mask worn by the robber and probably has been used by him. This mask should be carefully examined for hair or fiber evidence as well as any personal hygiene (e.g., cologne, hair gel) residues. The hair and fiber evidence should be characterized using the microscopic techniques described in this chapter. The personal hygiene residues are organic material.

2. A short, brown beard hair found inside the ski mask indicates the transfer of hair evidence. It is reasonable to assume that a man with this color of hair wore the ski mask at some point. Although the person with the brown beard may not be the last person to put on the mask, it is reasonable that the police should follow this lead.

**Chapter Spotlight**

The microscopic techniques used to investigate trace fiber and hair evidence focus on their morphology. The methods employed for morphological comparisons of questioned and control samples often are used to show that two samples do not match, rather than that the individual who left behind the questioned trace sample was the same person who was the source of the control sample.

- The common types of microscopes used in processing trace evidence are the compound microscope, the comparison microscope, the polarizing (optical) microscope, the microspectrophotometer, and the SEM.
- In addition to identifying the refractive index, which provides information about fiber composition, microspectrophotometry can be used to analyze the composition of unknown materials, particularly dyes on fibers.
- SEMs are capable of magnifying an object 10 to 100,000 times. They are used to compare fiber surface morphologies between samples and, when combined with EDX, provide compositional information.

The portions of a hair that are vital to forensic examination are the cuticle, cortex, and medulla. These layers of the hair shaft may reveal important information about the source of the hair (e.g., if it is human, whether it belongs to the suspect).

- At a crime scene, collection of hair and fiber evidence can be done by using a vacuum with specialized filters and/or using lift tape. In the lab, collection of hair and fiber evidence can be done by gently shaking the evidence over white paper and by using a vacuum or lift tape. Collection of hair and fiber evidence from a body generally involves the use of lift tape.
- Once a sufficient number of hairs have been collected (50 head hairs), these hairs are compared under a microscope, and the morphology is noted and matched to standards and unknown samples from other sources.
- Fiber evidence can be classified as natural (e.g., cotton, flax, wool) or synthetic (e.g., polyester).
- Fibers are compared with standards provided by manufacturers when available.
Amorphous material  A solid without order in the arrangement of its atoms.

Anagenic phase  The initial phase of hair growth, when the hair follicle is producing hair.

Anisotropic material  Material that appears different when the direction of observation is changed.

Basecoat  The layer of automotive paint that contains the colored pigment.

Becke line  A bright line that develops as the objective lens of a microscope is moved out of focus.

Binder  The material that hardens as the paint dries, forming a continuous film.

Birefringent material  An anisotropic material.

Catagenic phase  The intermediate stage of hair growth, which occurs between the anagenic and telogenic phases.

Cellulosic fibers  Fibers that are produced from cellulose-containing raw materials, such as trees or other plants.

Clearcoat  Outermost layer of automobile paint that contains no pigment.

Comparison microscope  Two microscopes linked by an optical bridge.

Compound microscope  A microscope with one body tube that is used for magnification in the range of 25 to 1200 times.

Condenser  A lens under the microscope stage that focuses light on the specimen.

Cortex  The body of the hair shaft.

Cuticle  A scale structure covering the exterior of the hair.

Depth of focus  The depth of the area of the specimen that is in focus.

Electrocoat primer  First layer of paint applied to the steel body of an automobile.

Field of view  The part of the specimen that can be seen through the microscope lenses.

Follicular tag  Tissue surrounding the hair shaft that adheres to hair when it is pulled out.

Illuminator  The part of a microscope that illuminates the specimen for viewing.

Isotropic materials  Materials that have the same optical properties when observed from any direction.

Keratin  The primary protein that forms hair and nails.

Medulla  A column of cells running down the center of the hair.

Micrometer  One-millionth of a meter (µm).

Microspectrophotometer  A microscope that measures the interaction of infrared or ultraviolet radiation with a sample.

Objective lens  The lower lens of a microscope; the lens closest to the specimen.

Ocular lens  The upper lens of a microscope; the lens nearest to the eye.

Pigment  Added to paint to give it color.

Plane-polarized light  Light that oscillates in only one plane.

Pleochroism  A property of a substance in which it shows different colors when exposed to polarized light from different directions.

Polarizer  A lens that passes light waves that are oscillating only in one plane.

Polarizing microscope  A microscope that illuminates the specimen with polarized light.

Polymer  A large organic molecule made up of repeating units of smaller molecules (monomers).

Primer surfacer  A layer of automobile paint that slows corrosion of the underlying steel.

“Real” image  The actual nonmagnified image.
**Refraction** The bending of light waves.

**Refractive index** A ratio of the velocity of light in a vacuum to its velocity in any other medium.

**Regenerated fibers** Fibers made by treating cotton or wood with a variety of chemicals.

**Scanning electron microscope (SEM)** A microscope that illuminates the specimen with a beam of electrons.

**Solvent** The liquid in which the components of paint are suspended.

**Spectroscopy** Measurement of the absorption of light by different materials.

**Stereoscopic microscope** A microscope with two separate body tubes that allow both eyes to observe the specimen at low or medium magnification.

