

CHAPTER 3

The Study of Hair

NEUTRON ACTIVATION ANALYSIS OF HAIR

In 1958, the body of 16-year-old Gaetane Bouchard was discovered in a gravel pit near her home in Edmundston, New Brunswick, across the Canadian–U.S. border from Maine. Numerous stab wounds were found on her body. Witnesses reported seeing Bouchard with her boyfriend John Vollman prior to her disappearance. Circumstantial evidence also linked Vollman with Bouchard. Paint flakes from the place where the couple had been seen together were found in Vollman's car. Lipstick that matched the color of Bouchard's lipstick was found on candy in Vollman's glove compartment.

At Bouchard's autopsy, several strands of hair were found in her hand. This hair was tested using a process known as neutron activation analysis (NAA). NAA tests for the presence and concentration of various elements in a sample. In this case, NAA showed that the hair in Bouchard's hand contained a ratio of sulfur to phosphorus that was much closer to Vollman's hair than her own. At the trial, Vollman confessed to the murder in light of the hair analysis results. This was the first time NAA hair analysis was used to convict a criminal.



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Investigators search for clues in a gravel pit similar to the one in which Gaetane Bouchard was buried.

OBJECTIVES

By the end of this chapter you will be able to

- 3.1 Identify the various parts of a hair.
- 3.2 Describe variations in the structure of the medulla, cortex, and cuticle.
- 3.3 Distinguish between human and nonhuman animal hair.
- 3.4 Determine if two examples of hair are likely to be from the same person.
- 3.5 Explain how hair can be used in a forensic investigation.
- 3.6 Calculate the medullary index for a hair.
- 3.7 Distinguish hairs from individuals belonging to the broad racial categories.



TOPICAL SCIENCES KEY

VOCABULARY

- class evidence** material that connects an individual or thing to a certain group
- comparison microscope** a compound microscope that allows the side-by-side comparison of samples, such as of hair or fibers
- cortex** the region of a hair located outside of the medulla containing granules of pigment
- cuticle** the tough outer covering of a hair composed of overlapping scales
- hair follicle** the actively growing root or base of a hair containing DNA and living cells
- individual evidence** a kind of evidence that identifies a particular person or thing

- keratin** a type of fibrous protein that makes up the majority of the cortex of a hair
- medulla** the central core of a hair fiber
- melanin granules** bits of pigment found in the cortex of a hair
- neutron activation analysis** a method of analysis that determines composition of elements in a sample
- trace evidence** small but measurable amounts of physical or biological material found at a crime scene

INTRODUCTION

An investigator finds a blond hair at a crime scene. She thinks that it might help solve her case. What information could be gained from analysis of that

hair (Figure 3-1)? What are the limitations of the information that hair can provide?

Figure 3-1. A forensic scientist prepares a hair for analysis.



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Hair is considered **class evidence**. Alone (without follicle cells attached), it cannot be used to identify a specific individual. In the best case, an investigator can identify a group or class of people who share similar traits who might share a certain type of hair. For example, the investigator can fairly confidently exclude people with Asian and African ancestry as producers of the blond hair found at a crime scene. She could also compare the hair collected with hair from a blond suspect. However, even though the hairs may share characteristics, they may not necessarily be from the same source.

Hair can easily be left behind at a crime scene. It can also adhere to clothes, carpets, and many other surfaces and be transferred to other locations. This is called *secondary transfer*. Secondary transfer is particularly common with animal hair.

Because of its tough outer coating, hair does not easily decompose. Hair found at crime scenes or secondary locations can be analyzed. The physical characteristics of hair can offer clues to the broad racial background of an individual. Chemical tests can provide a history of the use of drugs and other toxins, indicate the presence of heavy metals, and provide an assessment of nutritional deficiencies. When the follicle of a hair is present, DNA evidence may be obtained. Results of DNA analysis is not considered class evidence. It is better, because it can lead to individual identification, thus it is **individual evidence**.

HISTORY OF HAIR ANALYSIS

Investigators recognized the importance of analysis of hair as **trace evidence** in criminal investigations in the late 1800s. The case of the murder of the Duchesse de Praeslin in Paris in 1847 is said to have involved the investigation of hairs found at the scene.

A classic 1883 text on forensic science, *The Principles and Practice of Medical Jurisprudence* by Alfred Swaine Taylor and Thomas Stevenson, contains a chapter on using hair in forensic investigations. It includes drawings of human hairs under magnification. The various parts of human hair are identified. The book also references cases in which hair was used as evidence in England.

In 1910, a comprehensive study of hair titled *Le Poil de l'Homme et des Animaux* (*The Hair of Man and Animals*) was published by the French forensic scientists Victor Balthazard and Marcelle Lambert. This text includes numerous microscopic studies of hairs from most animals.



The history of prescription drug-use by Henri Paul was determined by analysis of his hair. Paul was the driver of the car in which he, Dodi Fayed, and Princess Diana died on August 31, 1997.

The use of the **comparison microscope** to perform side-by-side analysis of hairs collected from a crime scene and hairs from a suspect or victim first occurred in 1934 by Dr. Sydney Smith. This method of comparison helped solve the murder of an eight-year-old girl.

Further advances in hair analysis continued throughout the 20th century as technological advances allowed for comparison of hairs through chemical methods. Today, hair analysis includes neutron activation analysis and DNA fingerprinting and is considered a standard tool in trace evidence analysis.

THE FUNCTION OF HAIR

All mammals have hair. Its main purpose is to regulate body temperature—to keep the body warm by insulating it. It is also used to decrease friction, to protect against sunlight, and to act as a sense organ. In many mammals, hair can be very dense, and it is then referred to as fur.

Hair works as a temperature regulator in association with muscles in the skin. If the outside temperature is cold, these muscles pull the hair strands upright, creating pockets that trap air. This trapped air provides a warm, insulating layer next to the skin. If the temperature outside is warm, the muscles relax and the hair becomes flattened against the body, releasing the trapped air.

In humans, body hair is mostly reduced; it does not play as large a role in temperature regulation as it does in other animals. When humans are born, they have about 5 million hair follicles, only 2 percent of which are on the head. This is the largest number of hair follicles a human will ever have. As a human ages, the density of hair decreases.



All of the hair follicles in humans are formed when a fetus is five months old.



THE STRUCTURE OF HAIR

Obj. 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, and 3.7

A hair consists of two parts: a follicle and a shaft (Figure 3-2). The **follicle** is a club-shaped structure in the skin. At the end of the follicle is a network of blood vessels that supply nutrients to feed the hair and help it grow. This is called the *papilla*. Surrounding the papilla is a bulb. A sebaceous gland, which secretes oil that helps keep the hair conditioned, is associated with the bulb. The erector muscle that causes the hair to stand upright attaches to the bulb. Nerve cells wind around the follicle and stimulate the erector muscle in response to changing environmental conditions.

