The SCIENCE OF TATTOOING

HANNAH WOLF

The Science of Tattooing
5250 College Ave
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www.thescienceoftattooing.com

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Director

Hannah Wolf

Authors

Dr.David Warmflash
Dr. Shelley Mason
Dr. Kevin Choo

Peer Review Team

Selina Medina
Laurel Arrigona
KC Stevenson
Jennifer Walker

Editors

Beth Schechter
Louisa Jordan

INTRODUCTION

At the time of this book's publication in 2019, regulation was starting to play a more prominent role in the tattoo industry. Local municipalities are becoming more involved with the tattoo industry and we are starting to see the federal government show more interest about the materials used in tattooing. When I started tattooing in 2003, adherence to public safety measures was more of a suggestion and not an enforced requirement for tattoo studios. Artists were not required to register with health departments. The shop had an autoclave, that was regulated by the health department, and the business owner was required to do periodic spore testing. This was the only requirement public health and safety officials placed on our studio. My mentor taught me about cross contamination and simple tasks like how to appropriately take off gloves. As with most apprenticeships at that time, I received valuable information from a few experts within our industry. Tattooing seemed like a mystic dark art, filled with alchemy and unexplainable secrets.

Nearly everyone in the industry I met back then had the view that sharing knowledge and information was dangerous and inappropriate; however, when you learned from someone who knew, you sure did learn a lot. The problem was, at that time, there was no Google or other references on the internet for fact checking. Those who learned this craft before the opening of the world wide web had a very hard learning curve. Even today, the spread of misinformation and "fake news" in tattooing was one of my motivations to write this book.

I had questions I wanted answered but I could not find the answers. I had others asking me questions and I felt terrible I could not answer their questions. After nearly two decades in this craft, it was time for some answers. Tattooing has become too accessible and popular for operators to not take control of our own education and knowledge of our materials. I hope this book opens many doors in the future for tattoo artists, and collectors alike, to

arm ourselves with the knowledge we need to protect ourselves and our industry from negligence and ignorance.

I had a traditional apprenticeship. I would spend my days building needles, cleaning, tuning machines, and keeping every element of the shop in an orderly condition. By the time I started tattooing in the early 2000s, most materials were available by mail order and making our own materials was no longer a necessity. I was fortunate to learn how to create and build all the materials involved in the tattoo process from my mentor and other individuals along the way. Once or twice, I made my own ink and learned about metal conductivity and what chemicals could be used for soldering. I have always had a curiosity in this world, and even with what I had lerned so far, I still had so many questions. Questions that up until I started this book, I could not answer in full detail. Questions about what exactly is in tattoo ink? What are autoimmune conditions? How can that affect tattooing? When should I deny tattoos to clients? What is an allergic reaction and why do they happen?

Turns out, it was difficult to find some of the answers to questions that not only did I have, but my clients had, too. Well, I did the research and I hope this book answers some of the questions you have. I would love to hear more questions that this book doesn't answer. This is only the first edition in a series of publications and educational materials, that I hope will help everyone better understand the dark side of tattooing. Knowledge can bring power and the more we educate ourselves about this phenomenon we love, the more we can keep this crazy ride on the right track. Thank you for taking the time to read my introduction and this book. Let's work on making a smarter and safer tomorrow.

-Hannah Wolf

TABLE OF CONTENTS

SENSING & PERCEPTION: PAIN & SIGHT

Unit 1: Overview & Inquiry

Topics Covered

- The contrast and relationship between sensing and perception on a physiological level.
- The somatosensory system, including the central and peripheral nervous systems.
- How pain is perceived and processed in the body.
- How light and color are sensed and perceived.

Questions to Keep in Mind

- What is the difference between sensing and perception? What are the different stages of perception?
- What are the different parts of the nervous system and how do they work?
- What are the different kinds of stimuli that the body may interact with? What are they called?
- How does the body process chemical and mechanical elements differently? What is similar about those processes?
- What specific parts of the body sense and perceive pain?
- What is the Electromagnetic Spectrum? What is its role in how the body senses and perceives light and color?

How does the body sense the world around it and experience pain?

Tattoos are associated with pain, and for good reason: the practice involves puncturing the skin hundreds if not thousands of times a minute to create a (hopefully) beautiful work of art. Depending on the size and complexity of the piece, this experience may require multiple sessions, each lasting many hours. What is happening at a physiological level within the body when humans experience this pain?

The answer has to do with the body's mechanics of sensing and perception, which in this case starts in the skin and travels to the brain through a network of nerves. This unit takes an in-depth look at the mechanics specific to the transmission of pain, so that readers can gain an understanding of what the nervous system does in response to the stimulus of receiving a tattoo and healing from the procedure.

The other key sensory function at play with tattoos is vision—how human eyes take in light and transform it into color and images. Thus—in addition to covering the basics of sensation, perception, and pain—this unit also includes an overview of how sight works.

The information in this unit is also foundational for understanding the specifics of why people experience certain reactions to inks, needles, the environment, or other stimuli. Details of adverse reactions and side effects will be presented in detail in Chapter 12.

Tattooing and the Perception of Touch and Pain

Getting a tattoo involves the sensation of pressure when the skin is stretched by the tattoo artist and vibrations from the tattoo machine as the needles rapidly move up and down and repeatedly puncture the skin. However, when the tattoo machine stops and the tattoo artist releases the tension of the skin being stretched, there is a momentary sensation from the freedom of the grip and absence of vibration felt by the client.

A tattoo also requires the mechanical violation of the topmost layers of the skin. Tattoos are essentially puncture wounds made deep within the dermal layer of skin. Both the epidermis and dermis are innervated (supplied with nerves) with sensory nerves that relay information from the skin to the brain where it is processed into pain or other sensations. These sensory nerves function to sense and transmit heat, pain, and other noxious sensations (John Hopkins Medicine 2018).

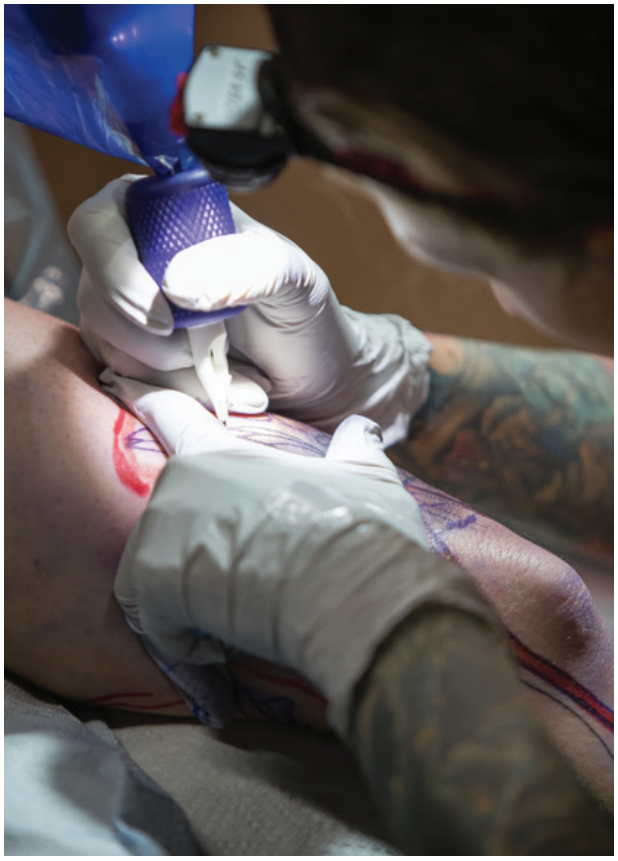


Figure 1: Tattoo artist tattooing a client.

The perception of pain is greatly dependent on the individual getting tattooed and the context in which it occurs. Although pain is generally felt throughout the tattooing process, there can be a diminished response to the vibration and stretching experienced early in the procedure. This has to do with a combination of factors, including sensory adaptation and the conscious response by the client.

1 NEUROPHYSIOLOGY OF SENSATION & PERCEPTION

By Dr. Shelley Mason

Most people are familiar with the five **senses**—sight, hearing, taste, touch, and smell—but it turns out that there are many more (Fig. 2). Scientists have discovered between 14 and 20 different senses, depending on how the word is defined. For example, proprioception senses the position of a body part relative to the rest of the body. Humans perceive many things in relation to proprioception, including spatial orientation, movement, vibration, temperature, pain, hunger, and also time. Additionally, neural transmissions from mechano- (mechanical) and chemo- (chemical) receptors located within our internal organs allow us to monitor changes in pressure or chemical balance.

This process of sensing environmental stimuli **neurophysiologically** (through the brain and body) is called sensory perception. **Sensory perception** requires the ability to detect, recognize, and interpret an internal or external stimulus and understand where the signal originated. The ability to sense helps humans learn about the surrounding environment while comprehending the internal state of being. Senses help govern behavior while navigating dynamic terrain and external surroundings.

Distinguishing Sensation and Perception

Sensation and perception are often used synonymousl but are in fact distinct phenomena. The sensation of a stimulus occurs through the activation of sensory receptor cells and sensory organs. Perception is the awareness and interpretation of a sensation. How the world is perceived is unique to each individual.

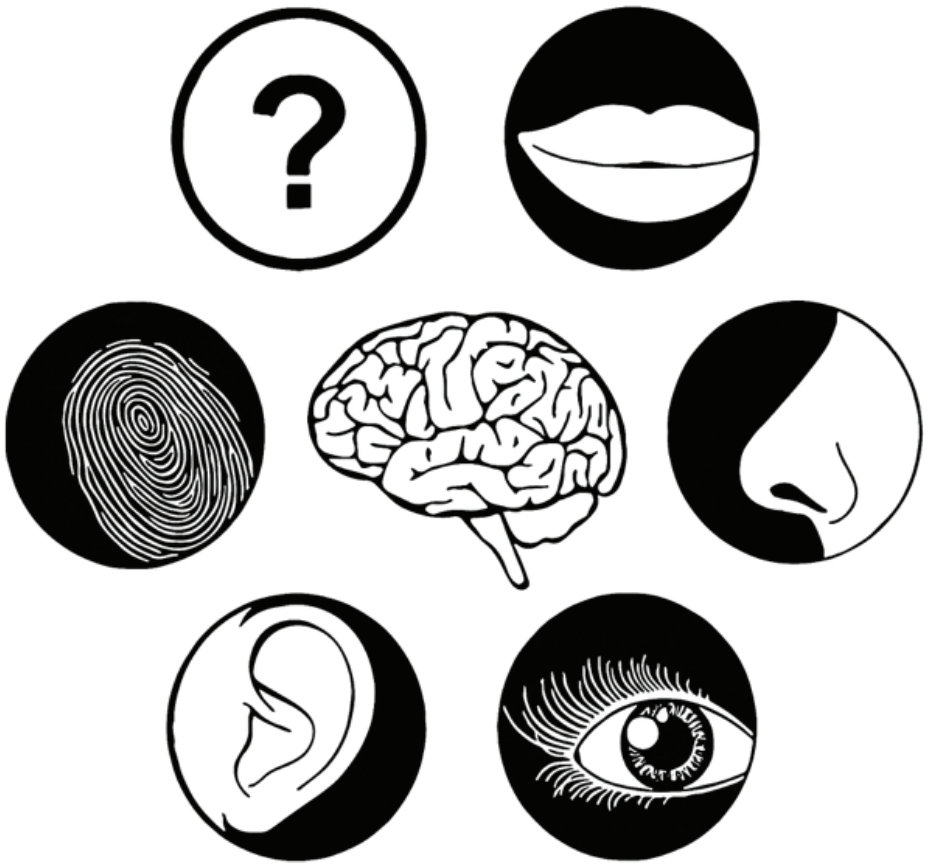


Figure 2: The misconception about human senses. People are often taught about having five senses as if they are the only senses of the human body, but in reality, there are many more.

Take Figure 3, for example—Rubin's Vase or Rubin's Face—which illustrates how the visual cues in an image can be perceived differently. Is it a mirror image of a vase or of two faces? Is it possible to see a face and a vase at the same time, or does the image switch from one to the other? If the image is inverted, does the focal object change? If someone speaks the word "face," is it possible to concentrate on the vase or does the focus switch back to the face? What we think we see in the image changes with our conscious focus. How humans look at the world has more to it than just light particles entering the visual field and sending waves of signal patterns to the brain (covered later in this unit). There is a level of awareness and interpretation associated with conscious thought.

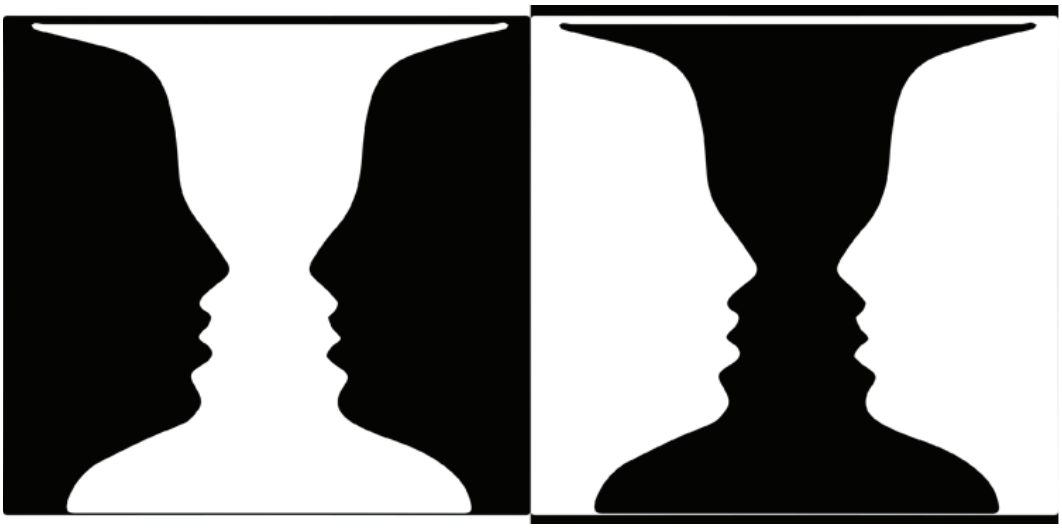


Figure 3: Rubin's Vase or Rubin's Face. This illusion is known as the "Rubin Vase" because it was created by Edgar Rubin. It is an example of an image that has two different states.

When people look at an object within their focal plane, they not only see; they observe. Observation helps people to gain information about their ever-dynamic environment, using all of their senses and conscious thought processes simultaneously. When someone hears something, they often look in the direction of the sound. When someone smells something, they often glance toward the source of the odor. Thus, sensing is not an isolated process. It can also often be compromised and biased, which is why taste testers wear blindfolds.

2 SENSORY RECEPTION

By Dr. Shelley Mason

While the previous chapter discussed how sensing is distinguished from perceiving, this chapter covers sensing in detail. In contrast to perception—which has to do with how people interpret events—sensing is primarily a physiological process. It functions in the nervous system and its myriad of receptors, which all work together through a series of electrochemical impulses. Understanding this system is key to understanding how the body responds to the environment, including in the detection of pain.

The Central and Peripheral Nervous Systems

A key component in sensation is the nervous system, which encompasses two sub-systems: the **central nervous system (CNS)** and the **peripheral nervous system (PNS**) (fig. 4). The brain and spinal cord make up the CNS, which receives, processes, and transmits information to and from the PNS. The CNS encompasses discrete centers that integrate incoming sensory information and execute sensory and motor responses. The lower centers (**spinal cord** and **brain stem**) and higher centers (**cerebral cortex**) are involved in higher conscious thought and function.

The PNS is composed of nerves and **ganglia** (a bundle of nerve cell bodies) that are connected to the brain and the spinal cord but are outside of the CNS. The PNS is an extensive network of spinal and cranial nerves that run throughout the body and contain sensory receptors, which relay information to the CNS about the ever-changing environment.

Neurons are the cells that make up the brain as well as the rest of the nervous system. Neurons are sometimes also referred to as nerves or nerve cells.

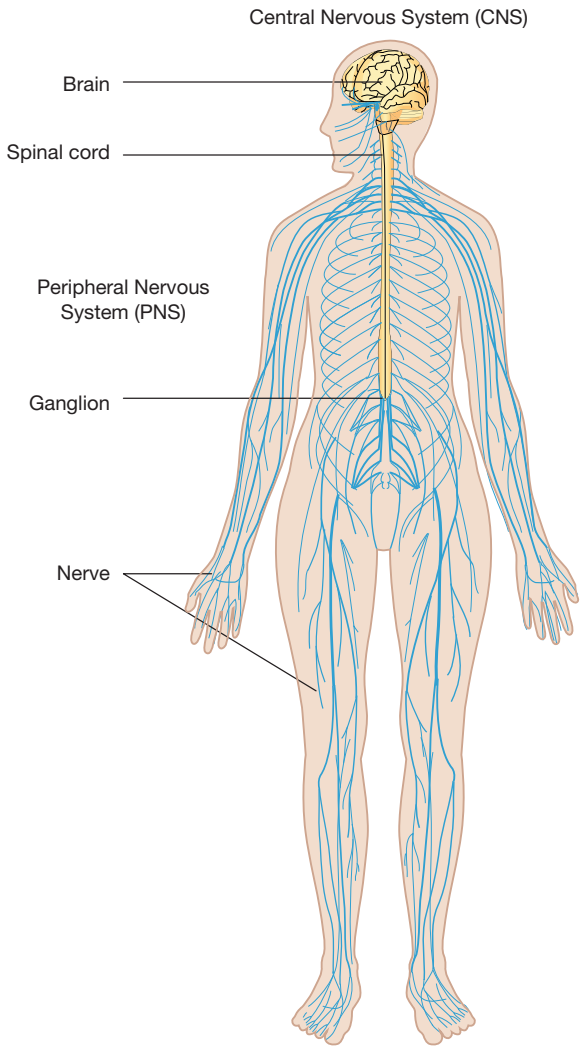


Figure 4: The nervous system. The brain and spinal cord make up the central nervous system (CNS), and the peripheral nervous system (PNS) is comprised of the nerves and ganglion outside of the CNS.

Sensory Receptors

An external stimulus initially captures the attention of the human body through specialized **sensory receptor cells**. **Sensory organs**—like the eyes, ears, cochlea (which control equilibrium), nose, tongue, and skin—are composed of these specialized receptors, which can capture and convert information from the external world.

Different types of stimuli—which may be **intrinsic** (a natural part of the internal system) or **extrinsic** (operating from outside that system)—activate different types of receptor cells. Eyes turn light into an electrical impulse, which is transported by the optic nerves to allow humans to see. People can taste and smell because specialized receptor cells in the nose and on the tongue convert chemical molecules into an electrical impulse that is relayed to and understood by the brain. Specialized neurons under the skin sense pressure, temperature, vibration, and pain, transforming them into sensations communicating an interaction with the external world. This means sensory organs are receivers and transducers: they convert the five types of environmental stimuli—chemical, mechanical, electrical, light, and temperature—into electrical signals that the brain can understand. This conversion process is known as **transduction**.

Types of Sensory Receptors

Sensory receptors are categorized by the nature of the stimuli that they transduce, which include:

- **Mechanoreceptors**, which sense mechanical stimuli (such as touch or sound);
- **Thermoreceptors**, which sense thermal stimuli (like heat or cold);
- **Proprioceptors**, which sense kinesthetic stimuli (such as body position or the flexing of a muscle);
- **Baroreceptors**, which sense arterial stretch and pressure (pressure in the aorta of the heart);
- **Nociceptors**, which sense stimuli that cause pain; and
- **Chemoreceptors**, which sense chemical stimuli (including taste).

Some sensory receptor classes are interchangeable (fig. 5). For example, thermoreceptors can be involved in nociception when detecting high levels of heat. Mechanoreceptors can also be proprioceptors when, for example, the left hand lays on top of the right. Many, if not all these types of reception, are at play in the experience of getting a tattoo. Of them, mechanoreception and nociception are the most relevant to cover in this book.

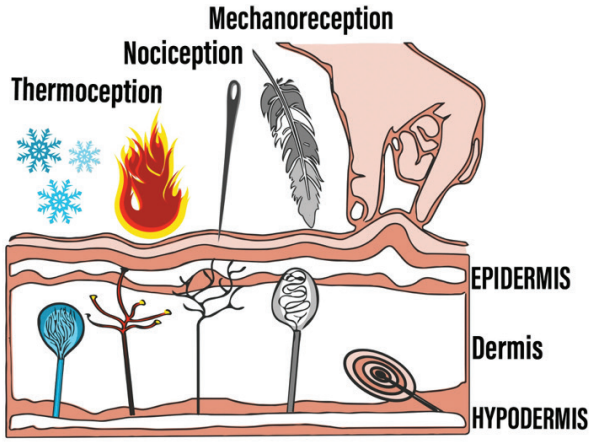


Figure 5: Somatosensory receptors and sensations. The physiology of somatosensory receptors, such as thermoreceptors, nociceptors, and mechanoreceptors, tend to overlap.