**Synthetic fibers** Fibers produced from chemicals made from refined petroleum or natural gas.

**Telogenic phase** The final phase of hair growth, during which hair falls out of the follicle.

**Virtual image** An image that is seen only by looking through a lens.

**Warp** Lengthwise strand of yarn on a loom.

**Weft** Crosswise strands of yarn on a loom.

**Working distance** The distance between the object being investigated and the objective lens.

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### Putting It All Together

**Fill in the Blank**

1. A magnifying glass is a(n) _________ lens that is thicker in the middle than at the edge.
2. How much light bends depends on the change in _________ as the light enters and leaves the magnifying glass.
3. When using a magnifying glass, the magnified image is known as the _________ image.
4. A(n) _________ microscope has two lenses that are at fixed distances from one another in a hollow tube.
5. The lower lens in a compound microscope is the _________ lens.
6. The upper lens in the eyepiece of the compound microscope is the _________ lens.
7. A compound microscope can magnify objects up to _________ times.
8. As the numerical aperture (NA) of a microscope lens doubles, it is able to resolve details that are _________ as close to one another.
9. As the magnifying power increases, the field of view _________ (increases/decreases).
10. The thickness of the region that is in focus when using a compound microscope is called the _________.
11. The light rays from the illuminator are condensed and focused through the _________ lens.
12. Side-by-side comparisons of specimens are best performed by using a(n) _________ microscope.
13. The _________ microscope has two eyepieces.
14. The distance between the objective lens and the specimen is the _________.
15. _________ materials have the same optical properties when observed from all directions.
16. As the direction of observation is changed, _________ materials will change their appearance.
17. _________ is the property of a substance in which it shows different colors when exposed to polarized light coming from different directions.
18. The microspectrophotometer is an instrument that attaches a spectrophotometer to a(n) ________.
19. With a microspectrophotometer, the UV, visible, and ________ spectrum of the sample can be measured.
20. A spectrophotometer measures the light intensity as a function of ________ after the light has interacted with the sample.
21. The electrons that are immediately reflected back toward the electron source in a scanning electron microscope are called ________ electrons.
22. Hair is composed primarily of the protein ________.
23. A human hair has three layers: the ________, the ________, and the ________.
24. The medulla of human hair is ________ (cylindrical/patterned).
25. The initial phase of hair growth is known as the ________ (catagenic/anagenic/telogenic) phase.
26. During the final phase of hair growth, known as the ________ phase, hair becomes loose and falls out.
27. The three most basic weaves in fabrics are ________, ________, and ________.
28. Cellulosic fibers are produced from raw materials from trees or plants that contain ________.
29. Synthetic fibers are produced from chemicals made from refined ________.
30. Synthetic fibers made from cellulose fibers are also known as ________ fibers.
31. ________-shaped synthetic fibers reflect more light and give an attractive sparkle to textiles.
32. The first step in comparing two synthetic fibers is to examine the fibers with a(n) ________ microscope.
33. Synthetic fibers can be identified by comparing their ________.
34. Paints have three major components. They are ________, ________, and ________.
35. Paint evidence is especially important in ________ and ________ crimes.
36. Other than color, what is the most important physical property of a paint chip when making a comparison? ________
37. Paint chips can be picked up by sliding a piece of ________ under the chip.
38. A reference paint sample can be obtained from an automobile by using a(n) ________.
39. A unique fit of the edges of two paint chips is called a(n) ________ match.
40. Sometimes a paint chip is cast into a block of epoxy and cut with a microtome to reveal its ________ structure.
41. Infrared microspectrophotometry will reveal the ________ components of a paint chip.
42. Destructive chemical tests can be carried out on paint chips by applying ________ to the paint chips.
True or False

1. Microspectrophotometers can be used to determine fiber subgroups.
2. The race of the suspect may be indicated by microscopic hair analysis.
3. The age of the individual can be determined by microscopic hair analysis.
4. Hair grows at a constant rate of approximately 2 cm per month.
5. The first step in the comparison of synthetic fibers is an examination of the fibers with a comparison microscope.
6. When obtaining a reference paint sample from an automobile, only the top layer of paint should be removed.
7. Blue and green paints are made with organic pigments.
8. A reference paint sample can be obtained from any surface of the automobile being examined.
9. Using an SEM-EDX to analyze the layer structure of a paint chip will give the identity of the pigment in each layer.
10. The color, texture, and layer sequence of a paint chip can be easily observed by placing it under a stereomicroscope.

Review Problems

1. The medical examiner (ME) is examining a corpse from a crime scene. Describe in detail how the ME should collect and preserve hair evidence from the victim's head and clothes. Which of the hairs should be sent to the DNA unit for analysis?
2. You learn from a witness that the corpse from which the ME took samples in Problem 1 lived with a cat. Describe in detail how cat hair differs from human hair. Draw a diagram of a human hair and a cat hair. Show all parts and label the diagram.
3. You have been asked to examine a woven fabric. Describe in detail how you would perform your analysis. Which details about the fabric would you record?
4. A human body was recovered from a remote wooded site. The individual, who had naturally brown hair, regularly bleached his hair, and he had brown hair roots showing. His roommate remembered the day he last bleached his hair. The brown roots of the hair measured 0.25 cm. How much time elapsed between this date and the day he died?
Further Reading