The hair shaft is composed of the protein **keratin**, which is produced in the skin. Keratin makes hair both strong and flexible. Like all proteins, keratin is made up of a chain of amino acids that forms a helical, or spiral, shape. These helices are connected by strong bonds between amino acids. These bonds make hair strong.

Figure 3-2. This cross-section shows a hair shaft in a hair follicle in the skin. If the root of the hair is present, DNA may be extracted, amplified, and compared to known samples for identification. If no root is present, hair can be matched by other characteristics that can be viewed under a compound microscope.

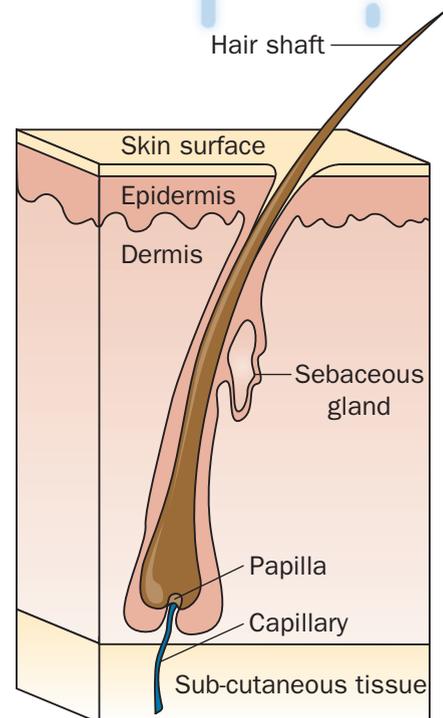


Figure 3-3. The structure of a hair shaft is similar to that of a yellow pencil.

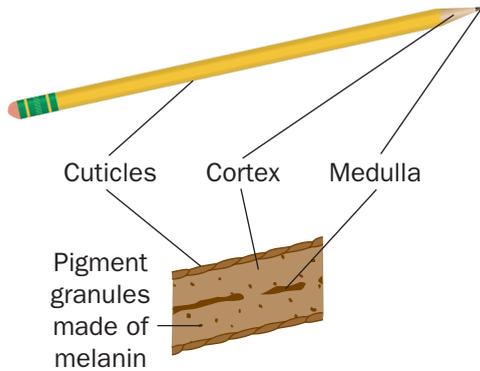
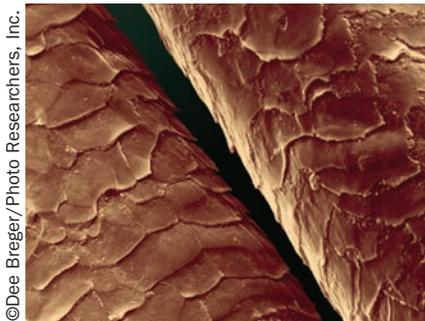


Figure 3-4. This scanning electron photomicrograph shows the cuticle of a human hair with the overlapping scales.



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Figure 3-5. The pigment granules in the red hair on the left are evenly distributed throughout the cortex. Commonly, the pigment is denser near the cuticle of human hairs, as shown on the right.



Courtesy, FBI; photos by Sandra Koch & Douglas W. Deedric

The hair shaft is made up of three layers: an inner **medulla**, a cortex, and an outer **cuticle**. A good analogy for the structure of a hair shaft is the structure of a pencil (Figure 3-3). The painted yellow exterior of the pencil is similar to the cuticle. The graphite in the middle of the pencil is similar to the medulla. The wood of the pencil is analogous to the cortex of a hair. Human hair has cuticle scales that are flattened and narrow, also called *imbricate*. Animal hair had different types of cuticles that is described and pictured later in the chapter under animal hair.

THE CUTICLE

The **cuticle** is a transparent outer layer of the hair shaft. It is made of scales that overlap one another and protect the inner layers of the hair (Figure 3-4). The scales point from the proximal end of the hair, which is closest to the scalp, to the distal end, which is farthest from the scalp. When examining a section of hair under a microscope, noticing the direction the scales point shows the younger and older ends of the hair. This information can be used when an investigator needs to analyze hair for the presence of different toxins, drugs, or metals at specific points in time. Human hair has cuticle scales that are flattened and narrow, also called *imbricate*. Animal hair has different types of cuticles that are described and pictured later in the chapter under animal hair.

TYPES OF CORTEX

In humans, the **cortex** is the largest part of the hair shaft. The cortex is the part of the hair that contains most of the pigment granules (**melanin**) that give the hair its color (Figure 3-5). The pigment distribution varies from person to person. Some people have larger pigment granules within the cortex, giving the cortex an uneven color distribution when viewed under the compound microscope.

TYPES OF MEDULLA

The center of the hair is called the medulla. It can be a hollow tube, or filled with cells. In some people the medulla is absent, in others it is fragmented, or segmented, and in others it is continuous or even doubled. The medulla can contain pigment granules or be unpigmented. Forensic investigators classify hair into five different groups depending on the appearance of the medulla, as illustrated in Figure 3-6.

TYPES OF HAIR

Hair can vary in shape, length, diameter, texture, and color. The cross section of the hair may be circular, triangular, irregular, or flattened, influencing the curl of the hair. The texture of hair can be coarse as it is in whiskers or fine as it is in younger children. Some furs are a mixture as in dog coats, which often have two layers: one fine and one coarse. Hair color varies depending on the distribution of pigment granules and on hair dyes

Figure 3-6. Five different patterns of medulla are identified in forensic hair analysis.

Medulla Pattern	Description	Diagram
Continuous	One unbroken line of color	
Interrupted (Intermittent)	Pigmented line broken at regular intervals	
Fragmented or Segmented	Pigmented line unevenly spaced	
Solid	Pigmented area filling both the medulla and the cortex	
None	No separate pigmentation in the medulla	

that might have been used (Figure 3-7). These attributes can all be used for identification or exclusion in forensic investigations.

In humans, hair varies from person to person. In addition, different hairs from one location on a person can vary. Not all hairs on someone's head are exactly the same. For example, a suspect may have a few gray hairs among brown hairs in a sample taken from his head. Because inconsistencies occur within each body region, 50 hairs are usually collected from a suspect's head. Typically, 25 hairs are collected from the pubic region.

Figure 3-7. Hairs coming from a single area on one person can vary in characteristics.



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HAIR FROM DIFFERENT PARTS OF THE BODY

Hair varies from region to region on the body of the same person (Figure 3-8). Forensic scientists distinguish six types of hair on the human body: (1) head hair, (2) eyebrows and eyelashes, (3) beard and mustache hair, (4) underarm hair, (5) auxiliary or body hair, and (6) pubic hair. Each hair type has its own shape and characteristics.