Mechanoreception

Mechanoreceptors respond to a broad range of extrinsic and intrinsic stimuli, including touch, pressure, stretching, movement, vibration, and itching. There are many different types of mechanoreceptors, including some specialized mechanoreceptors only found in complex animals like humans. These act to inform the body of changes to stimuli, such as posture, painful stimulation (nociception), and sound.

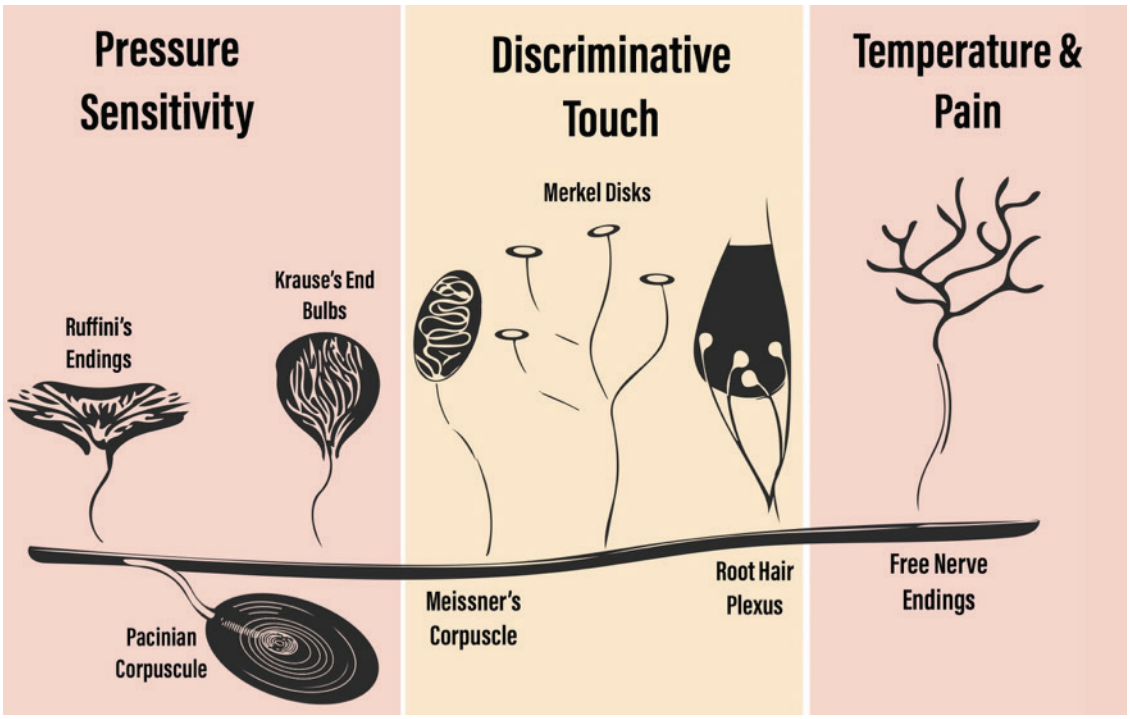


Figure 6: Examples of touch mechanoreceptors. In the skin and internal organs there are mechanoreceptors that sense various forces of pressure, discriminative or (fine) touch, and temperature and pain.

Each receptor is connected to a **sensory neuron**—a neuron that carries information from a sensory organ to the brain. It works by initiating a nerve impulse in response to physical **deformation** by an external force, such as touch or sound waves. In the skin and various internal organs, some mechanoreceptors are sensitive to forces of pressure, discriminative (fine) touch, and temperature and pain (fig. 6).

Touch receptors are found in the skin—the largest organ in the body—but they are not evenly distributed by type or number. Some parts of the body are much more sensitive to touch due to the concentration and type of mechanoreceptors found within the skin. For example, there are more mechanoreceptors in the fingers and palms than on the back of the hand. This is why the back of the hand is less sensitive than the palm and fingers. The type, combination, and concentration of mechanoreceptors determine the perception of a sensation, which can vary from person to person. Sensitivity to mechanical stimuli—such as touch and pressure—is unique in every individual.

Nociception (Pain)

Nociceptors respond to mechanical, thermal, and chemical stimuli that are noxious or, in other words, nociceptive. The sensation perceived has to do with how a sensory receptor receives a stimulatory signal; therefore, the perception of pain depends on how a nociceptor is deformed in order to activate it. The sensation of pain can be a short, intense feeling of pain that subsides, a brief dull throb, or a chronic ache. As discussed above, the sensation of pain can involve mechanoreception, thermoreception, and chemoreception. As with mechanoreception, the perception of pain is unique to all individuals.

Electrochemistry & Sensing

As mentioned earlier in this chapter, receptors translate internal and external stimuli into electrical impulses in a process called transduction. Nerves themselves work as microscopic electrical circuits in the body, and they work that way because of positive and negative charges in and around the cell bodies. This section covers the specifics of how that process works. Understanding it involves a little knowledge of chemistry, which will be covered briefly here. Chemistry fundamentals will be covered more in-depth in Unit 2

Membrane Potential & Action Potential

When in a resting state, a neuron is positively charged along the outer surface of the cell membrane and negatively charged along the inner surface of the membrane. This results in a **resting potential** of -70 millivolts (mV) across the membrane, meaning that the cell is literally a little battery. In this resting state, special pumps within the membrane are constantly pumping sodium cations (Na^+) outward from within the cell and pumping potassium cations (K^+) into the cell from the outside. This creates **ion gradients** that want to drive Na^+ into the cell and K^+ out of the cell, like the air that always wants to leave a balloon (fig. 7).

When the neuron is stimulated, however, special channels in the membrane open, allowing Na^+ to rush into the cell from the extracellular fluid. This influx of sodium cations causes a momentary flip in electrical polarity, or **depolarization**, along the membrane. This phenomenon brings the membrane potential from -70mV to roughly +30 to +40 mV. Almost immediately,

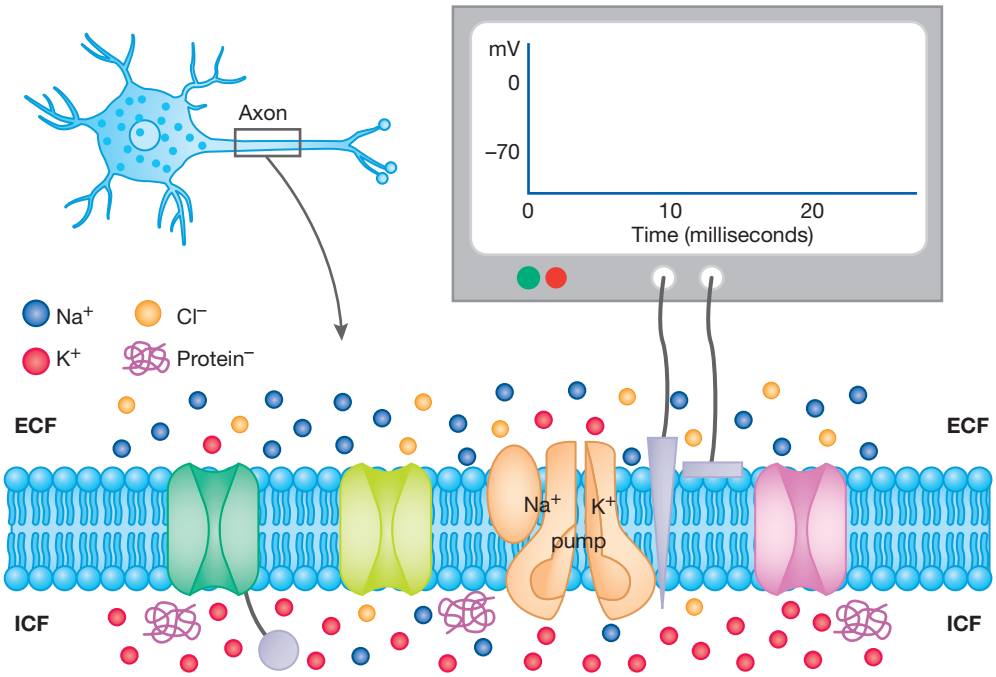


Figure 7: The resting potential across the cell membrane of a neuron is maintained by pumps acting on ions. Other entities, especially chloride anions outside the cell and proteins inside, carry negative charges. These balance out positive charges in fluid outside and inside the cell. Just along the membrane, however, there is a net positive charge outside and a net negative charge inside, resulting in the voltage across the membrane, which is the membrane potential.

however, other channels open, allowing K^+ to rush out of the cell, like air leaving a balloon through small holes. This movement of cations out of the cell repolarizes the cell to a membrane potential slightly more negative than -70 mV (fig. 8).

Then, more gradually, the action of the membrane pumps restores the normal resting potential by restoring the normal ion concentrations inside and outside the cell (fig. 9).

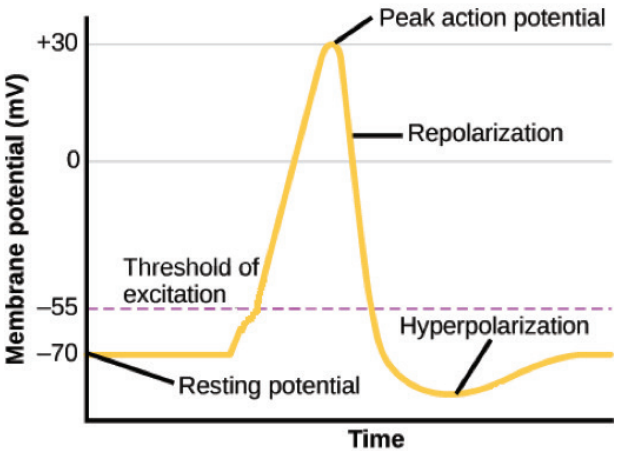


Figure 8: Change in membrane potential over time when a neuron is stimulated.

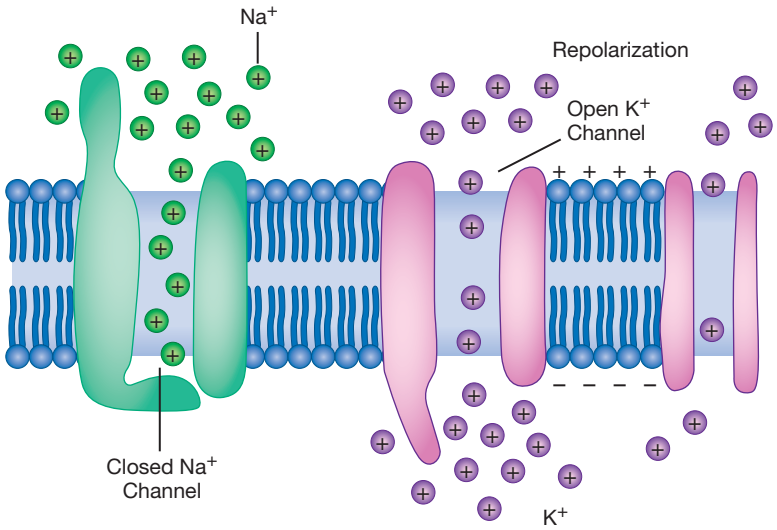


Figure 9: **Repolarization of the membrane** results from potassium channels in the membrane opening, thereby allowing potassium cations to leave the cell.

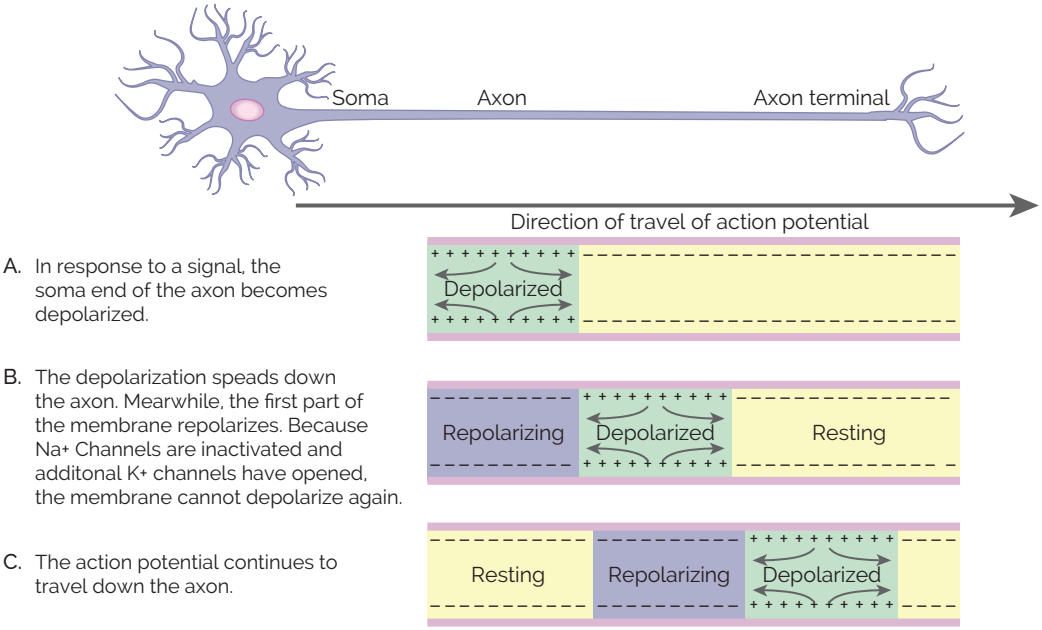


Figure 10: Propagation of an action potential along the axon of a neuron.

While the membrane recovers, the depolarization effect is transmitted along the neuron as a phenomenon called an *action potential*, which propagates along a long section of neuron, called the *axon* (fig. 10).

Electrochemistry, Mechanoreception, & Sensory Adaptation

In mechanoreceptors, nerve impulses occur in response to physical deformation by an external force such as touch, pressure, stretching, temperature, pain, motion, and sound waves. Any deformation of a mechanoreceptor can generate an action potential, which in turn induces an excitatory wave of information that is propagated to the CNS.

With continuous deformation, the frequency of action potentials decreases and eventually stops altogether due to a phenomenon referred to as **adaptation** (fig. 11). **Sensory adaptation** occurs in most sensory receptors, as it prevents the nervous system from being overwhelmed by continuously incoming but non-harmful information. Adaptation keeps people from feeling restricted by matter close to their bodies, such as clothing.

Adaptation rates vary among different types of sensory receptors. For example, sensory receptors involved in proprioception (movement of the limbs) are slow adapting, while mechanoreceptors that sense pressure tend to be fast adapting.

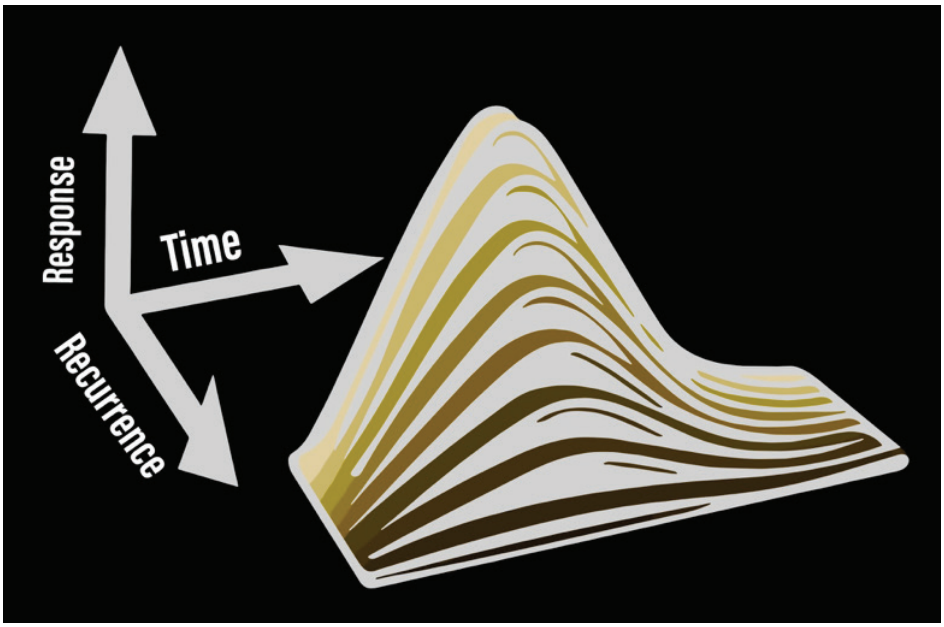


Figure 11: Sensory adaptation. Recurrent events of stimulation elicit progressively smaller responses. Sensitivity is significantly decreased when sensory receptors are subjected to constant stimulation.

3 THE SOMATOSENSORY SYSTEM: THE PERCEPTION OF TOUCH & PAIN

By Dr. Shelley Mason

Once a signal has been received by a sensory neuron, transformed into an action potential, and relayed to the brain, it can integrate with other sensory information. This integration often occurs with higher cognitive functions (awareness), bringing forth **perception**. Conscious perception of a stimulus can then guide a behavioral response (fig. 12), such as taking deep breaths through the pain associated with a long tattoo session.

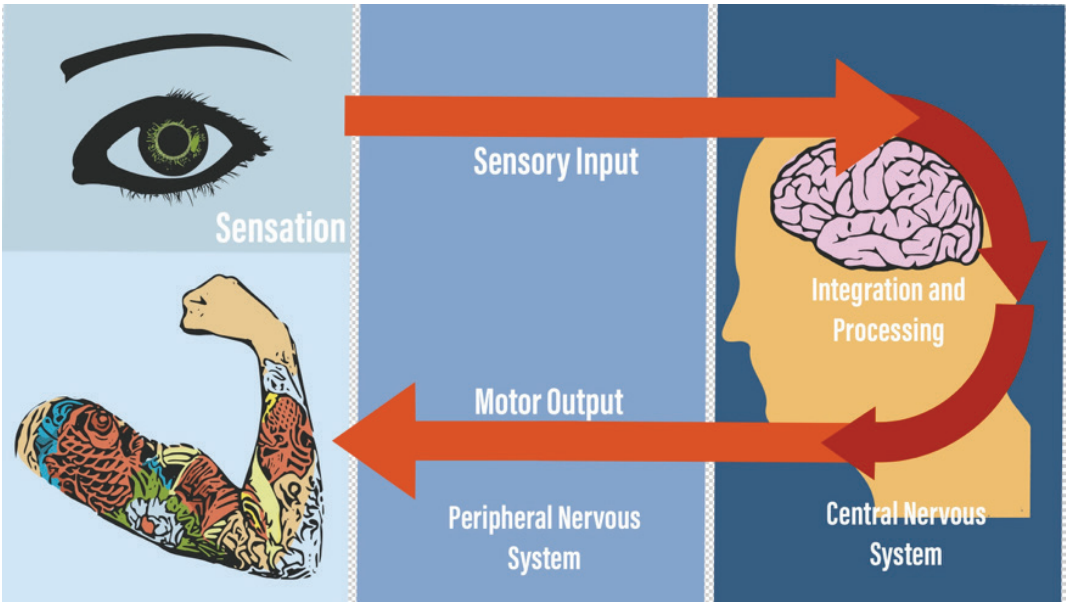


Figure 12: Sensory perception and information integration. Extrinsic stimuli elicit an action potential of a neuron, which is integrated with other sensory information in the CNS to become a conscious perception of the environmental stimulus.

In perception, people relate bits of information to past experiences, as well as beliefs, values, and memories. This interpretive function elucidates the meaning of an event and determines how to react, if necessary. Only perceived events stored in the brain's memory can be remembered or recalled. People use these previously formed associations and beliefs to remember the event and its personal effects. When we remember perceived information later, we recall the most important details of the event. Thus, perception has five steps: stimulation, organization, interpretation, memory, and recall—most of which happens in the brain.

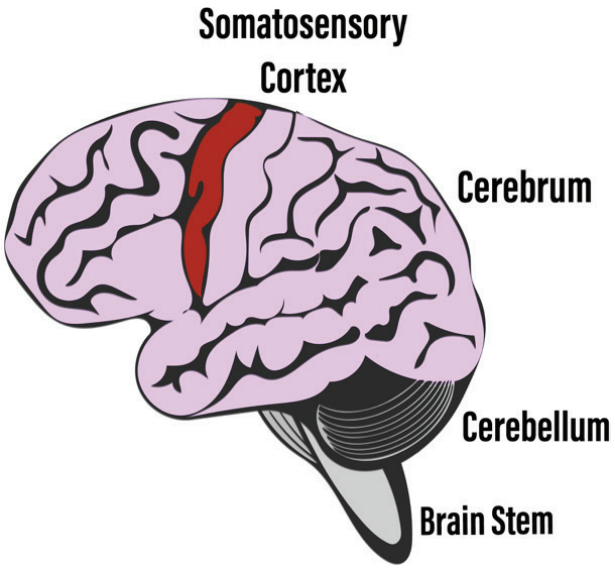


Figure 13: Somatosensory cortex. The somatosensory cortex is the area in the brain that processes conscious perception of touch and pain.