One of the ways in which hairs from the different parts of the body are distinguished is their cross-sectional shape. Head hair is generally circular or elliptical in cross section. Eyebrows and eyelashes are also circular but often have tapering ends. Beard hairs tend to be thick and triangular. Body hair can be oval or triangular, depending on whether the body region has been regularly shaved. Pubic hair tends to be oval or triangular.

Hairs from different parts of the body have other characteristic physical features. Hair from the arms and legs usually has a blunt tip, but may be frayed at the

Figure 3-8. The physical characteristics of hairs provide information about which part of the body they came from.

Courtesy, FBI; photos by Sandra Koch & Douglas W. Deedric



Pubic hair showing buckling



Beard hair with double medulla



Arm or leg hair with blunt, frayed end



You lose approximately 100 hairs from your head each day. These end up on your clothes, in your hairbrush, on furniture, and at the places you visit.



Figure 3-9. Examples of dyed human hair.



Courtesy, FBI; photos by Sandra Koch & Douglas W. Deedric

ends from abrasion. Beard hair is usually coarse and may have a double medulla. The diameter of pubic hair may vary greatly, and buckling may be present.

THE LIFE CYCLE OF HAIR

Hair proceeds through three stages as it develops. The first stage is called the *anagen stage* and lasts approximately 1,000 days. Eighty to ninety percent of all human hair is in the anagen stage. This is the period of active growth when the cells around the follicle are rapidly dividing and depositing materials within the hair. The *catagen stage* follows as the hair grows and changes (perhaps turning gray). The catagen stage accounts for about 2 percent of all hair growth and development. The final stage is the *telogen stage*. During this stage the hair follicle is dormant or resting and hairs are easily lost. About 10 to 18 percent of all hairs are in the telogen stage. There is no pattern as to which hairs on the head are in a particular stage at any time.

TREATED HAIR

Hair can be treated in many different ways (Figure 3-9). Bleaching hair removes pigment granules and gives hair a yellowish color. It also makes hair brittle and can disturb the scales on the cuticle. Artificial bleaching shows a sharp demarcation along the hair, while bleaching from the sun leaves a more gradual mark. Dyeing hair changes the color of the hair shaft. An experienced forensic examiner can immediately recognize the color as unnatural. In addition, the cuticle and cortex both take on the color of the dye.

If an entire hair is recovered in an investigation, it is possible to estimate when the hair was last color-treated. The region near the root of the hair will be colored naturally. Human hair grows at a rate of about 1.3 cm per month (approximately 0.44 mm per day). Measuring the length of hair that is naturally colored and dividing by 1.3 cm provides an estimate of the number of months since the hair was colored. For example, if the unbleached root region measured 2.5 cm, then 2.5 cm divided by 1.3 cm per month equals approximately 1.9 months or about 7 weeks. This information can be used to identify hairs from different locations as belonging to an individual.

RACIAL DIFFERENCES

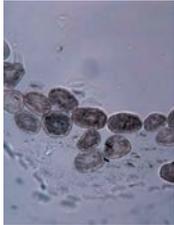
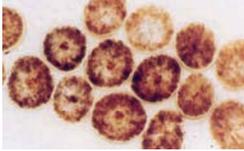
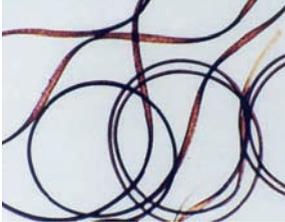
Hair examiners have identified some key physical characteristics that are associated with hair of different broad racial groups. These characteristics are only generalities and may not apply to individuals of certain races. In addition, a certain hair may be impossible to assign to a particular race because its characteristics are poorly defined or difficult to measure. The broad characteristics of hairs from different races are compared in Figure 3-10.

ANIMAL HAIR AND HUMAN HAIR

Animal hair and human hair have several differences, including the pattern of pigmentation, the medullary index, and the cuticle type. The pattern of the pigmentation can vary widely in different animals. While the pigmentation in human hair tends to be denser toward the cuticle, in animals it is denser toward the medulla. Animal pigments are often found in solid masses called *ovoid bodies*, especially in dogs and cattle. Human hairs are



Figure 3-10. A comparison of some general physical characteristics of hair from different races.

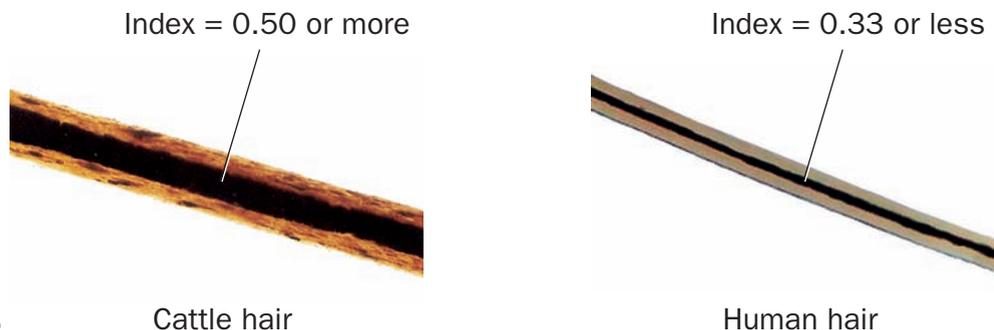
Race	Appearance	Pigment Granules	Cross Section	Other
European	Generally straight or wavy 	Small and evenly distributed	Oval or round of moderate diameter with minimal variation 	Color may be blond, red, brown, or black
Asian	Straight 	Densely distributed	Round with large diameter 	Shaft tends to be coarse and straight Thick cuticle Continuous medulla
African	Kinky, curly, or coiled 	Densely distributed, clumped, may differ in size and shape	Flattened with moderate to small diameter and considerable variation 	

Courtesy, FBI; photos by Sandra Koch & Douglas W. Deedric

usually one color along the length. Animal hairs can change color abruptly in a banded pattern.

In animals, the medulla is much larger than it is in humans (Figure 3-11). The ratio of the diameter of the medulla to the diameter of the entire hair is known as the *medullary index*. If the medullary index is 0.5 or greater, the hair came from an animal. If the medullary index is 0.33 or less, the hair is from a human.

Figure 3-11. The medulla of animal hair is much larger than in human hair, and it is always continuous.



Courtesy, FBI; photos by Sandra Koch & Douglas W. Deedric

The cuticle of the hair shaft can also help distinguish human hair from animal hair. There are different types of cuticles in different mammal hair cuticles. Rodents and bats have a *coronal* cuticle with scales that give the appearance of a stack of crowns. Cats, seals, and mink have scales that are called *spinous* and resemble petals. Human hair has cuticle scales that are flattened and narrow, also called *imbricate*.

USING HAIR IN AN INVESTIGATION

Whenever two objects are in contact, some transfer of material will occur. This is known as Locard's exchange principle. It is the fundamental reasoning behind the use of trace evidence in forensic investigations. If a person is at a crime scene, he or she will leave some trace of his or her presence behind, or pick up some trace evidence from the crime scene. One of the major examples of trace evidence is hair.

When investigators enter a crime scene, they collect trace evidence, including hair. Hair can be collected from evidence by plucking, shaking, and scraping surfaces. It can also be collected by placing tape over a surface so that the hair adheres to it. When surfaces are large, they can be vacuumed. The material that is filtered into the canister can be examined for hair and other trace particles. Investigators are always careful to prevent cross-contamination of evidence by inadvertently transferring hair from one object to another.

If a large number of hairs are collected from a victim or a crime scene, an investigator will compare the sample with hair taken from the six major body regions of the victim or suspect(s). An initial analysis is performed using a low-power compound microscope to determine whether the hair is human or animal.

MICROSCOPY

Hair viewed for forensic investigations is studied both macroscopically and microscopically. Length, color, and curliness are macroscopic characteristics. Microscopic characteristics include the pattern of the medulla, pigmentation of the cortex, and types of scales on the cuticle (Figure 3-12). Medullary index can be measured. Typical magnification for viewing hair is between 40 times and 400 times. A particularly useful microscope for hair analysis is called a comparison microscope. It allows for simultaneous viewing of two different samples.

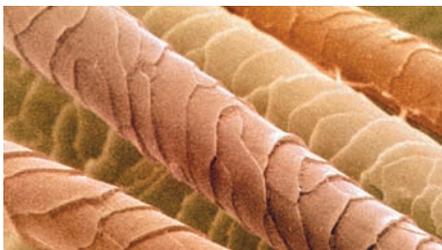
Several specialized microscopic techniques are also used in hair analysis. Phase contrast microscopy involves using a special objective lens and special condenser with a compound microscope. This configuration focuses light that passes through objects of different refractive indexes. The resulting image shows more contrast, especially when viewing translucent particles. Phase contrast microscopy in hair analysis is useful for observing fine detail

in hair structure.

Many dyes and other hair treatments will fluoresce under a certain color (wavelength) of light. In a fluorescence microscope, a beam of light of a certain color is used. If the sample contains particular chemicals, it will absorb some of the light and then reemit light of a differ-



Figure 3-12. Using microscopy, investigators might link dog hair to a dog owner or deer hair to a hunter.



Dog hair 400×



Deer hair 400×

Digging Deeper

with Forensic Science e-Collection

Edmund Locard was a French criminalist who played a pivotal role in expanding the field of forensic science. Originally trained as a physician, Locard became fascinated with police work and using laboratory techniques to help solve crimes. Search the Gale Forensic Science eCollection on school.cengage.com/forensicscience and research Locard's life. Write a short biography of this great researcher explaining how his contributions affected forensic science. What ideas did he have that advanced the field? Who were his most important influences? How has forensics changed as a result of Locard's ideas?



Forensic laboratories employ technicians to compare hair samples in preparation for presentation in hearings and trials. Their work involves the use of microscopes and digital imaging of evidence.

ent color. This is called *fluorescence*. A fluorescence microscope is equipped with filters to detect the fluoresced light, indicating the presence of a dye or other treatment.

Instead of using light to view a sample, electron microscopes direct a beam of electrons at a sample. Electron microscopes provide incredible detail of the surface or interior of the sample (Figure 3-13), magnifying the object 50,000 times or more.

TESTING FOR SUBSTANCES IN THE HAIR SHAFT

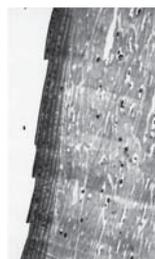
Because hair grows out of the skin, chemicals that the skin absorbs can become incorporated into hair. Ingested or absorbed toxins such as arsenic, lead, and drugs can be detected by chemical analyses of hair. During testing, the hair is dissolved in an organic solvent that breaks down the keratin and releases any substances that have been incorporated into the hair. A forensic chemist can perform chemical tests for the presence of various substances. In forensic investigations, this type of analysis can provide evidence of poisoning or drug use.

Because hair does not readily decompose, by testing different parts of the hair, it may be possible to establish a timeline for when exposure to poisons or other toxins might have occurred. The procedure for developing the timeline would be similar to the one used with hair color analysis discussed earlier in the chapter. Human hair grows at the rate of about 1.3 cm per month (approximately 0.44 mm per day). The hair can be analyzed in sections for the specific toxin. If the root is present to identify the base of the hair, these sections can be dated based on their distance from the root. If the toxin occurs 9 cm from the root, dividing this value by 1.3 cm per month provides an estimate of the number of months since the toxin was ingested. In this case, 9 cm divided by 1.3 cm per month equals approximately 7 months.

Neutron activation analysis (NAA) is a particularly useful technique that can identify up to 14 different elements in a single two-centimeter-long strand of human hair. The hair is placed in a nuclear reactor and bombarded with high-energy neutrons. Different elements will give off gamma radiation with different signals. These signals can be recorded and interpreted to determine concentrations of elements in the sample. Elements such as antimony, argon, bromine, copper, gold, manganese, silver, sodium, and zinc can be identified and quantified using NAA. The probability of the hairs of two individuals having the same concentration of nine different elements is about one in a million.

Figure 3-13. A transmission electron microscope produced this extremely detailed image of a long section of human hair. Notice the overlapping cuticle scales on the left side and the pigment granules in the cortex.

Courtesy, FBI; photos by Sandra Koch & Douglas W. Deedric



Digging Deeper

with Forensic Science e-Collection

How is DNA collected from hair follicles used in forensic investigations? What sorts of DNA testing are most often performed on hair follicles? What sorts of controversies surround these tests? Are errors ever made? What are the major problems with DNA testing of material associated with hair? Go to the Gale Forensic Science eCollection on school.cengage.com/forensicscience and enter the search terms "DNA hair analysis." Click on Academic Journals and read about some of the problems and successes associated with DNA analysis and hair. Write a brief essay describing your findings, and be sure to cite your resources.



TESTING THE HAIR FOLLICLE

If hair is forcibly removed from a victim, the entire hair follicle may be present. This is called a *follicular tag*. If this occurs, blood and tissue attached to the follicle may be analyzed. For example, blood proteins can be isolated to identify the blood type of a suspect. DNA analyses can also be performed on hair-follicle cells (Figure 3-14). DNA analysis of the hair follicle provides an identification with a high degree of confidence, whereas analysis of the hair shaft usually provides class evidence only. In many cases, a microscopic assessment of the hair is performed initially because it is more cost effective and rapid than blood protein and DNA testing. If a microscopic match between a suspect and a sample is found, then the samples will be forwarded for blood and DNA testing.