Somatosensory System Overview

The **somatosensory system is involved with the interrelationship between sensation and conscious perception.** The somatosensory system also includes the **visceral senses**, which provide information about the state of various internal organs, such as pain and pressure from water retention. The sensations and perceptions associated with the somatosensory system stem from sensory receptors located in the skin, bones, joints, fascia, skeletal muscles, internal organs, and parts of the cardiovascular system.

The primary somatosensory cortex (fig. 13) is an embodiment of the **cerebral cortex**, the part of the brain involved in perception, cognition and cognitive awareness, thought, memory, attention, language, and consciousness.

The cerebral cortex is the outer layer of the brain that is often referred to as gray matter, as it is a thin layer of tissue (cortex) with a grayish appearance (fig. 14). This appearance comes from nerves lacking a **myelin sheath**, which serves as insulation for the axon of a nerve cell. The **axon** is a long, threaded part of a nerve that helps to conduct impulses through the cell.

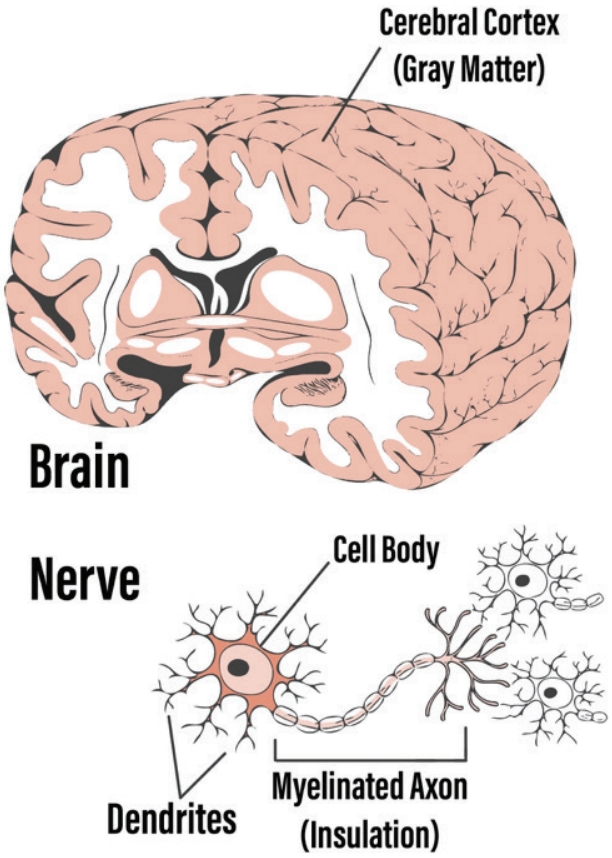


Figure 14: Cerebral cortex. The cerebral cortex is the outer layer of the brain, often referred to as gray matter due to its grayish appearance.

The **myelin sheath** is essential for a healthily functioning nervous system, as it helps to facilitate the conduction of electrical impulses passed from nerve cell to nerve cell, primarily in the PNS. These sheaths—layers of fatty tissue that wrap around the axons of nerve cells—protect the nerve fiber, similar to how insulation protects an electrical wire. Nerve signals relayed between myelinated axons are sent and received quickly. When damaged, the impulses are slower.

Brain tissue composed of mainly myelinated axons is referred to as **white matter** because of the white appearance of the myelin. Gray matter, by contrast, consists primarily of neuronal cell bodies, dendrites, unmyelinated axons, and capillaries, so it tends to have a pinkish hue.

Dendrites are branching filaments that carry impulses *toward* the cell body, while nerve impulses are transmitted *away* from the cell body through the axon. The conclusion of sensory processing (including feelings, seeing, speech, hearing, and memory) occurs in the gray matter or cerebral cortex. Communication between gray matter and other parts of the body occurs within the white matter, such as a signal from the cerebral cortex to the peripheral nervous system to elicit a motor response.

For example, the initial sensation from being tattooed in a mechanoreceptor rich area—such as the hairy skin of a leg—evokes a burst of nerve impulses in the PNS. These are transmitted quickly through the myelinated white matter to the gray matter, where they get processed as pain. A motor response, like

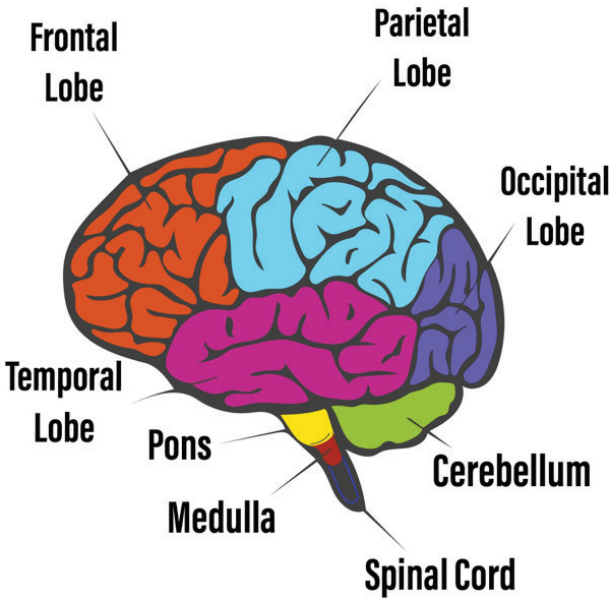


Figure 15: Lobes of the cerebral cortex. The cerebral cortical lobes are responsible for processing and interpreting incoming information and maintaining cognitive and sensory functions.

moving the leg out of harm's way, is consciously prevented in the cerebral cortex to avoid disturbing the tattoo procedure, although the initial sensation may cause a twitch.

The cerebral cortex surrounds the **cerebrum** (top part of the brain) and **cerebellum** (bottom portion of the brain, surrounding the brain stem), and it covers both its left and right hemispheres. There are four lobes separated by cerebral function and appearance of the cerebral cortex. These are responsible for processing and interpreting information from various sources of stimuli, as well as maintaining cognitive and sensory functions (fig. 15). For example, there are specific areas of the cerebral cortex involved in critical thinking, movement, and the neural process for somatosensory perception (touch). This means that when someone is experiencing pain, they are able to think about where it is coming from and how to move away from it.

Most cerebral functions stem from both hemispheres of the brain; however, some stem from one or the other. For example, language processing is typically only found in the left half of the brain. The **frontal lobe** is involved in decision-making, problem-solving, planning, and movement. The right frontal lobe controls the movement of the left side of the body, while the left frontal lobe controls the movement of the right side of the body. The **temporal lobe** is involved with memory, emotion, hearing, smelling, and language, while the occipital lobe is the primary center for visual processing. The **somatosensory cortex** is in the parietal lobe and is essential for processing sensations of touch.

The Perception of Touch

The skin is the largest organ of the body. It has many important functions including protecting the body against trauma, regulating body temperature, maintaining water and electrolyte balance, participating in vitamin D synthesis, and sensing painful and pleasant stimuli (Page 2018). As the boundary between human bodies and the external environment, it is home to a variety of nerves that help humans to sense and perceive touch.

Although sensations of touch, pressure, and vibration are often classified as separate impressions, they are detected by the same types of receptors. The main differences between somatosensory sensations are that:

- **touch** results from the stimulation of tactile receptors in superficial

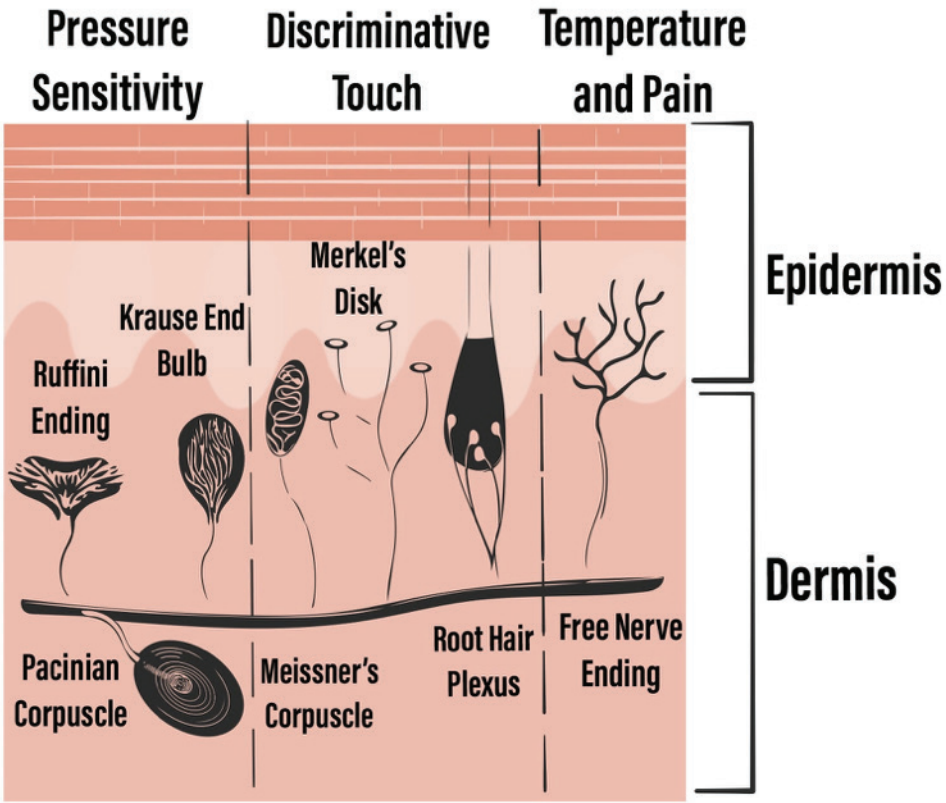


Figure 16: Mechanoreceptors in the skin. Pressure mechanoreceptors innervate the dermal layer, while tactile mechanoreceptors that respond to light touch are concentrated around hair follicles and innervate the epidermis.

layers of skin (epidermis) or immediately beneath it;

- **pressure** results from deformation of deeper tissues (dermis and hypodermis); and
- **vibration** stems from the rapid activation of mechanoreceptors found in both superficial and deeper tissues.

Even though sensory receptors are particular to specific sensations, the distinctions between the sensations and receptors are not always well defined because they can overlap.

Mechanoreceptors in the skin are either encapsulated or unencapsulated **free nerve endings**. **Encapsulated mechanoreceptors** have non-neural clusters of connective tissue innervated by large myelinated axons. These amplify the response to mechanical stimuli and ensure the rapid transmission of tactile information to the brain. There are five types of encapsulated tactile mechanoreceptors involved in the sense of touch, vibration, pressure, cutaneous tension, and temperature:

- Merkel's Disks,
- Meissner's corpuscles,
- Pacinian corpuscles,
- Ruffinian corpuscles, and
- Krause end bulbs (fig. 16).

Encapsulated mechanoreceptors are highly sensitive and are referred to as low-threshold receptors, as the slightest mechanical stimulation of the skin will induce an action potential. Large myelinated axons innervate low-threshold mechanoreceptors to ensure quick transmission of tactile information. Somatosensory receptors can also be classified by their location (cutaneous or deep), size of their receptive field (small

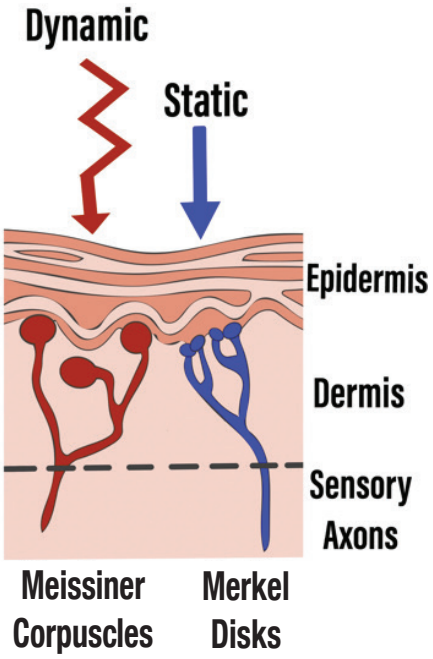


Figure 17: Epidermal mechanoreceptors. Meissner corpuscles respond to dynamic mechanical stimuli, while Merkel disks respond to static mechanical stimuli.

or large), and adaptation to stimulation (slow or rapid adaptation).

The physiology of mechanoreceptors is largely determined by their **morphology** (physical characteristics) and location within the sensory tissues and organs of the body. **Merkel's disks** (or Merkel Disks) and **Meissner corpuscles** are somatosensory touch receptors that innervate the superficial skin layers and relay tactile information (fig. 17). They exist in areas of the skin developed to discern spatial locations of touch sensations, such as the fingertips, hands and feet. Meissner corpuscles are present in non-hairy (**glabrous**) skin and are particularly abundant in the fingertips and lips. They are fast adapting to stimulation, which means they are highly sensitive to the dynamic movement of objects that lightly touch over the skin's surface, as well as low frequency vibrations. Merkel disks, by contrast, are located around hair follicles, adapt slowly, and respond to deep static pressure and touch from stimuli such as sharp objects and edges. While both Merkel disks and Meissner corpuscles play a major role in discriminative touch, they are also involved in the sensing of the body's position (proprioception).

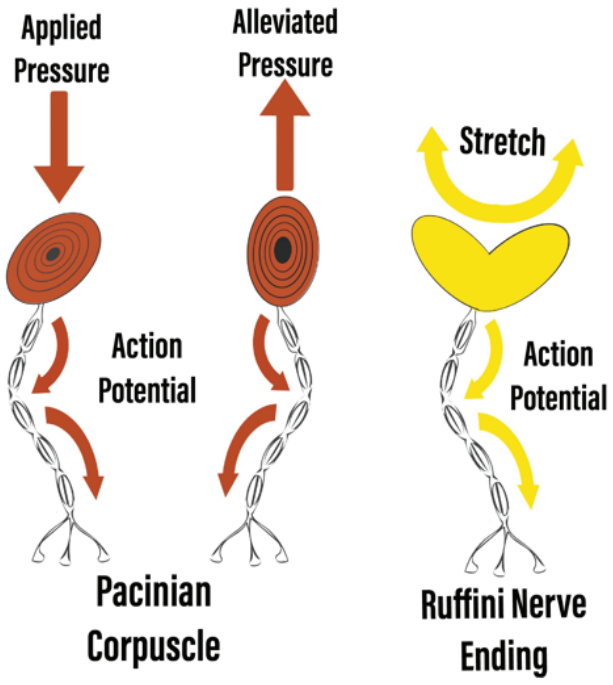


Figure 18: Activation of pressure-sensitive mechanoreceptors.

Pacinian corpuscles, **Ruffini's endings**, and **Krause end bulbs** are all pressure-sensitive mechanoreceptors found deeper in the skin's dermis, subcutaneous and connective tissues, as well as in various internal organs. Pacinian corpuscles, also known as **lamellar corpuscles**, are found deep in the dermal layer of the skin and are largely concentrated in the hands and feet. They are especially sensitive to vibration and readily adapt to constant pressure. When pressure is applied or quickly removed from an adapted Pacinian corpuscle, it generates a new burst of action potentials. The sensory nerve ending of the Pacinian corpuscle,

which resembles an onion, is wrapped in layers of connective tissue. When the membrane of the embedded nerve ending at the core of the mechanoreceptor is deformed by pressure or vibration, it emits sodium cations (positive ions) that create a nerve impulse along the axon of the sensory nerve's myelinated axon.

Similar to Pacinian corpuscles, Ruffini nerve endings—also known as **bulbous corpuscles**—are slow-adapting encapsulated mechanoreceptors found deep within the skin and in connective tissues. They have a greater response to mechanical stimuli applied horizontally, rather than vertical pressure (fig. 18), so they respond well to skin and joints being stretched. They also provide valuable feedback for gripping objects and controlling finger position and movement, so they contribute to proprioception and kinesthesia as well. Ruffini endings were originally classified as thermoreceptors because they are activated by warm temperatures.

In contrast to Ruffini endings, Krause end bulbs are thought to detect cold temperatures; and unlike Pacinian corpuscles and Ruffini endings, they are rapidly adapting mechanoreceptors. Krause end bulbs are found in the dermis, lips, mouth, and conjunctiva (connective tissue around the eyeball). Whether on the surface of the skin, deeper within it, or in specialized areas dedicated to the discrete sensation of touch, mechanoreceptors come in different shapes and sizes and have many different physiological functions designed to help people to feel the outside world.

Perception of Pain

Free nerve endings are an abundant type of receptor that are highly associated with pain. They are found throughout the body near blood vessels between epithelial layers of the skin, as well as in the cornea, the alimentary tract, and many connective tissues. Free nerve endings can be mechanoreceptors, thermoreceptors, or nociceptors—the latter being the most common type. Nociceptors in the skin have a high threshold for mechanical, chemical, or thermal stimuli and respond only when the intensity is high enough to cause tissue damage. Any somatosensory stimuli that is too intense (reaches maximum membrane potential) for prolonged periods of time can be perceived as pain because they are conducted along the same pathways that carry pain sensations.

Sensory Receptor	Type	Reception	Location	Stimuli
Free Nerve Endings	Unencapsulated Mechanoreceptor	Nociception, Thermoreception	Skin	Pain, temperature, touch
Krause End Bulb	Encapsulated Mechanoreceptor	Mechanoreception, Thermoreception	Skin, lips, oral cavity mucosa, and conjunctiva (eye).	Touch, pressure, and cold temperatures.
Meissner's Corpuscles	Encapsulated Mechanoreceptor	Mechanoreception, Proprioception	Glabrous (hairless skin) skin of palms and soles.	Fine to light touch and dynamic pressure.
Merkel's Discs	Unencapsulated Mechanoreceptor	Mechanoreception, Proprioception	Skin, hair follicles	Touch and static pressure.
Pacinian Corpuscle or Lamellar corpuscle	Encapsulated Mechanoreceptor	Mechanoreception, Proprioception	In the dermis, especially concentrated in the hands and feet.	Deep pressure, touch, and vibration.
Ruffinian Corpuscle or Bulbous Corpuscle	Encapsulated Mechanoreceptor	Mechanoreception, Proprioception, Thermoreception,	Dermis, subcutaneous, and connective tissue	Deep pressure, vibration, continuous touch, and stretching of skin, warm temperatures.

Table 1: Comprehensive list of somatic sensory receptors involved in touch and pain.

4 TRANSMISSION OF PAIN

By Dr. Kevin Choo

A response to an external stimulus requires transmission of that signal to the brain via an **ascending spinal tract** specific to that data. Once processed, the cerebral cortex will relay a response down a **descending spinal tract** thereby eliciting the appropriate motor response. The neurons that compose these tracts have varying levels of axonal thickness and myelination, allowing for differing speeds of transmission based upon how important the incoming data is to survival. There are four major types of nerve fibers (fig. 19):

- A-α for proprioception
- A-β for touch

Fiber	Informaton Carried	Myelin Sheath?	Diameter (micrometers)	Conduction Speed (m/s)
A-allpha	Proprioception	Myelinated	13–20	80–120 
A-beta	Touch	Myelinated	6–12	35–90 
A-delta	Pain (mechanical and thermal)	Myelinated	1–5	5–40 
C	Pain (mechanical, thermal, and chemical)	non-myelinated	0.2–1.5	0.5–2 

Figure 19: Conducted speed of information carried by type of nerve fiber.

- A-δ for mechanical and thermal pain
- C for mechanical, thermal, and chemical pain

Of these, pain is transmitted via A-δ and C fibers, the least conductive of the major types. A-δ fibershave the smallest axonal thickness of the myelinated fibers and are responsible for transmission of "fast pain," like placing your hand upon a hot stove. C fibers, dedicated to "slow pain" are the thinnest of the four types and are unmyelinated. With the slowest rate of neural conductivity, they transmit chronic pain, like the lingering pain as the burn from a stovetop heals.

Neural transmission is further differentiated using the aforementioned spinal tracts. Ascending tracts consist of three neuron pathways terminating in the thalamus or two neuron pathways synapsing in the cerebellum. Descending spinal tracts are comprised of an upper motor neuron and a lower motor neuron. These neurons are all linked via **synapses**, an association between two neurons with enough proximity that chemicals known as **neurotransmitters** can be released from the axon terminal of one to the dendrites of the other. Neurotransmitters can be both excitatory and inhibitory depending on the receptors to which they bind. In this way, much of neural signaling essentially occurs through a circuit of on/off switches (fig. 20).

Comprised of three separate neurons, the **lateral spinothalamic tract** transmits action potentials propagated in response to pain and temperature to the brain (fig. 21). The first-order neuron originates at the **dorsal root nerve ganglion (DNRG)** level of the spinal cord closest to the stimulus. It synapses with the cell body of the second-order neuron, located in the dorsal horn of the spinal cord in an area known as the **substantia gelatinosa (Rexed lamina II)**. At the point of synapse, the first-order neuron will release a neurotransmitter known as **Substance P**, which will stimulate the second-order neuron to transmit a signal of pain or injury to the brain. Prior to ascending to the cortex, the neural signal will **decussate** or cross over to the opposite side of the spinal cord through the **anterior white commissure**. This means that the pain of getting inked on your right arm is actually processed by the left side of your brain. Once ascending up the spinal column, the second-order neuron travels to the **thalamus**, which serves as a relay station for sensory information to the brain. Specifically, the second-order neuron synapses at either the **ventral**

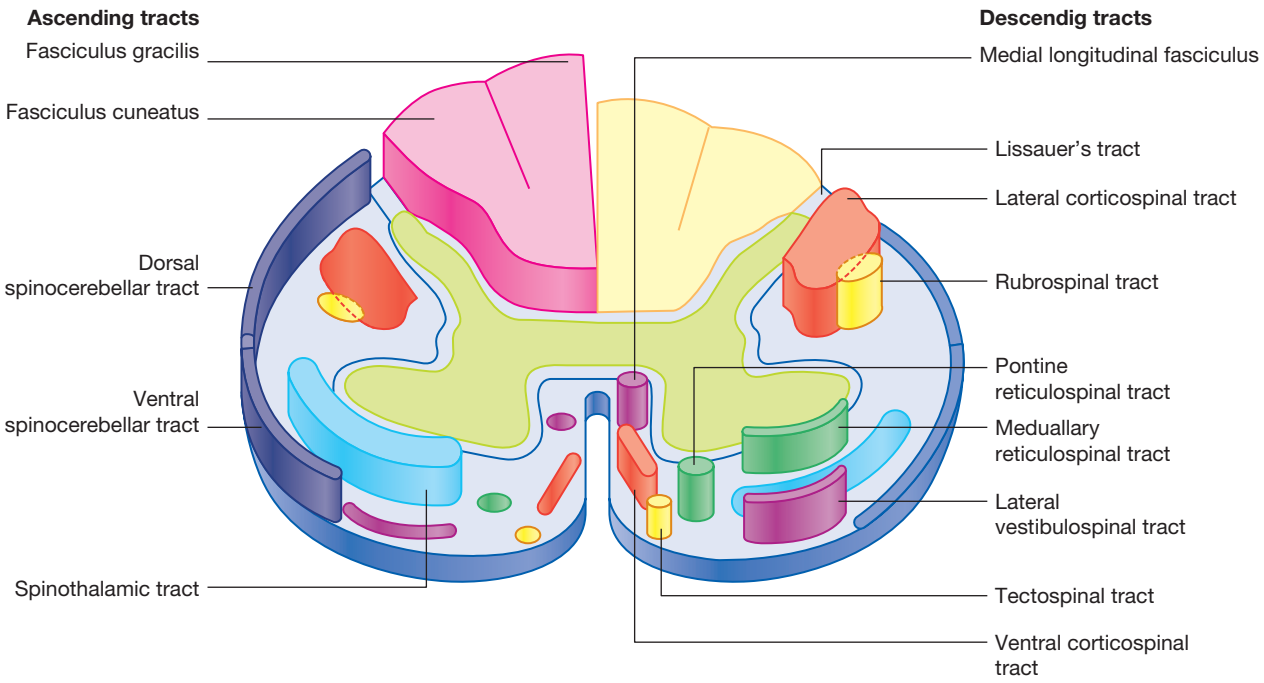


Figure 20: Cross section of ascending and descending tracts.

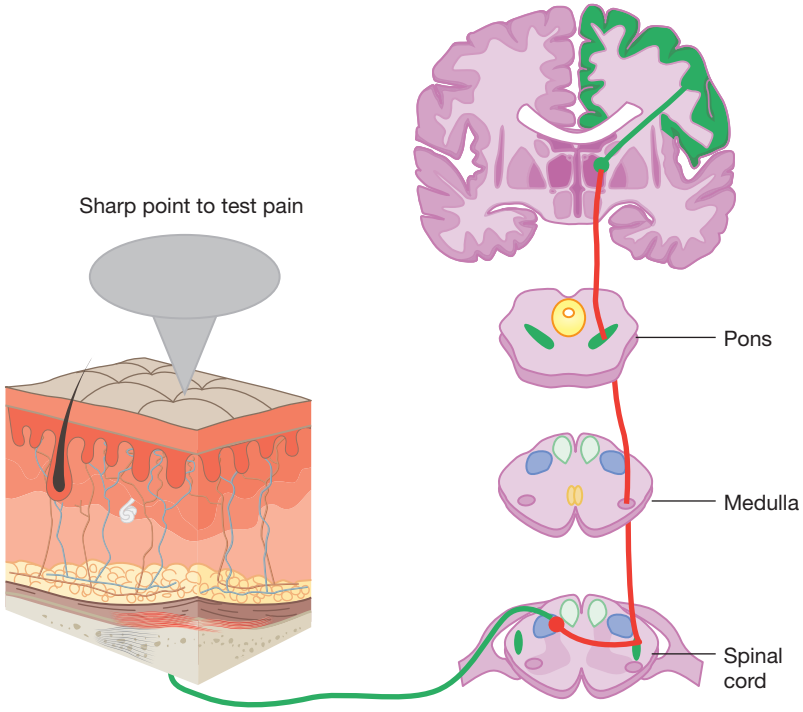


Figure 21: Lateral spinothalamic tracts.

posterolateral nucleus (VPL, stimuli from the body) or **ventral posteromedial nucleus (face, oral cavity)** of the thalamus. The third-order or tertiary neuron then travels from the VPL/VPM to the region of the cerebral cortex associated with the affected part of the body.

In response to continued stimuli, the descending pain pathway, comprised of two neurons, is activated. The descending pathway is responsible for controlling or inhibiting the transmission of pain to the cerebral cortex. The first-order neuron, inhibited under normal circumstances, is housed in a specific section of the midbrain known as the **periaqueductal gray**. It descends from the midbrain to synapse with the body of the second-order neuron in the **nucleus raphe magnus** of the medulla. The second-order neurons of the descending pain pathway travel from the medulla down the spinal cord and terminate in the dorsal horn within the substantia gelatinosa. There they release **norepinephrine (NE)** and **serotonin (5-HT)** upon two separate targets. The first of these are first-order neurons of the lateral spinothalamic tract, where the NE and 5-HT act to inhibit the release of Substance P, the neurotransmitter that functions as an on-switch for the transmission of pain up the spinal cord. The second are inhibitory interneurons, which are stimulated by NE/5-HT to release the endogenous opioid **enkephalin**. Enkephalin further disrupts signaling between first- and second-order neurons of the lateral spinothalamic tract. Along with NE/5-HT, it inhibits the first-order neuron from releasing Substance P and additionally prevents the depolarization of the second-order neuron. In this way, it functions as an off-switch, preventing an action potential generated by pain from further propagating a signal to the brain (fig. 22).

This regulation was studied by Ronald Melzack and Patrick Wall, who attempted to explain our perception of pain through their proposal of the **Melzack-Wall Pain Gating Theory** in 1965 (fig. 23). The pain gate theory draws heavily upon the differing speeds of neural conductivity due to the fiber types described earlier in this section. In short, in the absence of a painful stimulus, an interneuron serves as an off-switch to prevent small fiber (A-δ, C) transmission to the second-order neuron of the lateral spinothalamic tract and ultimately the brain. Small fiber activation in response to pain will inhibit the interneuron, essentially turning off an off-switch. Once the interneuron is turned off, the second-order neuron is free to transmit

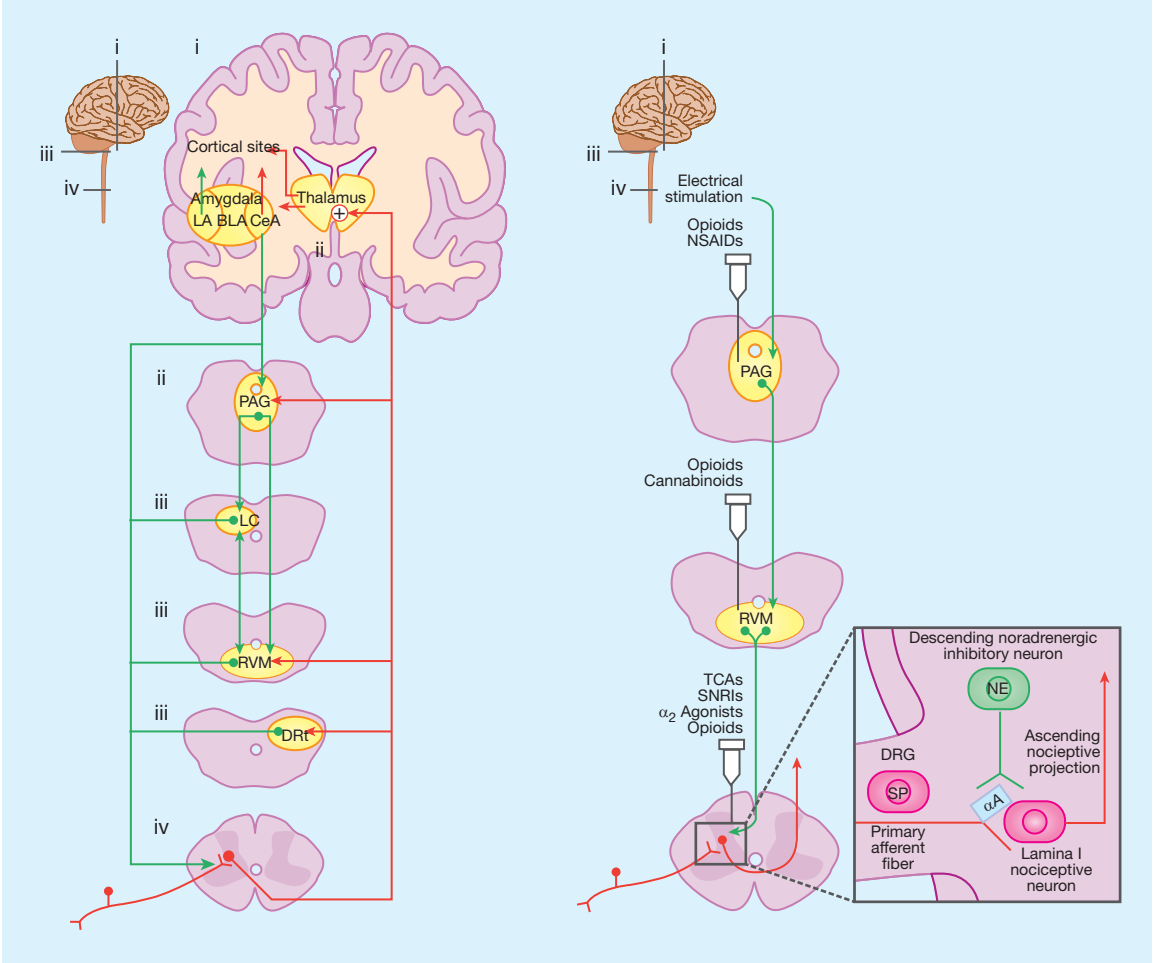


Figure 22: Pain modulatory circuits of brain stem and spinal cord.

pain to the brain. Large fiber signaling in response to proprioceptive change or touch can additionally affect the neural circuit of pain. It stimulates both the interneuron and the second-order neuron of the lateral spinothalamic tract simultaneously. While a signal of pain can still be sent to the brain, increased activation of the interneuron (off switch) decreases the strength of that signal. This explains why shaking your hand after hitting your thumb with a hammer (proprioceptive, large neural fiber transmission) decreases the pain initially felt when in response to

only A-δ or C transmission. From a tattooing standpoint, this is what makes lengthy sessions possible and semi-tolerable:

- Sensory adaptation occurs, decreasing the response to the repeated stimulus of the needling.
- The descending pain pathway activates, attempting to turn off the constant signal of pain to the brain.
- The proprioceptive input of the artist stretching the skin in the affected area activates large fiber signaling, serving to close the gate to the pain by overriding small fiber signaling from the needling.

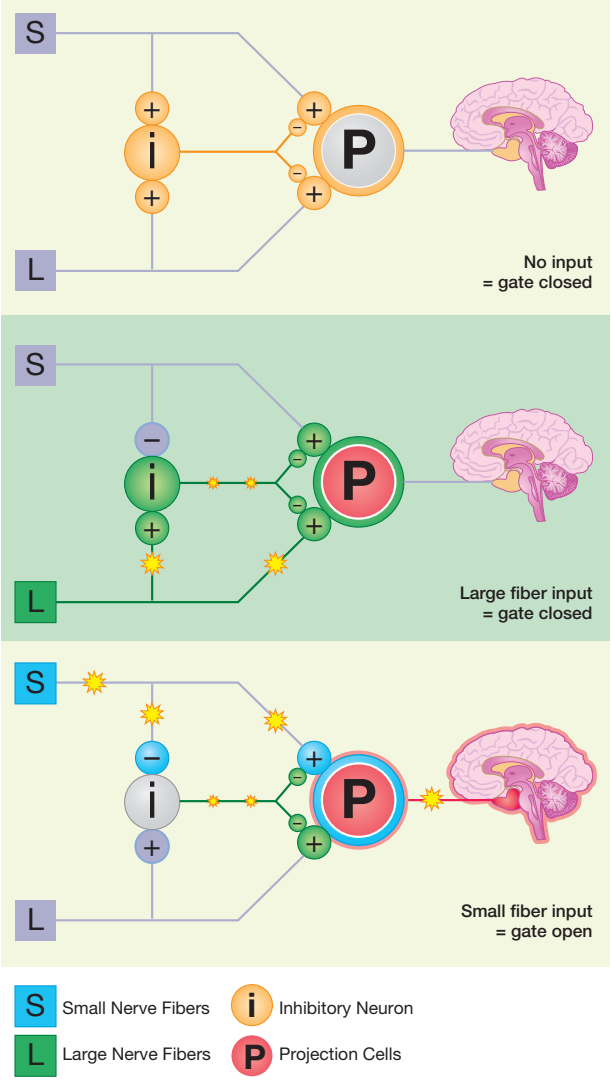


Figure 23: The Melzack-Wall Pain Gate. Further explanation of the verve fiber pathway.

5 PHOTORECEPTION: HUMAN SIGHT & VISUAL LIGHT SPECTRUM

By Dr. Shelley Mason

Human sight is a highly developed and sophisticated sensory system that requires neural translation and interpretation of incoming stimuli, which in this case is primarily light. Light is processed in several phases before it is received by the **primary visual cortex** and interpreted as an image (fig. 24). The **occipital lobe**—home to the primary visual cortex—maintains a basic spatial organization of visual information while extracting and organizing visual attributes like shape, motion, color, and depth.

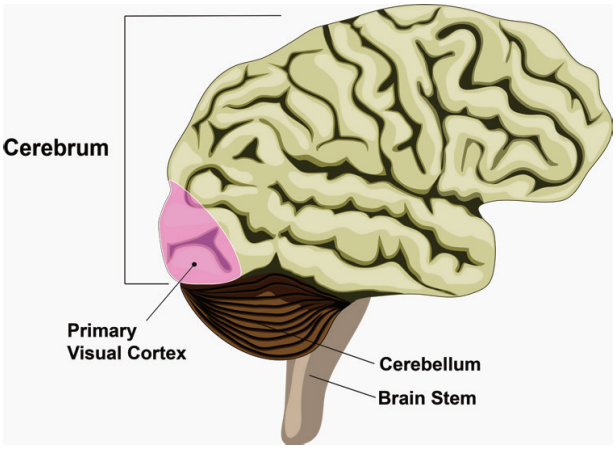


Figure 24: The primary visual cortex of the cerebrum. The primary visual cortex is where visual information is processed in the brain.

The visual system includes the eyes as well as connecting pathways through the visual cortex and other parts of the brain (fig. 25). The neural signals initially processed by the retina travel through the optic nerve, which is also known as the **second cranial nerve**. This paired nerve divides and crosses over itself, creating an X-shape called the **optic chiasm**. It then continues to the primary visual cortex, which processes the sensations into images and relates that information with images stored in memory (Duong 2017).

Composed of the optical elements including the cornea, iris, pupil, focal lens, and retina, the eye works similarly to a camera. Light enters through the cornea, which

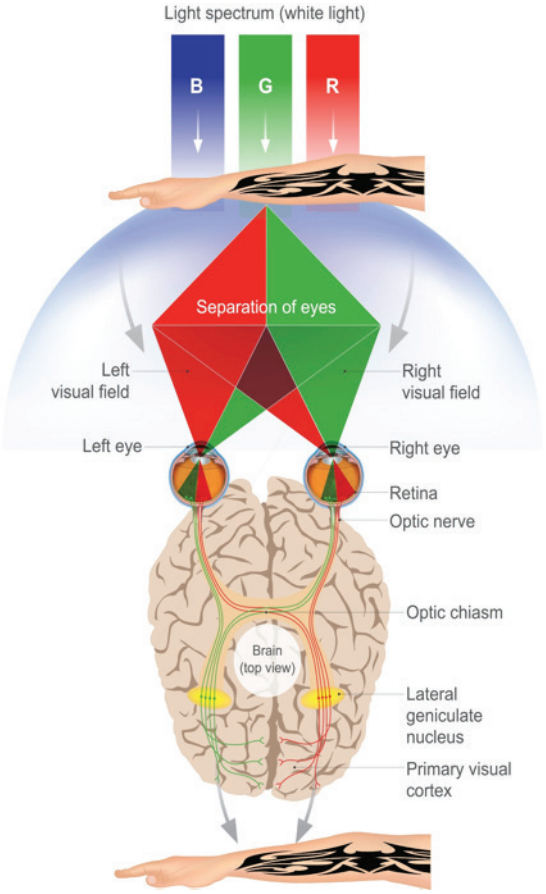


Figure 25: The visual system. The visual system includes the eyes connecting pathways to the visual cortex and other parts of the brain.

filters incoming light to prevent harmful ultraviolet (UV) rays from penetrating the eye. The iris, lens, pupil and ciliary body work together to control the amount of light that enters the eye before reaching the light-sensory cells—**photoreceptors** in the form of rods and cones—of the retina.

When focusing on an image, light comes through the cornea and lens and forms an inverted image on the retina, a membrane that contains millions of light-sensitive photoreceptors. Once photoreceptors detect objects, they translate or transduce the information from the light into electrical signals that can be interpreted by the brain (fig. 26). The photoreceptors of the retina—the cone and rod cells—network with the optic nerve (fig. 27). They contain **photopigments**, light-sensitive molecules made up of a protein called opsin, which is why photopigments are sometimes referred to as opsins (Twaddell 2018). Photopigments change shape in response to incoming light, which triggers a series of chemical reactions.

Each type of photoreceptor functions differently in response to light. Cone photoreceptors are responsible for color vision. Perceiving color allows humans to identify objects and set them apart from one another based on how light is reflected off of them and dispersed to the eye (Purves et al. 2001a, 2001b). Rod receptors are primarily responsible for vision in low-light situations (Rochester Institute of Technology).