Figure 3-14. DNA can be extracted from cells in the hair follicle for DNA analysis.



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SUMMARY

- Hair is a form of class evidence that has been used in forensic analysis since the late 19th century.
- Hair is a character shared by all mammals and functions in temperature regulation, reducing friction, protection from light, and as a sense organ.
- Hair consists of a follicle embedded in the skin that produces the shaft.
- The shaft is composed of the protein keratin and consists of the outer cuticle, a cortex, and an inner medulla, each of which varies among individuals or species.
- Hair varies in length and cross-sectional shape, depending on where on the body it originates.
- Hair development is broken into three developmental stages, called the anagen (growth), catagen (growth and change), and telogen (dormant) stages.
- Various hair treatments produce characteristic effects that are useful to forensic experts, and some hair characteristics allow them to be grouped into general racial categories.
- Forensic experts examine hair using light (phase contrast, fluorescence, comparing) and electron microscopy, and analyze hair chemically for drugs and toxins.
- Neutron activation analysis allows unique signatures of elements contained in hair to be identified, and the hair follicle can provide DNA for sequencing.

CASE STUDIES

Obj. 3.4, 3.5

Alma Tirtsche (1921)

Alma Tirtsche's beaten body was found wrapped in a blanket in what is known as Gun Alley in Melbourne, Australia. Because the body was relatively free of blood, the police deduced that she had been murdered elsewhere and brought to the alley. Her body had been washed before being wrapped in the blanket. A local bar owner, Colin Ross, was questioned. Ross admitted seeing Tirtsche in his bar earlier in the day.

Investigators collected blankets from Ross's home and found several strands of long, reddish blond hair on them. The length of the hair implied it had come from a female, and the concentration of pigment in the hair implied a younger woman. Some of the ends of the hair were irregular, implying the hair had been forcibly broken off. The physical similarity of the hair found on the blanket with that of Alma Tirtsche convinced the jury that Ross was the murderer. This was the first time that hair was used to secure a conviction in Australia. Unfortunately, analysis of the hairs 75 years later showed that two of the strands found on the blankets came from different individuals, which throws doubt on Ross's guilt.

©Digital Vision/Getty Images



Eva Shoen (1990)

In Telluride, Colorado, Eva Shoen was found dead from a single gunshot to her head. The police recovered the bullet and expected to solve the case using ballistics information. Unfortunately, they did not have any useful leads. Three years later, the police received a phone call from a man who believed that his brother, Frank Marquis, was responsible for Shoen's death. A gun was found on Marquis, but he had already tampered with its barrel, preventing a ballistic match.

From questioning a companion of Marquis's, police learned that Marquis had been in Telluride when Shoen was murdered. They also discovered that Marquis had thrown two bundles out of his car during his drive home to Arizona. Detectives searched the road until they found a bundle of clothing. One of the shirts in the bundle contained a single strand of hair. The color and structure of the hair matched that of Eva Shoen's hair. When confronted with the evidence, Marquis confessed to the murder and was imprisoned for 24 years.

Napoleon's Hair

Napoleon Bonaparte proclaimed himself emperor of France in 1804 after rising swiftly through the ranks of the French army. Following his defeat at Waterloo, he was exiled on the British island of St. Helena in the Atlantic Ocean. History books proclaim that he died in exile of stomach cancer.

In 2001, a Canadian Napoleon enthusiast, Ben Weider, challenged this theory. He had five strands of Napoleon's hair collected in 1805, 1814, and 1821 tested using neutron activation analysis. The results of the analysis showed that Napoleon's hair contained between 7 and 38 times more arsenic than normal, a fatal dose. In 2002, further analysis of Napoleon's hair showed extremely elevated levels of arsenic, leading researchers to joke that Napoleon should have died twice before his actual death, and suggesting that the hair must have been contaminated during storage.

Eventually, the esteemed chemist, Walter McCrone, tested a sample of Napoleon's hair. His work contradicted the previous reports, stating that the levels of arsenic that had been incorporated into Napoleon's hair were much too low to have killed him. The story continues to cause controversy. Most chemists believe that McCrone's work is the final story, but Napoleon enthusiasts believe that the emperor's death is surrounded by too many questions to disregard the possibility of murder.



Think Critically Do you consider hair evidence important in proving a crime? Explain your answer.

CAREERS IN FORENSICS



William J. Walsh, Chemical Researcher

With a doctorate in chemical engineering and a research record that includes such illustrious laboratories as Atomic Research in Ames, Iowa, Los Alamos National Laboratory in New Mexico, and Argonne National Laboratory in Illinois, William Walsh has spent more than 30 years studying chemical processes involved in nuclear fuel production, liquid metal distillation, and electrochemistry. Dr. Walsh has authored more than 200 scientific articles and reports and made numerous presentations on his research. Dr. Walsh is the Chief Scientist of the Health Research Institute and Pfeiffer Treatment Center, both in Illinois.

Dr. Walsh's work in chemistry led to an interest in developing tools and chemical methods for extracting information from hair. Dr. Walsh and his colleagues collected known chemistry information from more than 100,000 people and synthesized it into the world's first standard of known hair composition. Walsh has served as an expert chemist in numerous forensic studies of hair samples in collaboration with medical examiners, coroners, and police groups. Some of the more famous, or infamous, people whose hair chemistry Walsh has studied include Charles Manson (Manson Family murders), Henry Lee Lucas (20th-century



Scientist performing hair analysis.

serial killer), James Hubeity (McDonald's massacre), William Sherrill (Oklahoma post office slayings), and other notorious criminals. In addition, while volunteering at the Stateville Penitentiary in Joliet, Illinois, Walsh became interested in the way that chemicals can affect behavior. These combined interests—hair forensics and the influence of biochemicals on behavior—made Walsh the perfect candidate to head up one of the most famous hair investigations: that of composer Ludwig van Beethoven.

Walsh was the chief scientist on the Beethoven Research Project in 2000. The goal of the project was to understand whether chemical toxins may have played a role in Beethoven's death. Beethoven developed an illness in his twenties that involved abdominal distress, irritation, and eventually depression. By the age of 31, he began to lose his hearing, and by 42, he was completely deaf. He died of liver and kidney failure. Using highly sensitive techniques—scanning electron microscope energy dispersion spectrometry (SEM/EDS) and scanning ion microscope mass spectrometry (SIMS)—Walsh verified that Beethoven's hair contained extremely high concentrations of lead, which almost certainly contributed to his death.



Learn More About It

To learn more about forensics hair analysis, go to school.cengage.com/forensicscience.

CHAPTER 3 REVIEW

1

True or False

2

1. The shaft of the hair is considered class evidence in a trial. *Obj. 3.5*
2. Hair is composed of a protein called cellulose. *Obj. 3.1 and 3.2*
3. All hairs on the head of a person are identical. *Obj. 3.2*
4. The cortex may contain pigment granules. *Obj. 3.2*

3

4

Multiple Choice

5

5. The hair shaft is composed of the cuticle, cortex, and *Obj. 3.1 and 3.2*
 - a) medulla
 - b) root
 - c) crown
 - d) granules

6

7

6. Which factors are used to calculate the medullary index of the hair? *Obj. 3.6*
 - a) scale diameter of cuticle and the length of the hair
 - b) width of cortex and the width of the medulla
 - c) length of entire hair and the pattern of pigmentation
 - d) width of medulla and the width of the hair

8

9

7. Which of the following characteristics is found in typical Asian hair? *Obj. 3.7*
 - a) dark medulla
 - b) sparsely distributed pigment granules
 - c) flattened cross section
 - d) hair is curly

10

11

8. Human hair has which type(s) of cuticle? *Obj. 3.3*
 - a) imbricate
 - b) spinous
 - c) coronal
 - d) pigmented

12

13

9. Neutron activation analysis can check hair for the presence of *Obj. 3.5*
 - a) silver
 - b) DNA
 - c) water content
 - d) hair dye

14

15

10. Which part(s) of a hair can be analyzed for DNA? *Obj. 3.5*
 - a) root
 - b) cuticle
 - c) medulla
 - d) cortex

16

17

11. The cuticle scales of the hair always point toward the *Obj. 3.2 and 3.5*
- a) root
 - b) medulla
 - c) tip of the hair
 - d) follicle
12. The period of active hair growth is called the _____ stage. *Obj. 3.1*
- a) catagen
 - b) telogen
 - c) anagen
 - d) imagen
13. Although variations can occur, which of the following best describes northern European hair? *Obj. 3.7*
- a) kinky with dense, unevenly distributed pigment
 - b) straight with evenly distributed granules
 - c) round cross section with a large diameter
 - d) coarse with a thick cuticle and a continuous medulla
14. Which of the following is most likely a result of hair bleaching? *Obj. 3.5*
- a) increased number of disulfide bonds
 - b) a yellowish tint to the hair
 - c) a more triangular cross section
 - d) thickened scales on the cuticle

Short Answer

15. Why is hair considered class evidence? *Obj. 3.5*

16. Describe the structure of hair. Include in your answer the terms *follicle, medulla, cortex, and cuticle*. *Obj. 3.1 and 3.2*

17. Crime-scene investigators collected hair from a dead person's body. One of the first things that needs to be established is if this hair is human or animal. Describe two ways that animal hair differs from human hair. *Obj. 3.3*

18. The body of a woman was found in the woods. Some hair fibers found on the body were sent to the crime lab for analysis. The ends of the hair attached to the body were gray, but the tips of the hair showed that it had been dyed. The distance from the root of the hair to the beginning of the dyed area measured 8 mm. Investigators determined that the victim's hair had last been dyed on August 1, 2004. Assuming the hair grows at the rate of 0.44 mm per day, on approximately what date did the woman die? Explain your answer. *Obj. 3.5*

19. Calculate the medullary index of a hair whose diameter is 110 microns wide and whose medulla measures 58 microns. Is this a human or animal hair? *Obj. 3.3 and 3.6*

20. A woman with long hair is a suspect in a burglary case. At the crime scene, several long hairs were found attached to a broken lock of the safe. The police obtain a warrant and request a sample of 25 to 50 hairs from this woman. They tell the woman it is important that they pull the hairs from her head rather than to merely cut the hairs. The police suspect that the woman was stealing to help support a drug habit. *Obj. 3.4, 3.5, and 3.7*
- Why is it important that the police pull the hairs from her head rather than cut her hair?
 - Why is it necessary to obtain 25 to 50 hairs from this woman?
 - The woman denies that she is currently taking drugs and states that she stopped using drugs a year ago. Explain how the police can determine if the woman has been off drugs for over one year.
 - Suppose the hairs of the woman match the hairs found at the crime scene. Why does this not necessarily prove that she was the guilty party?

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ACTIVITY 3-1 *Ch. Obj. 3.1, 3.2, 3.4, 3.5, 3.6, and 3.7*

TRACE EVIDENCE: HAIR

Objectives:

By the end of this activity, you will be able to:

1. Describe the external structure of hair.
2. Distinguish between different hair samples based on color, medulla types, cuticle types, thickness, and length.
3. Compare a suspect's hair with the hair found at a crime scene.
4. Form a hypothesis as to which suspect could have been present at a crime scene.
5. Justify whether or not a suspect's hair sample matches the hair sample left at a crime scene.

Time Required to Complete Activity: 60 minutes

Introduction:

In this laboratory exercise, you will work with hair evidence that was collected at a crime scene. Your task is to try to match the hair evidence that was collected at the crime scene with hair collected from four suspects.

Materials:

Activity 3-1 Lab Sheet
plastic microscope slides
clear plastic tape
compound microscope
prepared slides of hair samples
2 glass slides
glass cover slips
scissors
clear nail polish

Safety Precautions:

Always carry a microscope using both hands.
Do not get nail polish on the lens.

Scenario:

A murder was committed. To dispose of the body, the suspect(s) tossed the body from the car into a ditch. When crime-scene investigators arrived, they photographed the crime scene and drew sketches of the body. Hair evidence was found on the victim. Hair samples were collected from the four suspects, as well as a sample of hair taken from the victim's head. At the crime lab, a comparison microscope was used to examine each of the hair samples. Your task is to examine all hair samples under the compound microscope and record your observations. After reviewing all samples, determine if any of the suspects' hair matches the hair found at the crime scene. You will need to justify your decision.

Procedure:

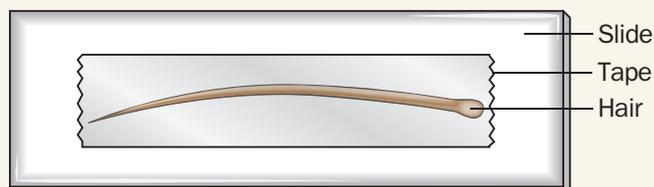
Part 1: Cuticle Impression

1. Obtain a clean glass slide.
2. Place the slide along the edge of the desk.
3. Wipe a thin layer of nail polish on the slide the length and width of a cover slip.
4. Either pull out or cut a hair from your head.
5. While holding onto the hair between two fingers in front of the slide, slowly lower the hair onto the slide being careful not to wiggle the hair back and forth. Pull the hair down into the nail polish and let go of the hair.
6. Wait 10 minutes to remove the hair.
7. After 10 minutes, grasp the loose end of the hair and pull straight up to completely remove the hair from the nail polish.
8. Observe the slide under 100 \times . Sketch your cuticle.