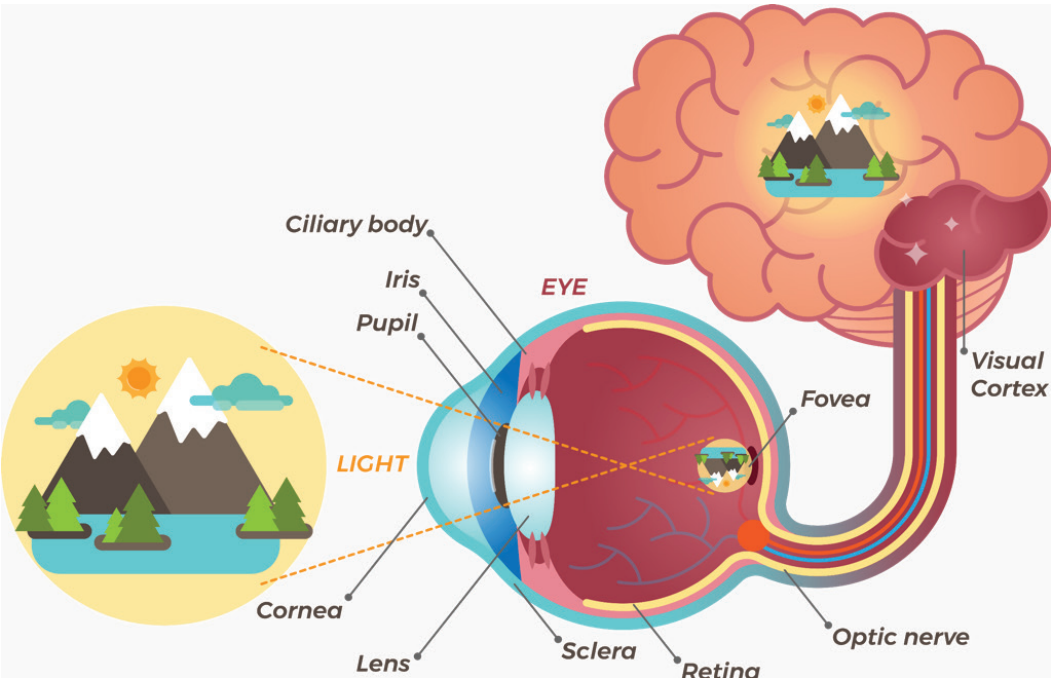


Figure 26: How eyes work to visualize light. Light enters through the eye, where it is filtered and controlled for protection and acuity. Light that enters through the focal plane of the lens forms an inverted image on the retina, a membrane of photoreceptors that line the back of the eyeball. The photoreceptors translate light signals into electrical signals that are relayed to the visual cortex via the optic nerve, where it is interpreted by the brain.

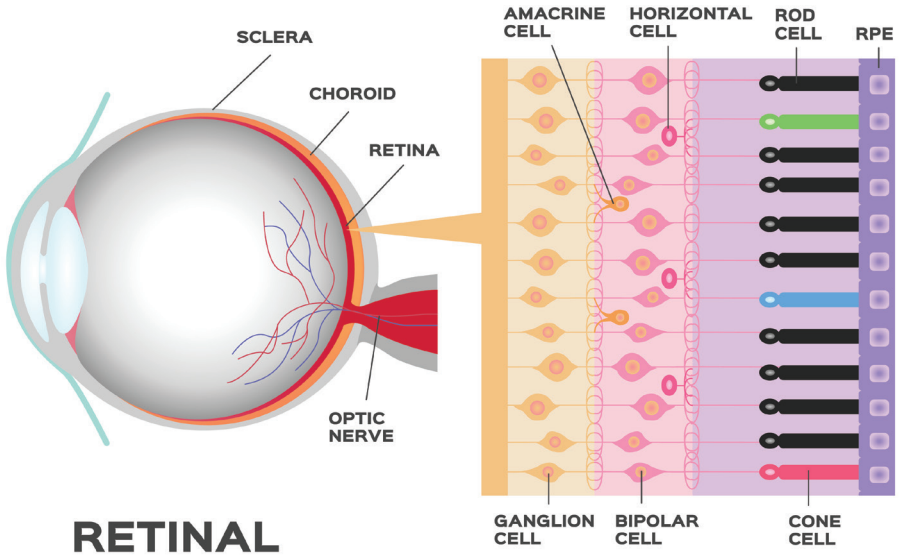


Figure 27: Diagram of cones and rods in the eye.

The Visible Light Spectrum

Light travels in the form of electromagnetic radiation, the energy that moves at the speed of light through the electric and magnetic fields of space and material (objects). Electromagnetic waves are produced by a vibrating electric charge that consists of both an electric and magnetic component, and they exist in a vast range of wavelengths. This continuous range of frequencies is known as the **electromagnetic spectrum**. It is subdivided into specific electromagnetic regions based on the interactions of the specific electromagnetic wave and matter. Figure 28 illustrates the various regions of the electromagnetic spectrum. The lower frequency, longer wavelength regions are on the far left, while the higher frequency, shorter wavelength regions are on the far right.

The **visible light spectrum**—the narrow band of light that humans are able to see—is a small window of frequencies within the electromagnetic spectrum (fig. 28) in between the infrared- and ultraviolet-wave spectra.

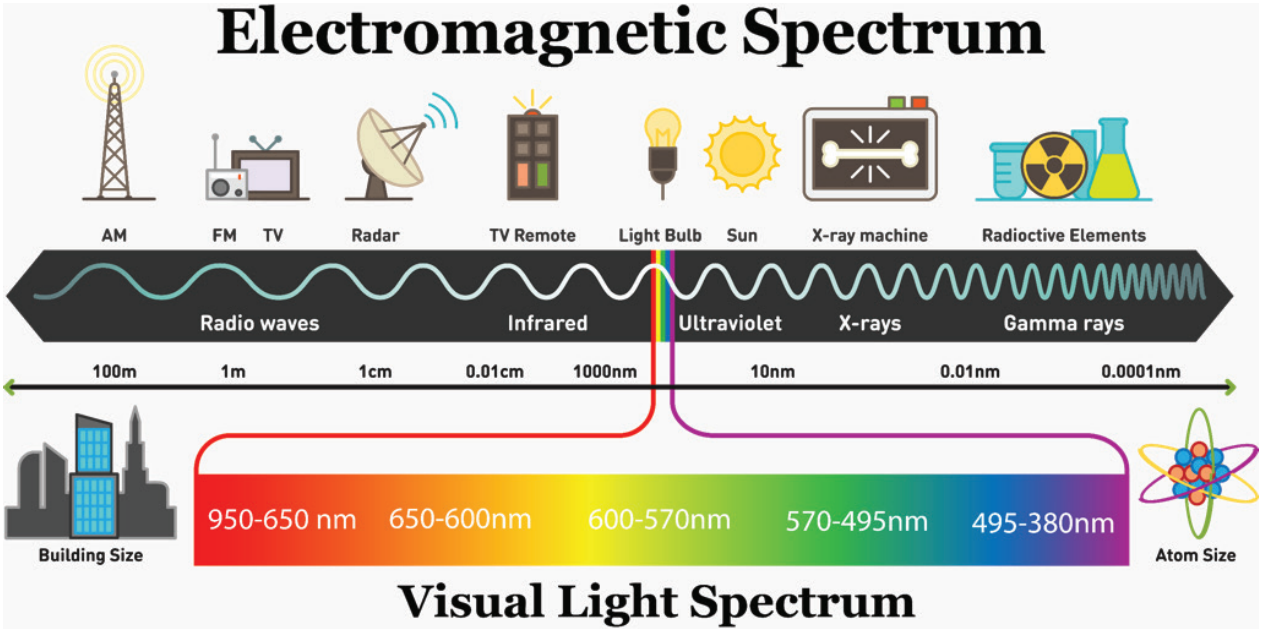


Figure 28: The electromagnetic spectrum. The spectrum of electromagnetic radiation is the flow of energy at the speed of light through space or material in the form of electromagnetic waves such as radio waves, infrared, visible light, and gamma rays. Electromagnetic waves are characterized by intensity (wavelength height) and frequency (wavelength time variation).

In general, the term **light** is used to describe the type of electromagnetic waves that stimulate the retina (fig. 28). When light of a particular wavelength collides with the retina, it is perceived as a particular color. That said, wavelengths of visible color on the electromagnetic spectrum—red, orange, yellow, green, blue, indigo, and violet—are not absolute but vary with the intensity of light. The optical frequencies of human response are around 400 nanometers (nm) to 700 nm, with a peak sensitivity at 555 nm—the green region of the spectrum (Davidson 2015). In the blue-green region (around 500 nm), only 50% of light entering the eye reaches the image point on the retina, and only 10% at 400 nm (violet region). This is because the transmission of light decreases as the wavelengths get shorter (Davidson 2015).

The retina contains different types of photoreceptors that are tuned to respond to distinct wavelengths. The cone receptors work similarly to a Red Green Blue (RGB) video monitor or color camera, as there are three types of cone cells that also work in concert to create color. Their centered maximum response is 430 nm (blue), 535 nm (green) and 590 nm (yellow). Each of them responds to light by utilizing complementary photopigments. The stimulation of each cone type, alone or in combination with one another, determines how we see colors. When each type of cone gets simultaneously activated, the color looks white—or is seen to be **achromatic**, meaning without color.

When photoreceptors detect light, photopigments conformationally change in a way that allows them to interact with a protein that **transduces** light into an electrical signal. The intensity of the wavelength and distribution of light encountered by the cone photoreceptors determines how humans see color. A light wave that falls within the blue visible light range will elicit a significant response from the cone cells tuned to 430 nm, activate the blue color photopigment in specific cones, and elicit the perception of the color blue. A light that travels around 550 nm is recognized as green, while a light wave moving at a frequency of 600 nm appears red.

How Light Works

Isaac Newton demonstrated that shining light through a **prism**—a transparent solid triangle that scatters light—will separate light into its different wavelengths, displaying all of its colors. The separation of visible light into individual wavelengths of color is known as **dispersion** (fig. 29).

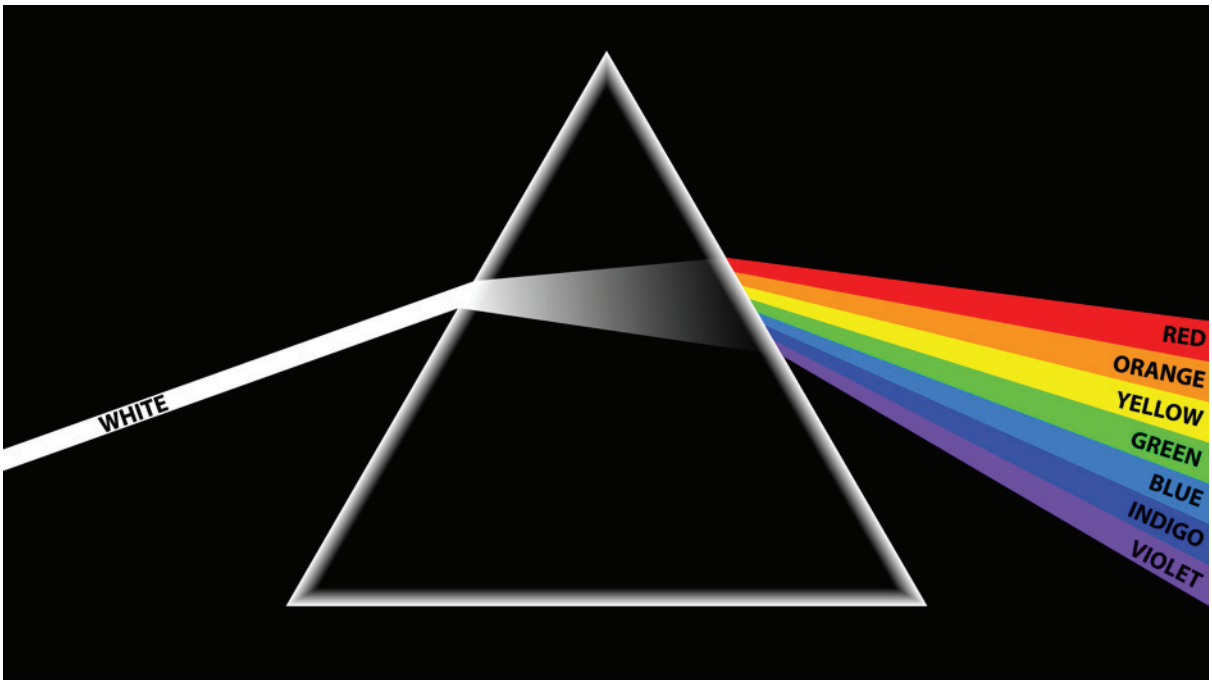


Figure 29: Dispersion of light through a prism. Dispersion of visible light produces the colors red, orange, yellow, green, blue, indigo, and violet.

Again, visible light is light that is perceivable to the human eye. The sun's visible light appears colorless or white unless it is reflected from an object. White is not considered to be part of the visible light spectrum, as white light is not light of a single color. Instead, it is a combination of all colors (fig. 30). When sunlight passes through water—such as rain or vapor—or through a glass prism, it creates a rainbow. This happens because as light waves move through clear but solid objects, they begin to bend and travel at different speeds in a process called **refraction**. Conversely, if visible colors of light overlap, they can combine to create white light. So, just as white light can be separated into different visible colors of light, various combinations of light –yellow with blue, magenta with green, and cyan with red—it can also make white light.

Colors can be made by absorbing some frequencies of light while reflecting others (Harris and Freudenrich 2000); the colors seen are the colors reflected, while the unseen colors are absorbed (fig. 31). If a person looks at a shirt and sees that it is the color blue, that is because the material is reflecting blue light while absorbing

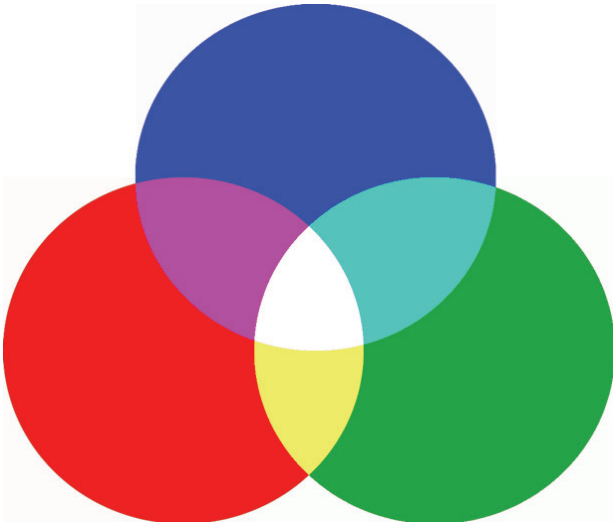


Figure 30: Color spectrum of light. White light is a mixture of all the visible colors of light. When green, red, and blue light overlap and create magenta, cyan, and yellow, they combine to create white where all shades of light meet.

other frequencies of white light, like red and green. This is known as **subtractive color**, and it is how people see color from paints and dyes. Paint or dye molecules absorb specific frequencies and reflect other frequencies that are visible to the eye. Color is made up of those reflected frequencies. For example, the leaves of plants are generally green because they contain the pigment chlorophyll. Chlorophyll absorbs blue and red colors of the visible spectrum and reflects green.

On the atomic level, the frequency of incoming light waves interacts with the vibration frequency of the electrons in

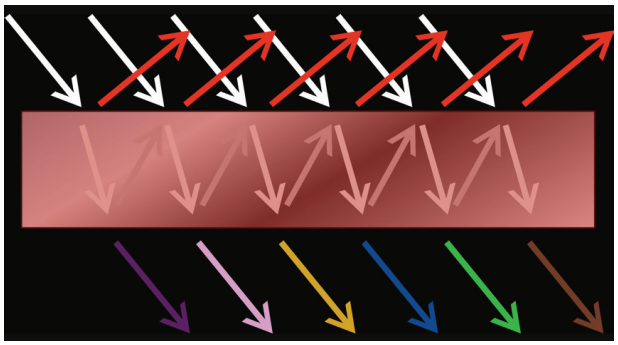


Figure 31: Light absorption and reflection. When white light moves through a red pigment, it absorbs all visible light except for red, which it reflects.

the material. The electrons take in the energy of the light wave (which consists of **photons**) and get excited (or vibrate). Absorption occurs when the electrons are held tightly and the vibrations of the photon are passed to the nuclei of the atoms, which makes the atoms speed up and collide with other atoms in the material. The absorption of light makes an object dark or opaque in relation to the frequency of the incoming wave (Harris and Freudenrich 2000). Some materials are opaque to some frequencies of light but transparent to others. Glass is an example of this phenomenon, as it is opaque to ultraviolet light but transparent to visible light.

Pigments, Dyes, and Color

Understanding how light works is key to understanding how color is perceived,

including the color of tattoo pigments. Dyes and pigments are often spoken of synonymously, but there are some fundamental differences. The primary distinction is that dyes are dissolved in a solution while pigments are suspended, retaining a crystal or particulate structure throughout the coloration process.

Dyes and pigments have also been given some official definitions. According to The Ecological and Toxicological Association of Dyes and Organic Pigment Manufacturers (ETAD), **dyes** are defined as intensely colored or fluorescent organic substances that transmit color to a substrate by selective absorption of light (SDC 2018). Dyes are soluble or indirectly soluble through a process that, at least temporarily, destroys any crystal structure by absorption, solution, mechanical retention, or chemical bonding. The Color Pigment Manufactures Association (CPMA) defines **pigments** as colored, black, white, or fluorescent particulate organic or inorganic solids. Pigments are usually suspended in vehicles or substrates both to preserve the integrity of their physical or chemical makeup and for application. This is true for many manufactured inks, paints, plastics, or other polymeric materials (SDC 2018).

When applying a pigment to a base like paper, it will lay on top of the paper and form a coat over it. While fine particles of the pigment can get stuck in the pores of paper and stain it, as dirt can stain fabric, the particles do not chemically bind. Pigments are essentially painted on, and it is the medium—such as the pigment carrier—that makes it stick to a base. A dye, on the other hand, will **chemically bind** to a base like paper. Some dyes need a chemical fixative—or **mordant**—to induce binding. Unlike pigments, dyes are not painted onto a surface. Instead, they become a part of the material they are applied to.

Modern Pigments & Dyes

Today, most pigments are synthetically produced. Modern chemistry provides a way to create an extensive palate of colors that are bright and stable. In general, higher-quality pigments are more expensive, and lower-quality pigments will be made with cheaper materials. Some of the lower-quality pigments are dye coated.

Artist's paints are created from pigments. Watercolor paints are water-based, created from very finely ground pigments suspended in a carrier that is

water-soluble. Oil paints are made from pigments suspended in linseed oil, and acrylic paints are suspended in an acrylic medium. Permanent markers, such as Sharpie brand markers and alcohol-based inks, are made with dyes.

Knowing whether a color medium is a pigment or dye will help an artist understand how it should be used and applied. For example, pigment-based colors tend to be opaquer because they are suspended particles that do not bind to the base material to which they are applied. Since pigments are particles that coat material, rather than bind to it, the concentration of pigment in suspension influences light transmission (opacity). Because dyes are dissolved in liquid and not particulate, light transmission is not affected and using dye-based colors will have more of a translucent effect. For example, if you paint a piece of glass with black acrylic paint, it will block the transmission of light through the glass, while coloring a piece of glass with a Sharpie will not. **Light is transmitted through a dye, rather than reflected as it is with a pigment.**

A **vehicle** is the carrier, or medium, that a dye or pigment is dissolved or suspended in. How a pigment or dye interacts with its chemical environment depends on the vehicle in which it is carried. For example, whether a paint is waterproof depends on its vehicle. Raw umber is a dirt-based pigment, and dirt can be washed off with water. When mixed with linseed oil to make oil paint, however, it becomes waterproof. Dried raw umber acrylic paint is water-based and washable, but it is waterproof once it dries. Umber watercolor paint, however, will wash off a paint brush even after drying.

CHEMISTRY, TATTOOS, & THE BODY

By Dr. David Warmflash

Unit 2: Overview & Inquiry

Topics Covered

- The history and structure of the periodic table.
- How atoms work, and how that affects both their charge and how they interact with one another.
- The chemical composition of pigments, dyes, and other materials involved in tattooing.
- How tattoo pigments are metabolized and processed in the body.

Questions to Keep in Mind

- What are the important parts of an atomic element? How does that information affect how they interact with one another?
- What are the different ways that atoms can bond together?
- What is the chemical composition of tattoo pigments and dyes? How does that affect their color and pH?
- What is the role of the lymphatic system in the processing of tattoo pigments?
- What are the chemical and environmental factors at play in tattoo fading?

What chemistry is involved in tattooing and how does that interact with the body?

When someone gets a tattoo, they come into contact with a variety of different chemicals and metals. Needles are made of steel—which includes elements like carbon, iron, nickel, and chromium—while inks contain polymer-based pigments and metal salts. Antiseptic agents can both kill bacteria and dry out the skin due to their chemical makeup. As the elements and molecules present in these materials interact with the body, they create no shortage of opportunities for chemical and physiological reactions.

This unit covers the chemistry of tattooing, starting with a basic overview of the periodic table of elements and how the composition of those elements affects their interaction with one another. This unit will cover the chemistry of tattoo pigments and how they are metabolized in the body; it will also cover a material overview of common tattoo materials like antiseptic agents, anesthetics, and steel.

The aim of this unit is for readers to discover what's happening in the body on an elemental and molecular level during and following a tattoo procedure. This information will help you to better understand the potential adverse effects and medical considerations discussed in Unit V.