Part 2: Observation of Your Own Hair

1. Obtain a plastic slide. Write your initials on the end of the slide.
2. Remove a hair from your head, preferably a hair that contains a root. You may pull it out or use scissors to cut it.
3. Place the hair on your desk.
4. Fold the tape with the sticky side facing the hair on the table. Hold the tape near the hair, but do not touch the hair. The hair should be attracted to the sticky surface of the tape.
5. Place the tape with the attached hair to the plastic slide. Use your finger to press down on the tape to squeeze out any air pockets. Cut off the excess tape. You now have a permanent slide.



The finished slide.

6. Label the slide with your name using a permanent marking pen.
7. Focus the hair using 100 \times magnification.
 - a. Draw your hair in the space provided on Data Table 1.
 - b. Identify the type of medulla, cuticle, color, and any other distinguishing features.

Data Table 1

Source of Hair	Sketch	Color	Medulla	Cuticle	Straight or Curly	Other Characteristics
Your name						



Part 3: Comparative Analysis of Suspect and Crime Scene Hair

1. Obtain a slide of the victim's hair from the envelope prepared by your instructor. Draw a sketch of the victim's hair, and record all of the information in Data Table 2. Return the slide to the envelope as soon as you are finished so that someone else can use the slide.
2. Look at each of the four suspects' hairs. Draw sketches and record all required information in Data Table 2. Please take only one slide at a time!
3. You will need to rule out that the hair found on the victim did not come from the victim's own head. You will need to examine the sample entitled "Victim's Own Hair."
4. Compare your results with another classmate. If you find you have different answers, it might be necessary to examine more than one hair sample from any individual. Recall that not all hairs are exactly alike.
5. Is it possible to match any of the suspects' hair with the evidence hair that was found on the victim? Be prepared to justify your answer using forensic evidence.
6. Record your results in Final Analysis.

Final Analysis:

1. Does your crime scene hair match any of the suspects' hairs? If yes, which particular suspect?
2. Cite three different characteristics of hair that can be used to support your answer to question number 1. Use complete sentences and correct terminology.



Data Table 2

Source of Hair	Sketch	Color	Medulla	Cuticle	Straight or Curly	Other Characteristics
Crime Scene Hair						
Suspect 1						
Suspect 2						
Suspect 3						
Suspect 4						
Victim's Own Hair						



ACTIVITY 3-2 *Ch. Obj. 3.2, 3.4, 3.5, and 3.6*

HAIR MEASUREMENT AND MATCH

Objectives:

By the end of this activity, you will be able to:

1. Describe how to measure the diameter of a hair that is viewed under a compound microscope.
2. Measure hair samples and determine if the diameter of the hair samples from different sources are the same.

Time Required to Complete Activity: 60 minutes

Introduction:

Hair is an example of trace evidence that can be left at a crime scene or removed from a crime scene (Locard's exchange principle). Although hair is not unique to a specific person, it can be used to identify a class of individuals. (The exception to this occurs if the root of the hair is present and DNA can be extracted and a match made with a crime-scene sample.)

Materials:

(per group of 2 students)
Activity 3-4 Lab Sheet
compound microscope
clear plastic mm ruler
2 glass slides
dropper of fresh water
pencil
pre-made slide of crime scene hair
pre-made slide of the victim's hair
pre-made slide of suspect #1 hair
pre-made slide of suspect #2 hair
pre-made slide of suspect #3 hair

Safety Precautions:

Always carry the microscope with both hands.
No special safety concerns

Scenario

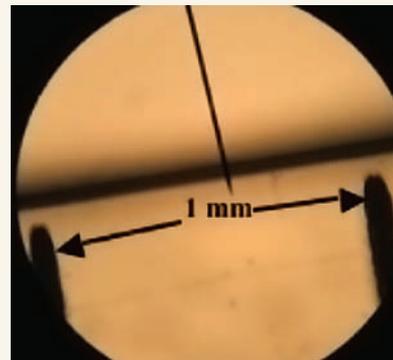
You might say that some people's hair is very fine. Others may have hair that is very coarse. The diameter of the hair provides us with another way to compare a suspect's hair to the crime scene hair. In this lab activity, you will compare the crime scene hair with three suspect's hairs by comparing their medulla, cortex, and cuticle types, as well as compare the diameter of the hair samples.

Procedure:

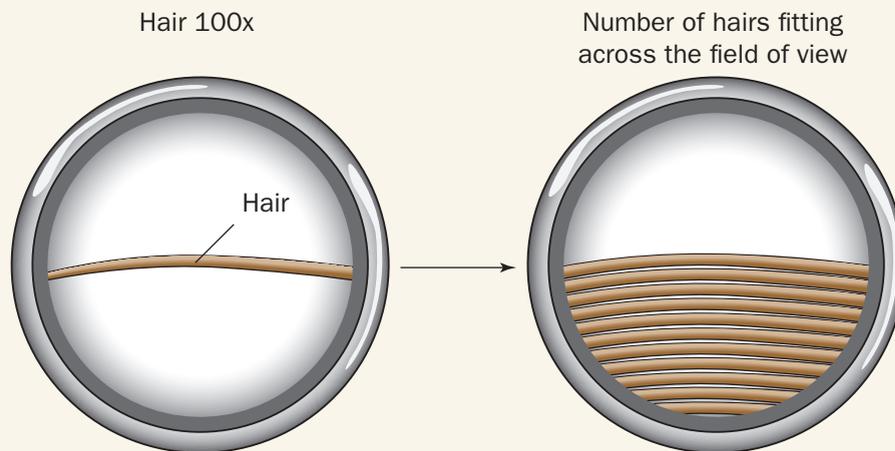
1. Measure the size of the diameter of the microscope under 100×.
 - a. If an ocular micrometer is available, measure the diameter of the field of view. (Most microscopes have a field of view of approximately 1.2 mm.)
 - b. If an ocular micrometer is not available:
 - Place a small, clear plastic ruler under the microscope under 100×.
 - Focus on the metric side of the ruler.
 - Measure the diameter of the field of view to the nearest tenth of a millimeter.
 - Record your answer in Data Table 1.
2. Pull out one of your hairs and place it in a drop of water on a microscope slide.
3. Place a cover slip over the hair and view under LOW power (100×).
4. Note the following characteristics of your hair and record the information in Data Table 2:
 - Color of cortex
 - Type of medulla (e.g., continuous, interrupted, fragmented, solid, none)
 - Type of cuticle (e.g., spinous, coronal, or imbricate)
5. Measure or estimate the width of the hair using the diameter of your field of view as a reference. Record your answer in Data Table 2. For example: Center your hair so that it is in the middle of the field of view. Estimate how many hairs would fit across the field of view (100×).



Plastic ruler viewed under 100×.



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It appears that about 10.5 hairs fit across half of the diameter of the field of view (100×). Therefore, it would take about twice as many hairs (or $2 \times 10.5 = 21$ hairs) to fit across the field of view.

The diameter of the single hair is $\frac{1}{21}$ of the diameter of the field of view.

If the diameter is 1.2 mm, or 1200 microns, then the size of a single hair is:

Diameter	= $\frac{1}{21}$ of 1.2 mm Diameter	= $\frac{1}{21}$ of 1200 microns
	= 0.05×1.2 mm	= 0.05×1200 microns
	= 0.06 mm	= 60 microns



6. Focus your hair under 400 \times . Draw a sketch of your hair. Record your answer in Data Table 2.
7. The diameter of the high-power (400 \times) field of view is $\frac{1}{4}$ of the diameter of the field of view under 100 \times , or approximately 300 microns. Calculate the diameter of your field of view under 400 \times in microns. Record your answer in Data Table 3.
8. Obtain a pre-made slide of a hair sample from the crime scene from your teacher. Measure (or estimate) the diameter of the hair in microns. Record your observations and sketch the hair sample in Data Table 4.

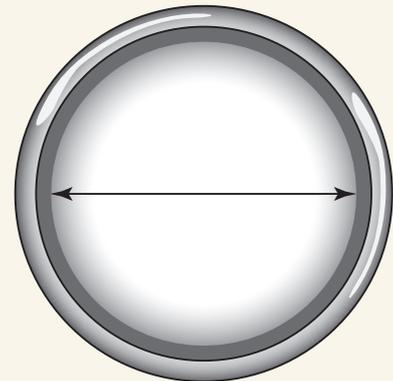
You will need to record the following information:

- Sample number
 - Width of the hair in microns
 - Color of cortex
 - Type of medulla
 - Type of cuticle
 - Straight, curly, or kinky
9. Obtain a premade slide of a suspect's hair sample from your instructor. Measure (or estimate) the diameter of the hair in microns. Record your observations and sketch the hair sample in Data Table 4.

You will need to record the following information:

- Sample number
 - Width of the hair in microns
 - Color of cortex
 - Type of medulla
 - Type of cuticle
 - Straight, curly, or kinky
10. Based on the forensic analysis of hair and the size of the hair's diameter, would you consider the suspect's hair to match the evidence or crime scene hair? Justify your answer using the information recorded in your Data Table 4.
 11. Check with your classmates regarding the other suspects' hair sample analysis. Did anyone find a hair sample that did seem to match the hair evidence left at the crime scene? Does more than one hair sample match the hair sample left at the crime scene?
 12. Record the data obtained from your classmates regarding the other suspects' hair samples to Data Table 5. You do not need to view these slides under the microscope since your team of classmates is sharing their data with you. Indicate whether these two other suspects' hair matches the crime-scene hair and justify your answer.

Diameter of the field of view at high power = $(\frac{1}{4}) \times$ diameter at low power.



Bonus:

Describe how you can determine that the hair sample left at the crime scene is definitely a human hair and not an animal's hair. Include calculations in your answer. Record your answer on the last page of the data sheet.

Data Table 1: Size of Field of View Under 100×

Diameter of Field of View under 100×	
(millimeters)	(microns)



Data Table 2: Your Own Hair

Your Name	Color Cuticle	Type of Medulla	Type of Cuticle	Straight, Curly, or Kinky	Width in Microns	Sketch

Data Table 3: Size of Microscope Diameter under 400×

Diameter of Field of View 100× in Microns	Calculations $\frac{1}{4}$ Diameter of Field of View under 100×	Diameter of Field of View under 400× Microns

Data Table 4: Whose Hair Matches the Crime-Scene Hair?

Hair Sample	Color Cuticle	Type of Medulla	Type of Cuticle	Straight, Curly, or Kinky	Width in Microns	Sketch
Crime Scene						

Hair Sample #	Match? or Not a Match	Justification

Data Table 5: Check with Two Other Classmates

Hair Sample #	Match? or Not a Match?	Justification
Sample # _____		
Sample # _____		

Thought Questions:

Explain each of your answers.

1. Is it possible that none of the hair samples matches the hair found at the crime scene?
2. Is it possible that more than one person's hair matches the crime scene?
3. If someone's hair does match the crime-scene evidence, does that mean that he or she committed the crime?
4. If someone's hair did match the crime scene, what type of evidence could be obtained to indicate that the DNA at the crime scene is a match to their DNA and not to anyone else's DNA?

Return all materials, complete this sheet, and hand it in during your lab. Explore further information at links on the Forensic Fundamentals and Investigations web site at school.cengage.com/forensicscience.

Bonus:

Is the last sample animal hair or human hair? Explain your answer.

ACTIVITY 3-3 Ch. Obj. 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, and 3.7

HAIR TESTIMONY ESSAY



Objectives:

By the end of this activity, you will be able to:

1. Write a clear and organized essay.
2. Describe the basics of forensic hair analysis.
3. Explain why hair is considered class evidence.
4. Write a convincing argument stating your case that the suspect's hair either matches the hair found at the crime scene or that the hair does not match hair found at a crime scene

Time Required to Complete Activity: 1.5 to 2 hours

Background:

Your task is to write an essay. You are an expert witness called on to testify in a court case. You are asked to prepare a presentation to the jury that will demonstrate that a particular suspect can be linked to the crime scene. You should assume that the jury knows nothing about hair. Your paper should be typed (double-spaced), with paragraphs separating major ideas. Use spellcheck to correct any spelling errors.

Procedure:

You should prepare:

1. An introductory paragraph addressing the following questions:
 - a. Who are you?
 - b. Why are you here?
 - c. Remember: do not cite specific information about hair within your opening statement to the jury.
2. A body paragraph in which you educate the jury about hair.
 - a. Include a graphic or visual aid. Cite the source of your picture.
 - b. Define all terms.
 - c. Describe what characteristics or traits to look for when analyzing hair.
 - Macroscopically
 - Microscopically
3. Another body paragraph in which you convince the jury why you believe a particular suspect is a match to the hair found at the crime scene.
 - a. Recall that hair is class evidence, and describe how it pertains to your argument.
 - b. Recall that the hair could have been left at the crime scene prior to the murder.
 - c. Your job is to convince the jury that the crime-scene hair evidence is a match to a particular suspect.
4. A concluding paragraph in which you:
 - a. Summarize your findings.
 - b. Remind them you are an expert.
 - c. Restate your conclusion about the evidence hair and the crime-scene hair.
 - d. Remember: do not introduce any new information in your conclusion.