6 THE PERIODIC TABLE OF ELEMENTS

At the core of chemistry are a series of elements and compounds. These are composed of atoms, molecules and ions. Elements make up matter, they have specific physical and chemical properties which cannot be broken down. An atom is the smallest unit of matter that retains all the physical and chemical properties of an element. When atoms interact with one another, they create molecules. It is not an exaggeration to say that atoms are the building blocks of the universe, and like so many things in the universe, they follow a specific set of rules and patterns. Some of these patterns are at work in the **periodic table of elements**, also known simply as the **periodic table**, which organizes elements in relation to their chemical and physical properties (fig. 1).

Consisting of horizontal rows called **periods** and columns called **chemical groups** (or just **groups**), the modern periodic table sequences elements—from left to right and top to bottom—according to their **atomic number**. In chemistry, the atomic number of an element is the number of **protons** in the **nucleus** of an atom of that element. In its current form, the periodic table has 18 groups (numbered across the top of the table) and 7 periods (numbered along the left side of the table). With the exclusion of hydrogen, elements of Groups 1, 2, and 13–18 are known as the **main group elements**.

In addition, there are two series of 14 elements each that most drawings of the periodic table show below Period 7. The atomic numbers of these additional elements belong between Group 3 and Group 4. Known as the **lanthanide series**, or simply the **lanthanides**, elements 58–71 fit between lanthanum (La) and hafnium (Hf) in Period 6. Similarly, the **actinide series** (or *actinides*) consists of elements 90–103, located between actinium (Ac) and rutherfordium (Rf) in

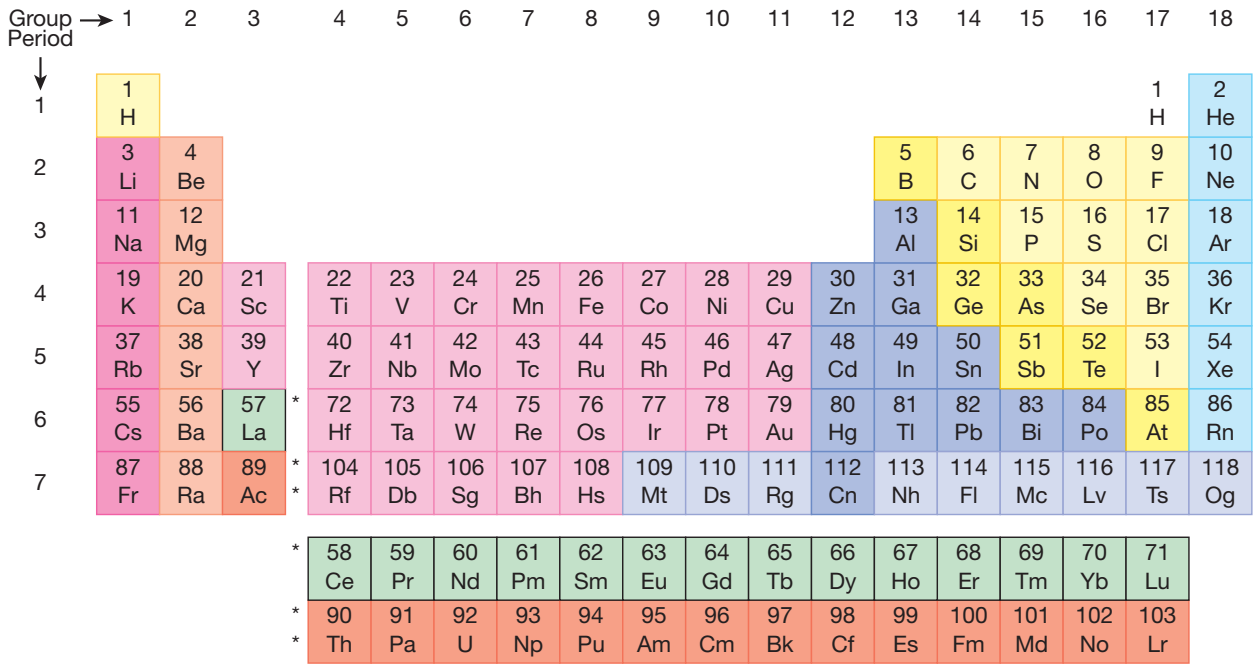


Figure 1: Periodic table of elements.

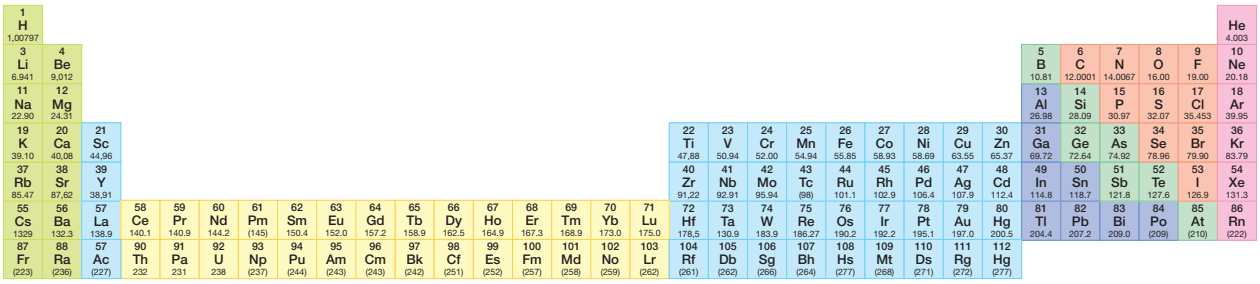


Figure 2: **Periodic table of elements with lanthanide and actinide series** inserted between Groups 3 and 4.

Period 7. Consequently, the periodic table is sometimes drawn stretched out horizontally with each of these series inserted into the appropriate period, with a big gap between Group 3 and Group 4 (fig. 2).

Electrons, Protons, & Neutrons

The nucleus of an atom is the center of the atom, the part where nearly all its mass is located. Yet this concentration of

mass is exquisitely small in volume compared with the volume of the entire atom. What makes the atom much larger than its nucleus is the **electron shell**, a region surrounding the nucleus that contains subatomic particles called **electrons**.

Each electron carries an **electrical charge**. All electrons hold a negative charge, which is the same magnitude for all electrons, regardless of the size of the atom to which they belong. Although the electron cloud is solely composed of electrons, their negative charges are offset by the atomic nucleus. The nucleus—containing positively charged **protons**—carries an overall positive charge. Even though protons are much more massive than electrons, their positive charge is of equal magnitude to the negative charge of an electron. Along with protons, atomic nuclei also contain another type of particle called a **neutron** (fig. 3). The only exception is the element hydrogen, which can have neutrons in its nucleus, but does not need them.

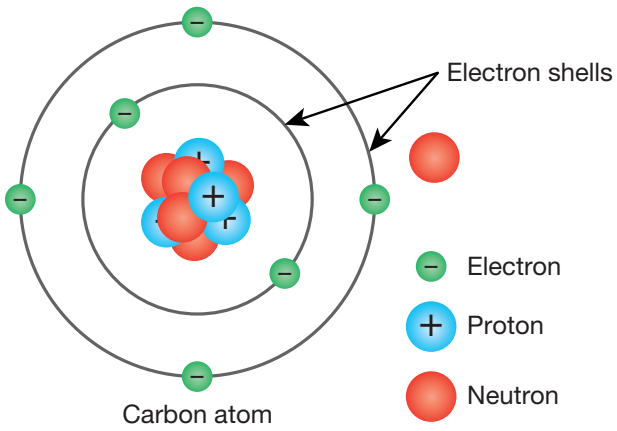


Figure 3: A simplified representation of an atom, showing the nucleus consisting of protons and neutrons. Protons each carry a positive charge, while neutrons are neutral. Outside the nucleus is the electron cloud, a region that contains electrons, each of which carries a negative charge.

Valence

The chemistry of an element is determined by the number and arrangement of its electrons. As a general rule, electrons occur, roughly, in rings around the nucleus, starting with a ring of two and followed by rings of up to eight. For example, a neutral chlorine (Cl) atom—atomic number 17—has 17 protons and 17 electrons. There are 2 electrons on the inner ring, 8 electrons in the middle ring, and 7 electrons on the outer ring. The electrons on the outer ring are called **valence** electrons. On the periodic table, these special electrons follow a pattern:

- Group 1 elements have one valence electron.
- Group 2 elements have two valence electrons.
- Group 13 elements have three valence electrons.

- Group 14 elements have four valence electrons.
- Group 15 elements have five valence electrons.
- Group 16 elements have six valence electrons.
- Group 17 elements (also known as **halogens)** have seven valence electrons.

Most elements obey what is called the **octet rule**, meaning that their atoms strive to have eight valence electrons. Thus, the number of valence electrons determines how many more electrons an element might need to "complete" its outer ring, which affects which other elements it will bond to. For example, chlorine—in Group 17—easily bonds to sodium (Na) in Group 1 to create NaCl, or salt.

Group 18—the noble gases—each have eight valence electrons. The only exception is helium, which is included in this category because its two electrons make its own full outer electron shell. As such, elements of Group 18 are said to have a **full outer electron shell** and a **valence number** (or **valency**) of 0. Having a full outer electron shell makes this group of elements satisfied to exist as they are, and less likely to participate in chemical reactions. To appreciate the non-reactivity of noble gases, consider that helium is the gas of choice for lighter-than-air craft, such as blimps, because helium will not ignite. In dramatic contrast, hydrogen—although even lighter than helium—is a dangerous choice as a lifting gas. This is because hydrogen's valence makes it easily combustible, as occurred in the disastrous explosion of the hydrogen-filled Hindenburg zeppelin in 1937 (fig. 4).

Like hydrogen, the rest of the main group elements react chemically in various situations, all in relation to their valence numbers, which are:

- +1 for Group 1
- +2 for Group 2
- -2 for Group 16
- -1 for Group 17

For Groups 13, 14, and 15, valence changes in different situations, making their patterning harder to determine. Groups 4 through 12 and in the lanthanide and actinide series also follow a different set of patterns with regards to their valence. Nevertheless, the number of electrons in an atom both affects its valence and is related to its position on the periodic table (fig. 5).

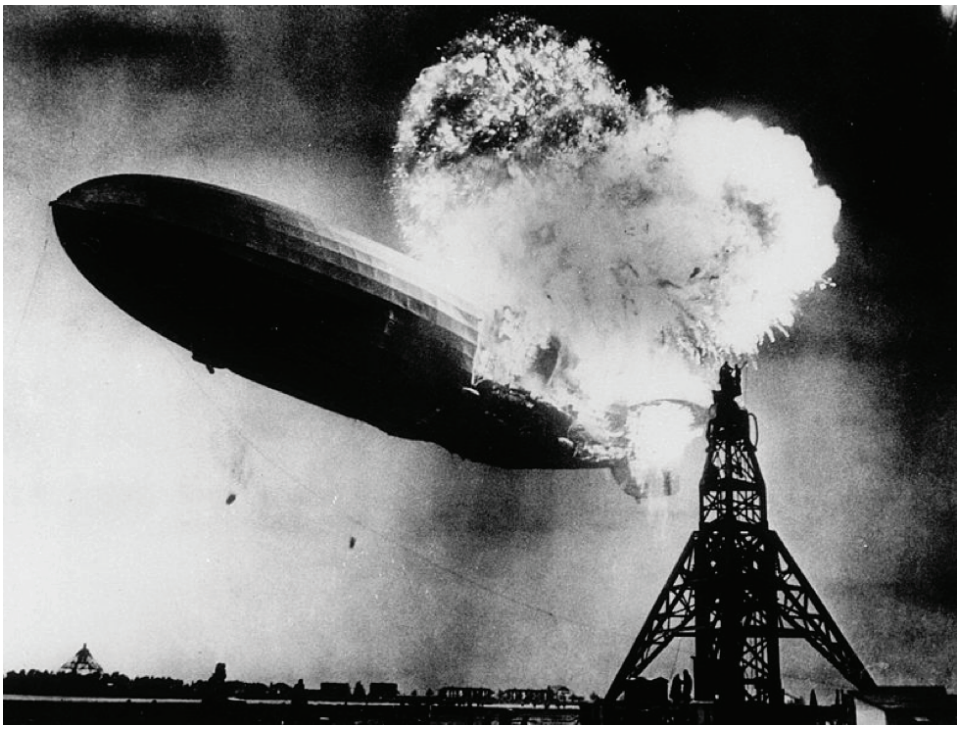


Figure 4: Explosion of Hindenburg Zeppelin. Hydrogen is easily combustible.

1 + Cations	2 + Cations	3 + Cations	2 – Anions	1 – Anions

Periodic Chart of the Elements

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	IIA	INERT GASES
1 H 1,00797																1 H 1.00797	2 He 4.0026
3 Li 520	4 Be 9,0122											5 B 10.811	6 C 12.0112	7 N 14.0067	8 O 1310	9 F 18.9984	10 Ne 20.183
11 Na 22,9898	12 Mg 24,912											13 Al 26.9815	14 Si 28.086	15 P 30.9738	S S 1000	17 Cl 35.463	18 Ar 39.948
19 K 39,102	20 Ca 40,08	21 Sc 44,956	22 Ti 47,90	23 V 50.942	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 950	35 Br 79.909	36 Kr 83.80
37 Rb 05.47	38 Sr 87,62	39 Y 38,905	40 Zr 91,22	41 Nb 91.906	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.905	46 Pd 106.4	47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 870	53 I 126.904	54 Xe 131.30
55 Cs 132,905	56 Ba 137,34	* 57 La 138,91	72 Hf 178,49	73 Ta 180.948	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.0	78 Pt 195.09	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 200.980	84 Po (210)	85 At (210)	86 Rn (222)

Figure 5: An element's group on the periodic table determines whether its atoms tend to form ions and, if so, which type of ions. Group 1 (excluding hydrogen) and Group 2 elements form +1 and +2 cations, respectively. Most elements of Groups 13, 16, and 17 form +3 cations, -2 anions, and -1 anions, respectively.

Isotopes, Atomic Mass, & Atomic Weight

To make use of the periodic table, it is also important to learn about **neutrons**. A neutron has slightly more mass than a proton (protons are positively charged; electrons are negatively charged) and is roughly the same size. In contrast to protons, neutrons are electrically neutral, meaning they do not carry a charge. Due to their positive electrical charges, protons repel one another, like two magnets when their like poles are brought close together. Since neutrons are electrically neutral, however, they act as a kind of glue in the atomic nucleus. For any element with at least two protons, there must be neutrons to keep the nucleus from flying apart (fig. 6).

Atoms of the same element that have different numbers of neutrons are called **isotopes** of that element. Each isotope is defined by its **atomic mass** number, which equals the number of protons plus neutrons in the nucleus. On the periodic table, hydrogen is element number 1, because each hydrogen nucleus has one proton. Hydrogen does not need neutrons, because its single proton does not need to be kept from repelling any other protons. Although it does not need them, sometimes it does have them, as hydrogen can naturally exist in three different isotopes:

- ^{1}H (the most abundant) has 1 proton and 0 neutrons;
- ^{2}H has 1 proton and 1 neutron; and
- ^{3}H has 1 proton and 2 neutrons.

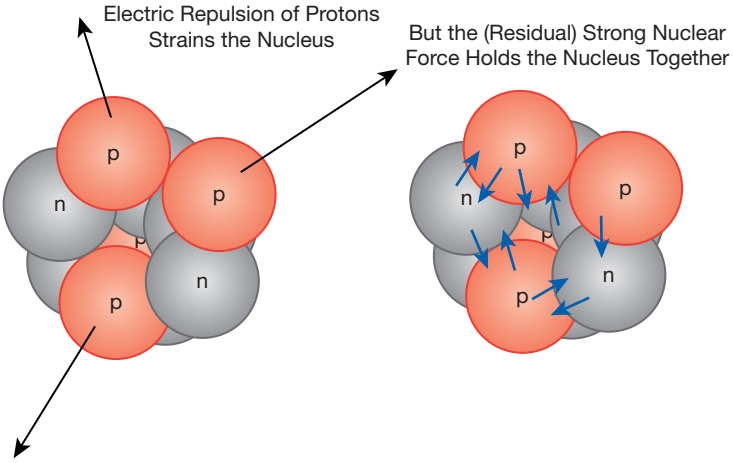


Figure 6: Neutrons act as a kind of glue that holds the atomic nucleus together. Without them, the protons of an atomic nucleus would repel one another, causing the nucleus to fly apart.

Since a proton and a neutron have roughly the same mass, this means that a hydrogen atom can have an atomic mass of 1, 2, or 3, depending on which isotope it is. As for the next element on the table, helium, in nature, there are two helium isotopes that are stable. One isotope is helium-3 (^{3}He), which has two protons and just one neutron. The other is helium-4 (^{4}He), which has two protons and two neutrons (fig. 7).

Moving along the periodic table, one finds that elements can exist as different isotopes. But as the atomic number increases, so does the number of neutrons needed to keep the nucleus glued together. This concept is important because isotopes relate to another chemical value called **atomic weight**, which is listed for each element on the periodic table. This measurement was the basis of the original periodic table created by Russian chemist Dmitri Mendeleev in 1869.

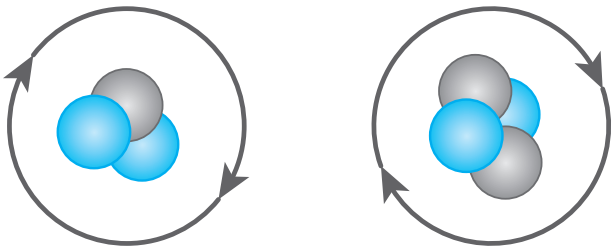


Figure 7: Helium-3 and helium-4 isotopes both have two protons in the nucleus. However, helium-3 has just one neutron whereas helium-4 has two neutrons. Both nuclei are stable (they exist indefinitely without flying apart), but helium-4 is heavier than helium-3.

Learning from Mendeleev's Simple Periodic Table

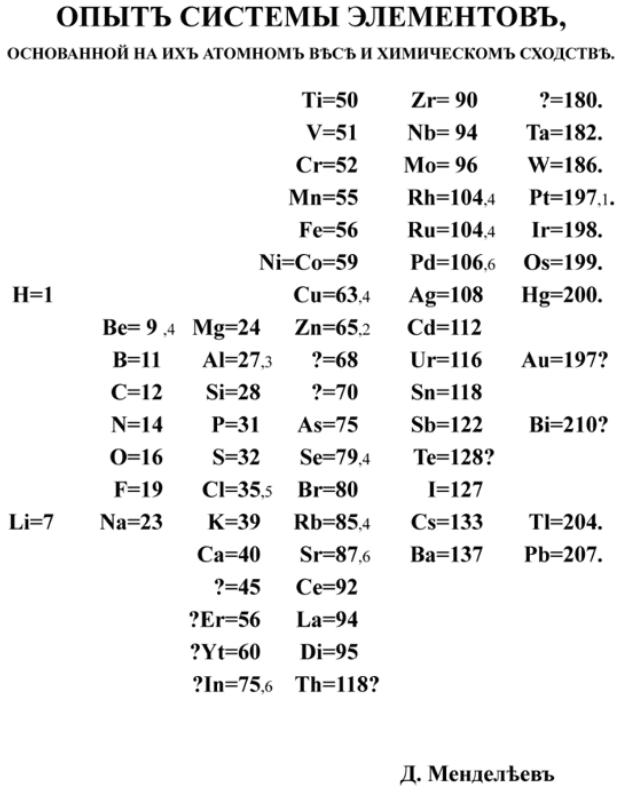
Unlike the atomic number, which is always a whole number (simply representing the number of protons in the nucleus), atomic weight is listed as a number with decimal points. Oxygen, for example, has an atomic weight of 15.999. This is because the atomic weight of an element is the weighted average of all the naturally occurring isotopes of that element. To appreciate the organization and function of the modern periodic table, it is helpful to delve briefly into Mendeleev's table, which he based on atomic weight. This value could be measured for each known element, even though chemists of that era were unaware of the isotope phenomenon and the existence of subatomic particles.

Mendeleev based his table on observations that chemical elements exhibited **periodicity** in their properties when the elements were lined up according to their atomic weights. Periodicity refers to the phenomenon that properties repeated

themselves at regular intervals as the atomic weight increased. Moving from lighter to heavier elements, Mendeleev found that their chemical behavior would change gradually—but only up to a certain point. The properties would then shift abruptly to resemble the properties of a lighter element, then change gradually again as atomic mass increased, until the properties reverted abruptly again to resemble those of a lighter element.

To account for the periodically repeating patterns, Mendeleev organized the elements into columns and rows. In his original table, moving downward in a column—or *period*—atomic mass increased from one element to the next, while each row was comprised of a *group* of elements that exhibited similar properties (fig. 8). Later, Mendeleev shifted the orientation of his table so that the periods appeared in horizontal rows while each group of elements with similar properties lined up vertically. Importantly, Mendeleev allowed the properties of two elements with similar atomic weights to dictate their sequencing, even when this meant that a slightly heavier element would be placed before a slightly lighter one. Mendeleev placed cobalt before nickel, for instance, even though cobalt was known to be slightly heavier. In doing this, Mendeleev, unwittingly, set chemistry on the path of organizing the elements based on what is now known as atomic number. Later—in the early 20th century, on their way to discovering protons—chemists rewrote the periodic table, using the atomic number as the organizing principle (fig. 9).

The periodic table used today has evolved from the table of the 1920s, but atomic



ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ,

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

			Ti=50	Zr= 90	?=180.
			V=51	Nb= 94	Ta=182.
			Cr=52	Mo= 96	W=186.
			Mn=55	Rh=104,4	Pt=197,1.
			Fe=56	Ru=104,4	Ir=198.
			Ni=Co=59	Pd=106,6	Os=199.
H=1			Cu=63,4	Ag=108	Hg=200.
	Be= 9 ,4	Mg=24	Zn=65,2	Cd=112	
	B=11	Al=27,3	?=68	Ur=116	Au=197?
	C=12	Si=28	?=70	Sn=118	
	N=14	P=31	As=75	Sb=122	Bi=210?
	O=16	S=32	Se=79,4	Te=128?	
	F=19	Cl=35,5	Br=80	I=127	
Li=7	Na=23	K=39	Rb=85,4	Cs=133	Tl=204.
		Ca=40	Sr=87,6	Ba=137	Pb=207.
		?=45	Ce=92		
		?Er=56	La=94		
		?Yt=60	Di=95		
		?In=75,6	Th=118?		

Д. Менделѣевъ

Figure 8: Dmitri Mendeleev's original table, published in the year 1869 with periods as columns and chemical groups as rows. Two years later, he reoriented the table so that periods were rows and groups were columns.

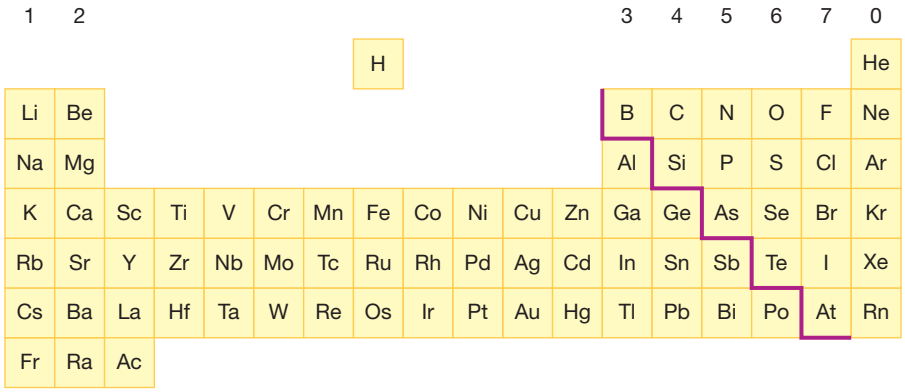


Figure 9: The first modern periodic table, created by the early 20th century chemist Henry Moseley.

number (the number of protons) still determines the chemistry of the elements. That is because the number of protons determines the number of electrons, which, in turn, determines the number of valence electrons in an atom of any element.

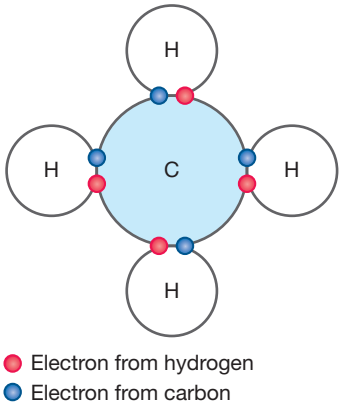


Figure 10: A simplified representation of covalent bonds in a molecule of methane (CH_4). In this molecule, four atoms of hydrogen each contribute one electron to a shared electron pair that constitutes a covalent bond with a carbon atom. The carbon atom contributes four electrons to each electron pair, constituting a covalent bond to a hydrogen atom.

Molecules, Ions, & Lattice Structures

As discussed earlier, valency determines how atoms interact with one another. It also determines the arrangements in which atoms coexist. One example of coexistence between atoms is a **molecule**. A molecule is a group of at least two atoms that are held closely together by type of chemical bonding called **covalent bonding** (also known as **molecular bonding)**. This means that atoms share valence electrons (fig. 10). To make this sharing possible, the atoms must remain close together, so close that their electron clouds partially merge. The tendency to form covalent bonds—as well as the types of covalent bonds that an atom

can form—relate to an element's position on the periodic table. Covalent bonding will be discussed in more detail in the next chapter.

Atoms are not restricted to coexistence only as molecules but can form additional entities. The ability of atoms to form molecules depends on whether sharing electrons is the easiest way for participating atoms to acquire full outer electron shells. For many elements, when they are combined into a solvent like water, often through agitation or with the use of energy (like heat), the atoms will then exist as **ions**. Elements in Groups 1 and 2 give up their one or two valence electrons, thereby transforming into a positive ion, or **cation** (positively charged ions). On the other hand, a Group 17 element—having seven valence electrons—can easily acquire an extra electron to fill its outer electron shell. In this case, it becomes a negative ion, or an **anion** (negatively charged ion). When in a solution, anions and cations are kept apart because each is attracted to a different side of the water molecule (fig. 11). However, when the environment dries, anions and cations are attracted so strongly toward one another that they are pulled together, forming an **ionic bond**. Unlike a covalent bond, an ionic bond does not form molecules; instead, it pulls ions into a crystal structure. An ionic bond

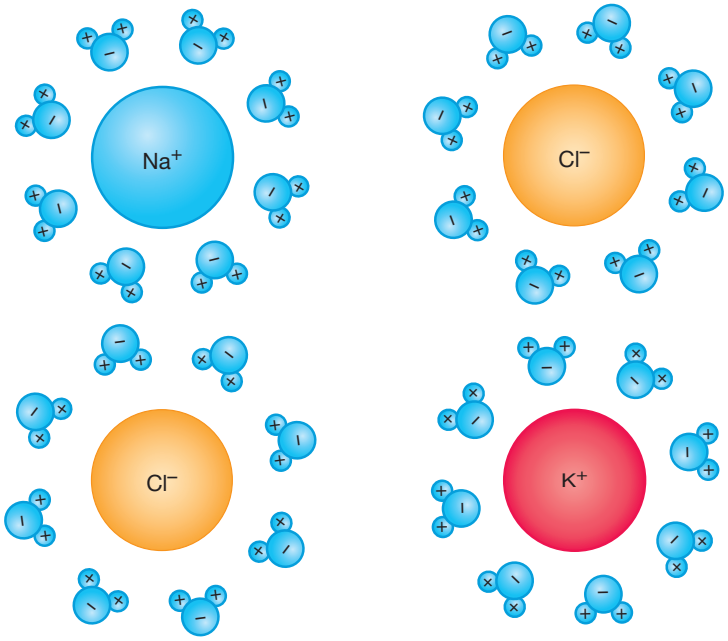


Figure 11: Group 1 cations (sodium and potassium) and Group 17 anions (chloride) in water solution (not drawn to scale).

can also occur when the environment is not dried.

Another way that ions of certain elements, namely metals, can relate to one another is to line up in what's called a (crystal) **lattice structure**. In such a situation, the valence electrons move around between atoms of the lattice (fig. 12). In addition to accounting for why metals are very good at conducting electricity, this is also why the elements of the periodic table are categorized as either metals, metalloids, or nonmetals.

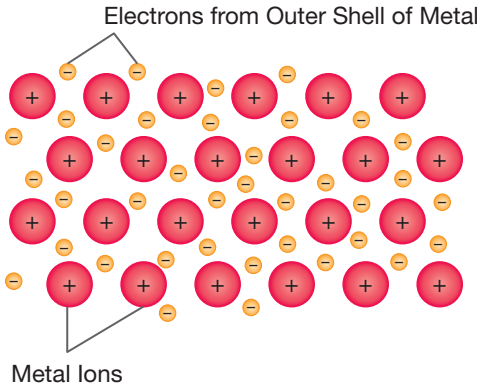


Figure 12: Metal lattice, consisting of cations with free-moving electrons.

Metals are elements that conduct electricity well. Metals want to give up their electrons because of the arrangement of those electrons in order to form molecules. These comprise the majority of elements on the periodic table. With the exception of hydrogen, nonmetals do not have a tendency to give up electrons. Instead, some nonmetals (not all) have a tendency to acquire electrons. Metalloids, the smallest of the three categories, have both metal and nonmetal properties. Figure 13 illustrates how metals, nonmetals, and metalloids are arranged on the periodic table.

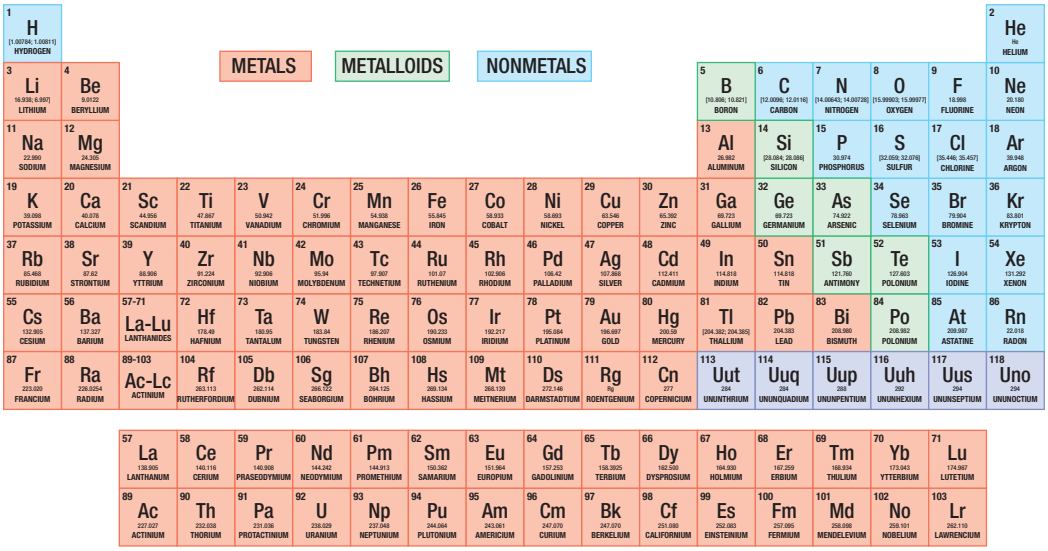


Figure 13: The periodic table, distinguishing between metals, nonmetals, and metalloids.

7 ACIDS, BASES, SALTS, & CARBON CHAINS

The previous chapter covered how an element's position on the periodic table relates to its number of valence electrons. Valence relates to an element's tendency to form cations or anions as well as the magnitude of the element's charge. Atoms that become cations by releasing electrons, and atoms that can become anions by acquiring electrons, can together form an *ionic bond*.

Valence also relates to the formation of *covalent bonds*. Covalent bonds result from the sharing of valence electrons between atoms. This kind of bond holds atoms together as molecules. These concepts are fundamental to the subject of this chapter—acids, bases, salts, and carbon chains—which are themselves key to understanding the chemistry behind tattoo pigments and dyes, covered in the following chapter.

Salts, Acids, & Bases

A dye dissolves in a solution and a pigment is insoluble. When in a dry environment, cations and anions are drawn together in ionic bonds. This kind of bonding does not produce molecules but, instead, crystalline assemblies of atoms called **salts**. Metal salts, like Cadmium sulpho-selenide Cd2SSe, can produce bright colors, in this case red. There are many kinds of salts, the most familiar being common table salt. It is formed from a cation of the Group 1 metal sodium (Na^+) and an anion of the Group 17 halogen chlorine (whose anion is known as **chloride** [Cl^-]), resulting in sodium chloride, identified by the chemical formula NaCl. When placed in a solvent—especially water—a salt will **dissolve**, meaning that the assembly of atoms comes apart and the cations and anions float freely, surrounded by the water molecules.

NaCl is an example of a salt formed from a chemical reaction between a metal (Na) and a nonmetal (Cl). The nonmetal is molecular chlorine, symbolized as Cl_2, because it naturally exists as a molecule of two chlorine atoms. The equation for this reaction is:

$$2Na + Cl_2 \rightarrow 2NaCl$$

This is called a **balanced chemical equation**, because the numbers of each type of atom are equal on both sides. In this case, the **reactants** in the equation are two sodium atoms and one chlorine molecule, which consists of two chlorine atoms. The product of the equation is two molecules of sodium chloride.

Many different types of salt are formed from reactions between a metal and a nonmetal, but various other types of chemical reactions also produce salts. For example, a reaction between an **acid** and a **base**—hydrochloric acid (HCl) (produces H^+ **ions**) and ammonia (NH_3) (produces OH^-) produces the salt ammonium chloride (NH_4Cl). In the next section, we cover the relevance of acid-base reaction and metals. This reaction can create brightly colored metal salts.

Anyone who has ever sucked on lemons or eaten a lot of pineapple may know that acid can wear down the enamel of teeth or irritate their gums. That's because acids are corrosive, even acids that are weak enough for humans to consume—including the citric acid in lemons. When strong enough, acids can also corrode metals, meaning they can burn skin and other biological tissues. Acids change the color of litmus paper. Litmus paper is designed to test the acidity and alkalinity of a substance. Litmus paper will turn red to indicate acidity and blue to indicate alkalinity. Just like strong acids, strong bases can also damage materials, including

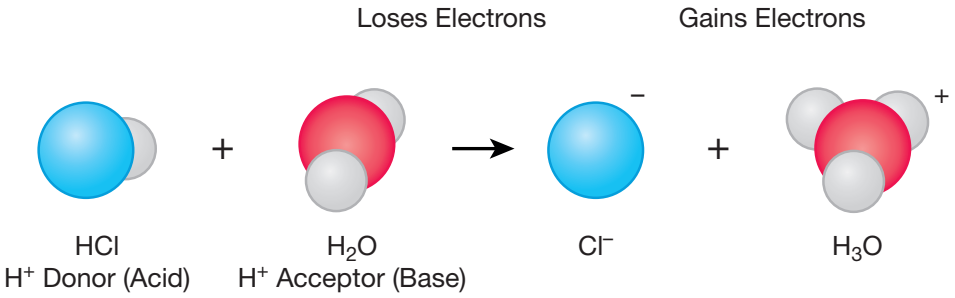


Figure 13: Acids, bases, protons, and electrons. An acid donates a proton or accepts electrons, whereas a base donates electrons or accepts a proton.

biological tissue. When involving materials in the tattoo process, it is important to keep in mind that products must be formulated to not irritate human tissue.

As for the chemistry, an acid is a molecule or other entity that can **donate** a hydrogen atom (a proton) to another entity or that can accept a pair of electrons from it. In contrast, a base is a molecule or other entity that can either accept a proton or donate electrons (fig. 14).

An example of an acid-base reaction is a **neutralization reaction** in which an acid and a base react, always producing water and a salt. For example, table salt (NaCl) can be produced by reacting hydrochloric acid (HCl) with a base called sodium hydroxide (NaOH). The equation for this reaction is:

$$HCl + NaOH \rightarrow H_2O + NaCl$$

acid base water salt

Another important concept within the topic of acid/base chemistry is the concept of **pH**. Invented by the Danish biochemist Sören Sörensen in 1909, pH is simply a scale for quantifying and measuring acidity and **alkalinity**, which describes the pH properties of a base. Running from 0 to 14, the pH scale (fig. 15) is a logarithmic scale, with the pH value related to the concentration of protons (H^+) in a solution through the following formula:

$$pH = -\log [H^+]$$

in which $[H^+]$ represents the concentration of protons in a solution.

Essentially, this formula means that moving from one point to the next along the pH scale represents a 10-fold change. Since a lower pH number means higher acidity and a higher pH number means higher alkalinity, a pH of 5, for example, represents 10 times more acidity than a pH of

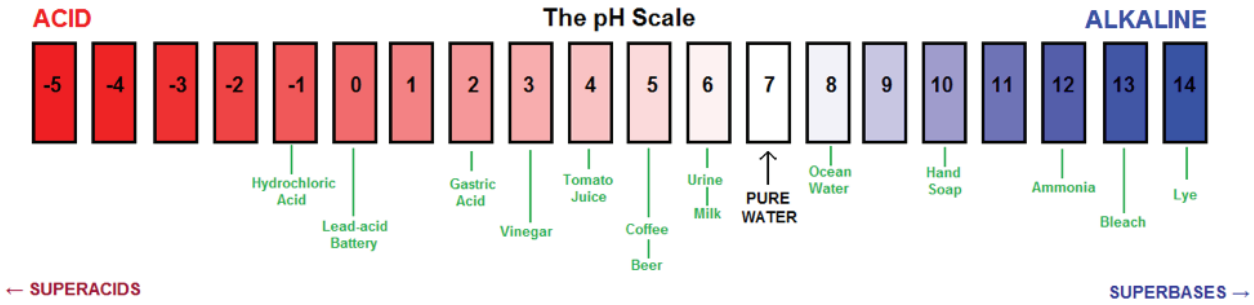


Figure 14: The pH scale.

Figure 15: **Iron(III)-chloride-hexahydrate**, an example of a metal salt.

6. We find pH relevant in tattooing when a pigment solution must be near a sensitive area like the eyes. Often cosmetic tattoo pigments are specially formulated at a pH of approximately 7.4 in order to not irritate sensitive areas or cause complications. Recall, a high acidity or alkalinity can burn or irritate human tissue.

Metal Salts, Metal Oxides, & Heavy Metals

When hydrogen atoms from acid molecules are replaced in chemical reactions with metal atoms, the resulting molecules are known as **metal salts**. This class of chemicals can be found in various tattoo pigments, as it can produce a variety of vibrant colors (fig. 16)**.** Other tattoo pigments include **metal oxides**, which are molecules consisting of metal and oxygen atoms bound together. One example is iron, which can produce several colors (fig. 17). The metals in these pigments are **heavy metals**, a term that encompasses metals with high atomic number (many protons), high atomic weight (many protons and neutrons), or high density (the metal weighs a lot per volume). Generally, heavy metals include all three of these properties. Examples include:

- lead
- iron
- chromium
- mercury
- antimony
- nickel
- beryllium
- cobalt
- arsenic

A variety of heavy metals are present in many tattoo pigments, as different metals in combination with other elements produce various desired colors.

Synthetic Iron Oxide Pigments

Color	Fe_3O_4 (%)	Fe_2O_3 (%)	Oil absorption (ml/100g)	Res.on 325mesh (%)	Water SOL.salts (%)	Moisture (%)	PH	Tamped density (g/cm3)	Compared with std. (ΔE)	Tinting strength (%)
Red		≥96	15-25	≤0.3	≤0.3	≤1.0	3–7	0.7–1.1	≤1	95-105
Yellow		≥86	25-35	≤0.3	≤0.3	≤1.0	3–7	0.4–0.6	≤1	95-105
Blue			20-30	≤0.3	≤2.0	≤1.0	8-10	0.4–0.8	≤1	95-105
Green			25-35	≤0.3	≤2.0	≤1.0	≥6	0.4–0.8	≤1	95-105
Orange		≥88	20-30	≤0.3	≤0.3	≤1.0	3–7	0.4–0.6	≤1	95-105
Brown		≥88	20-30	≤0.3	≤0.5	≤1.0	4–7	0.7–1.1	≤1	95-105
Black	≥90		15-25	≤0.5	≤0.5	≤1.5	5–8	0.9–1.3	≤1	95-105

Figure 16: Synthetic iron oxide pigments. Depending on how iron combines with oxygen, iron oxides can produce a range of color pigments.

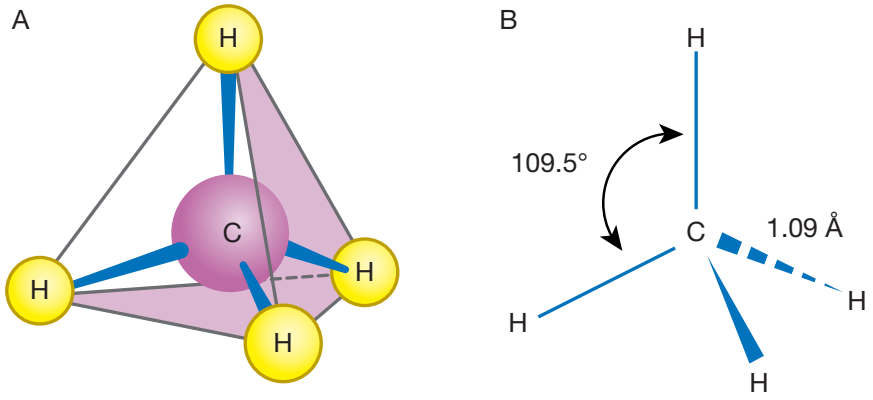


Figure 17: When carbon forms four covalent bonds, they are all single bonds, projecting outward from the carbon atom. The attached atoms form the corners of a tetrahedron, with an angle of 109.5˚ between the bonds.

Nonmetals and Organic Compounds

Metals and nonmetals are put into separate categories because their chemistry is very different. Atoms of certain nonmetals—particularly halogens—easily become anions that form ionic bonds with metal cations. However, nonmetals do not form ionic bonds with one another. Instead, nonmetal atoms group together into molecules by way of covalent bonding. This phenomenon enables nonmetal atoms to form, at times, very complex

molecules. Additionally, the ability to form covalent bonds allows for complex molecules to form **polymers**—extremely long molecules built of repeating subunits called **monomers**. Proteins, DNA, RNA, and complex carbohydrates are but a few examples of polymers that have emerged in nature. Polymers also include synthetic polymers, or polymeric substances that humans have synthesized. These synthesized polymers are what we most commonly see in present day tattoo pigments.

Nonmetals & Covalent Bonds

Polymers will be discussed further in the next chapter. Before learning about them, it is important to understand a few concepts about covalent bonds. Most nonmetals have a high number of valence electrons, meaning at least four. Hydrogen is the exception, as it needs only one electron to finish its outer ring. Nonmetals other than hydrogen obey the octet rule, meaning that their atoms strive to have eight valence electrons. In most cases, the best way to possess eight valence electrons is through covalent bonding with other atoms.

A covalent bond can be a single, double, or triple bond. In structural formulas of molecules, these are represented by a single line (-), double line (=), and triple line (≡ respectively, between the chemical symbols of covalently bonded atoms. As an example, a molecule of oxygen—consisting of two oxygen atoms joined by a double bond—can be drawn as O=O.

In a single covalent bond (also called a single bond), two atoms share one pair of electrons, with each atom supplying one electron of the shared pair. In a double covalent bond (double bond), two atoms share two pairs of electrons, while a triple bond consists of three electron pairs. The number of covalent bonds that an atom can form depends on the locations where atoms have fillable areas for electrons (covalent bonds), creating geometric shapes of the resulting molecules.

Each carbon atom, for instance, has four valence electrons. This means it has a valence number of -4 and needs four more electrons. In a carbon atom, the empty spots stick out in four different directions from the nucleus. This means that a carbon atom can form covalent bonds with four other atoms, if those bonds are all single bonds. Because of the locations of the fillable areas, the four atoms bonded to a carbon atom form the corners of a tetrahedron with the carbon atom at its

center (fig. 18). If one of the bonds is a double bond, however, then only three other atoms can be attached. The shape changes, as the angles between the three bonds are different.

This phenomenon has major implications for the structure of molecules built out of interconnected carbon atoms. It is also the basis of **organic chemistry**, or the chemistry of organic compounds. Chemical compounds built from carbon atoms covalently bond to other atoms, especially other carbon atoms and hydrogen atoms.

Note that in science, the word *organic* refers to carbon-based chemistry and should not be confused with the term *organic* as applied in the marketing of certain agricultural products. In this book, the term *organic pigments* refers to tattoo pigments made from organic molecules—molecules whose structure consists of chains and rings connected by carbon atoms. Organic pigments are distinct from metal-based pigments. They are not, however, created from "organically" produced agricultural products.

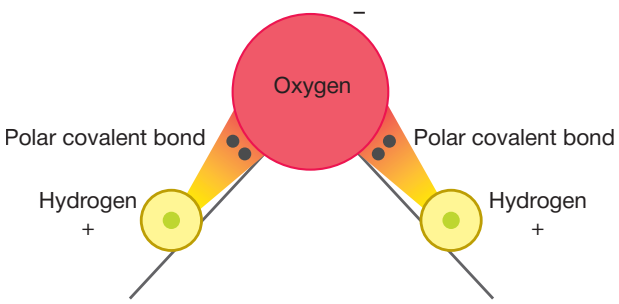


Figure 18: A water molecule contains two polar covalent bonds. Because of the polarity and orientation of the bonds, the entire molecule is polar, featuring a net negative charge on the oxygen side and a net positive charge on the hydrogen side, making water an excellent solvent for dissolving charged entities.

In contrast with carbon, nitrogen has five valence electrons. This means that nitrogen needs three more, so it can form up to three single covalent bonds with other atoms. Oxygen has six valence electrons and a need for two, so it can form up to two single bonds.

Polarization

Hydrogen works a little differently from the other nonmetals. That's because it has only one electron to share and needs only one more to be complete. It also does not hold onto electrons very tightly. Each hydrogen atom forms just one covalent bond with another atom, and the bond must be single. Considering hydrogen does not hold electrons very well, the covalent bond between hydrogen and another element tends to form more around the other element. This uneven

sharing results in **polar covalent bonds**. In contrast with **nonpolar covalent bonds** (which occur between atoms of the same element or between different elements that share electrons equally), polar covalent bonds occur between any atoms that are different. These bonds are uneven between atoms. Some atoms are very good at attracting electrons, such as oxygen or nitrogen, opposed to an atom that is very bad at attracting electrons, such as hydrogen.

Consequently, parts of a molecule—namely the parts near the atoms that attract electrons—can be more negatively charged, while other parts of the molecule are more positively charged. Such molecules are called **polar molecules**. The classic example of a polar molecule is water (H_2O). It is not a line going H-O-H, but rather a V shape, so that the hydrogen atoms are on one side of the molecule and the oxygen atom is on the other. This, in turn, leaves a negative charge on the oxygen side and a positive charge on the hydrogen side, giving water its very particular properties, including the ability to dissolve salts (fig. 19).

Importantly, the phenomenon of polarity is especially pronounced when electron-loving atoms—such as oxygen, nitrogen, and phosphorus—are bound as part of organic molecules. Compounds consisting of molecules containing only carbon and hydrogen are called **hydrocarbons**. Hydrocarbons can contain carbon atoms that are connected by single bonds to other carbon atoms and to hydrogen atoms. They can also include carbon atoms that are connected by double or triple bonds to other carbon atoms or other elements. Carbon atoms often link up in very large carbon chains. These chains can have branches, as well as attached groups of carbon atoms with double bonds and/or electron-loving atoms. Known as **functional groups**, these sections of organic molecules with carbon-carbon double bonds and electron-loving atoms make a considerable impact on a molecule's chemistry. This concept becomes important when understanding polymers, covered in the next chapter.

8 CHEMISTRY OF TATTOO PIGMENTS AND DYES

The previous chapter covered the composition of acids, bases, salts, and carbon chains, which have some key roles to play when it comes to the chemistry of tattoo pigments and dyes. Notably:

- **Metal pigments** are made from metal salts, metal oxides, and heavy metals, and each can be used to create vibrant colors.
- **Organic pigments** are made from organic molecules, or molecules whose structure consists of chains and rings with carbon atoms attached. They are not, however, created from "organically" produced agricultural products.

These two types of structures are present in tattoo ink, the latter more than the former. Both are present in a tattooed individual's body. This chapter takes a closer look at the chemistry of tattoo pigments and dyes in preparation for understanding how the body metabolizes these materials, which is covered in the next chapter.

Dyes versus Pigments

The terms, dyes and pigments, are often used synonymously, but there are some fundamental differences. The primary distinction is that **dyes** are dissolved in a solution while **pigments** are suspended, retaining a crystal or particulate structure.

Figure 19 illustrates the difference between a solution and a suspension. A solution is a mixture between two or more substances that cannot be separated by mechanical methods. The major component of the **solution**—the substance present in higher quantity—is called the **solvent**. In contrast, a **solute** is what is dissolved into the solvent, and there can be more than one. As noted in the previous chapter, water is a very good solvent for salts, because water molecules are

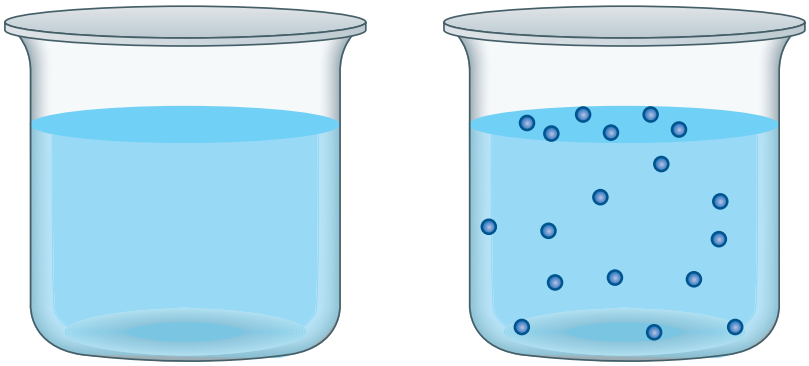


Figure 19: A solution and a suspension.

polar and the components of salts are electrically charged ions. Expanding on this idea, any substance that can break down into ions, can dissolve in water, although some substances require more than water or additional energy. An ion can consist of a single atom, like a chloride ion (Cl^-), or it can also be a molecule if, overall, it has a net positive or negative charge. Dyes form molecules, as they are composed of atoms covalently bonded together. Dyes that are bases dissolve as cations (positive ions). Three different categories of dyes—acid dyes, reactive dyes, and direct dyes—dissolve as anions (negative ions).

In contrast with a solution, a **suspension** is a mixture in which the minor component consists of particles that are small and distributed but can settle in a mixture over time. This works because they are not interspersed molecule-by-molecule with the major component of the mixture. Adding some dirt to water and shaking it up in a closed jar, for example, will create a suspension for a little while as dirt particles float around. They cloud the water and soon will settle at the bottom of the jar due to gravity. Pigments do the same thing. In ink, pigments are suspended in a medium that is usually water-based but often may contain ethyl alcohol and other ingredients.

The water- and/or alcohol-based medium in which tattoo pigments are suspended is often known as a **carrier solution**. The *carrier* part of the term relates to the fact that the medium serves to distribute the pigment so that it can be deposited precisely where the tattoo artist desires. The *solution* part of the term is a misnomer, considering the pigments are suspended,

not dissolved. On the other hand, when it comes to dyes within tattoo ink, the term *solution* is correct.

Types of Pigments & Dyes

Categories of pigments and dyes in tattoo ink consist of metal salts, metal oxides, and organic compounds, specifically organic compounds that classify both as *polymers* and *plastics*, terms that will be explained below. The Ecological and Toxicological Association of Dyes and Organic Pigment Manufacturers (ETAD) has defined dyes as intensely colored or fluorescent organic substances. Metal salts and metal oxides are generally considered pigments within tattoo ink, whereas organic colorings can be either dyes or pigments.

Dyes can be further classified as vegetable dyes (derived from plants with minimal processing) or as synthetic dyes (industrial products, often polymers). It is worth noting, to be clear, that plants are typically the source of the starting materials used to make polymers. Sometimes, the word *organic* is applied to the vegetable dyes, but, as noted earlier, the term *organic* applies to any complex molecule built of carbon. Nevertheless, it is correct to call vegetable dyes organic, because they do consist of organic molecules. However, plastics or polymers in tattoo ink are also organic in this way.

Polymers

As discussed in the previous chapter, *functional groups* are groups of one or more atoms of distinctive chemical properties. The atoms of functional groups are linked to each other and to the rest of the molecule by covalent bonds. In biological systems and in industrial chemistry, the presence of functional groups in organic molecules enables **polymerization**. For

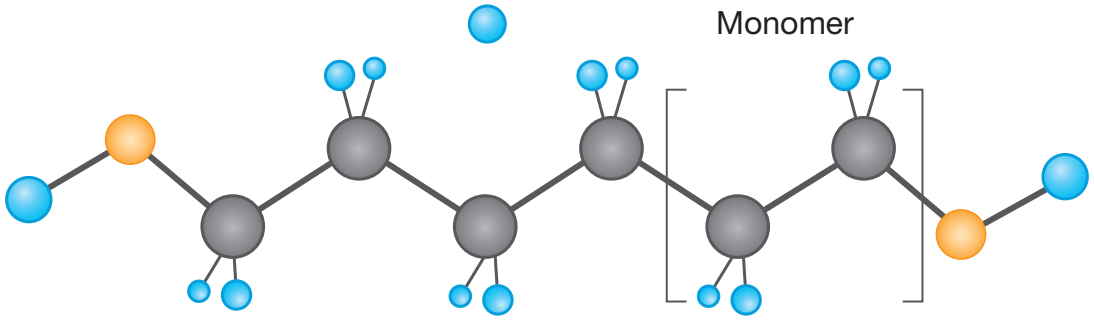


Figure 20: A polymer consists of subunits called monomers.

repeating units of polymers, functional groups attach to their nonpolar core of carbon atoms and thus add chemical character to carbon chains. The creation of *polymers* from smaller molecules called *monomers* (fig. 20). Usually, the starting material for making polymers is a **resin**, a viscous or sticky solid substance that can be either synthetic or taken from a plant source. Resins are often mixtures of organic compounds.

Polymers include **plastics**, an extremely broad range of nonmetal synthetic and semisynthetic substances, which are made from modified naturally-occurring materials substances. Some of these constitute important ingredients in certain tattoo inks. Most plastics are organic (based on carbon atoms), although some silicon-based materials can also be categorized as plastics. Sometimes, the words *plastic* and *resin* are used interchangeably, although the word *plastic* generally applies to the finished product.

One category of synthetic polymers consists of **vinyl** polymers. These are comprised of vinyl monomers, which each contain carbon-carbon double bonds. The simplest vinyl polymer is *polyethylene*, a common type of plastic

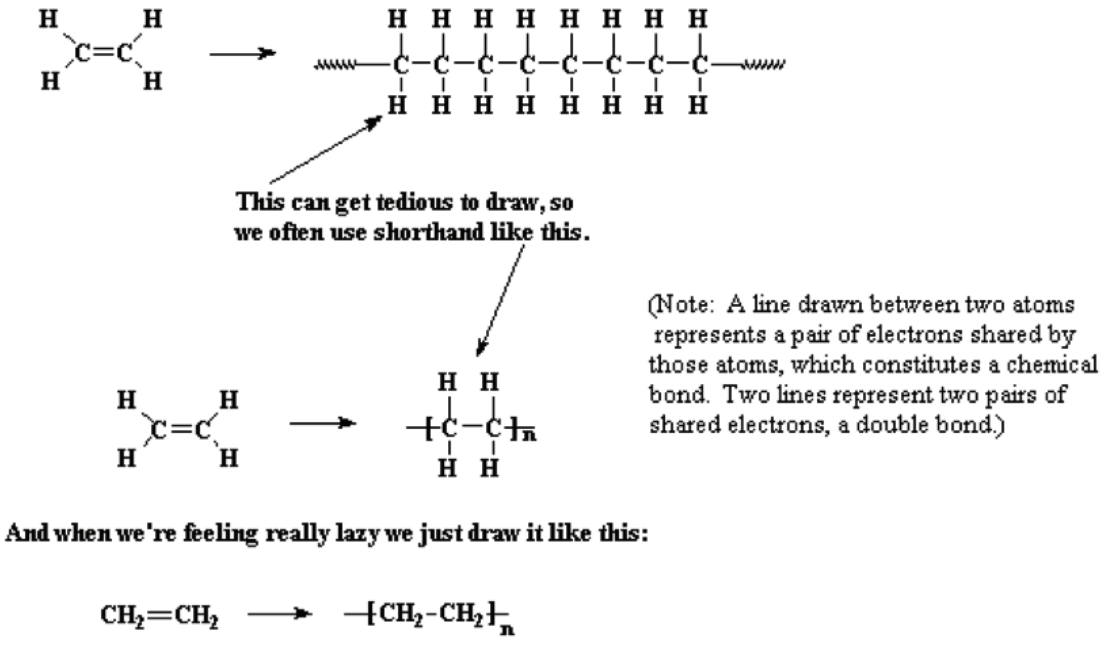


Figure 21: **Polyethylene** is created through the polymerization of ethene (ethylene) monomers.

made when a molecule called *ethylene* (also called *ethene*) is polymerized. The chemical structure of ethylene is written $H_2C{=}CH_2$, but when it loses a hydrogen atom it becomes a **vinyl group**, having the formula $-C{=}CH_2$. In the polymerizing process to form polyethylene, the double bonds disappear. The result is a chain of thousands of carbon atoms connected by single bonds with hydrogen atoms attached at the sides. Consequently, the repeating unit in polyethylene is simply CH_2, a carbon atom with two hydrogen atoms attached (fig. 21).

Using a range of chemical processes and starting materials other than ethylene, a variety of other synthetic polymers can be created. Each of these features particular functional groups of atoms sticking out sideways from the long chain in place of hydrogen atoms. In polyvinyl chloride—a common **thermoplastic** (a plastic that becomes soft and pliable when heated)—there is a chlorine atom substituted for every other hydrogen atom along one side or the chain (fig. 22). Similarly, the thermoplastic *polypropylene* has what is called a **methyl group** (CH_3) in the places where polyvinyl chloride has chlorine atoms (fig. 23). Those spots in *polystyrene* (an extremely common, hard plastic that constitutes Styrofoam®) feature a ring-shaped group of carbon atoms known as a **benzene ring** (fig. 24). Compounds with benzene rings are known as **aromatic compounds**. Teflon®, an extremely strong polymer, has a molecular structure just like polyethylene, except that all of the hydrogen atoms on both sides of the chain are replaced with atoms of fluorine. This makes the material useful for a range of applications that include non-stick frying pans and medical devices like catheters.

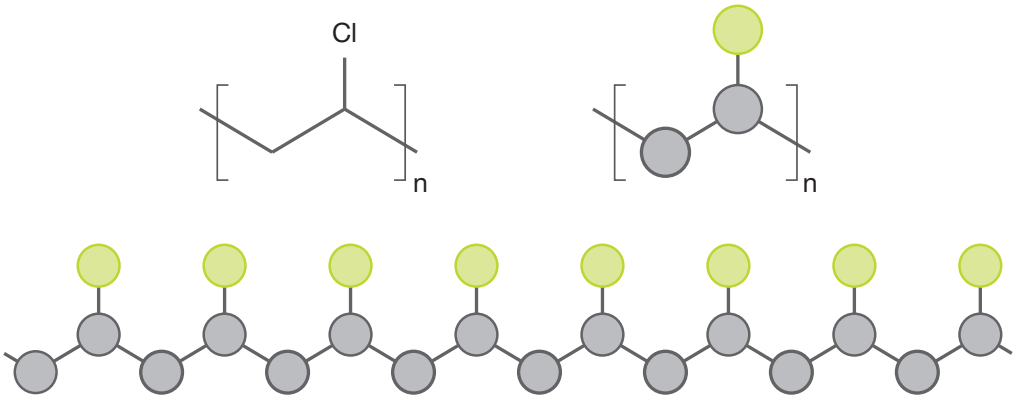


Figure 22: Polyvinyl chloride.

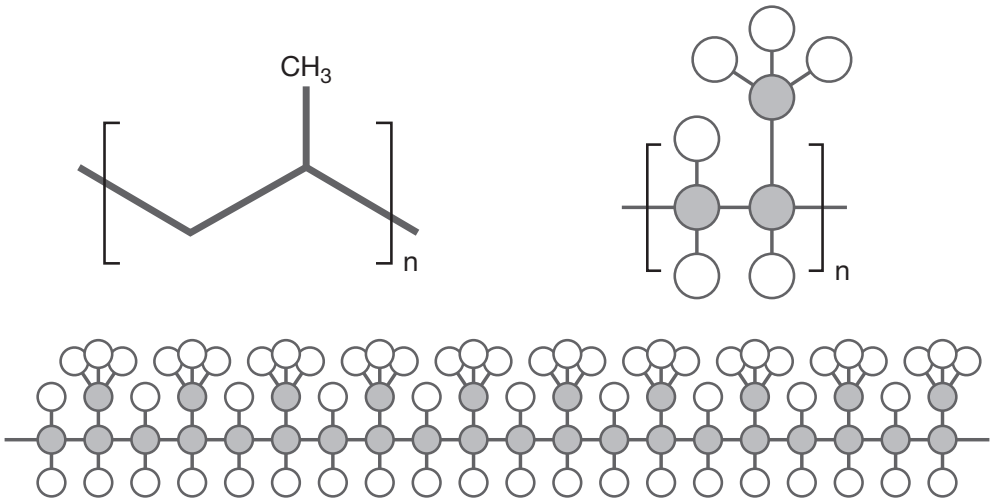


Figure 23: **Polypropylene** is comprised of chains of propylene monomers.

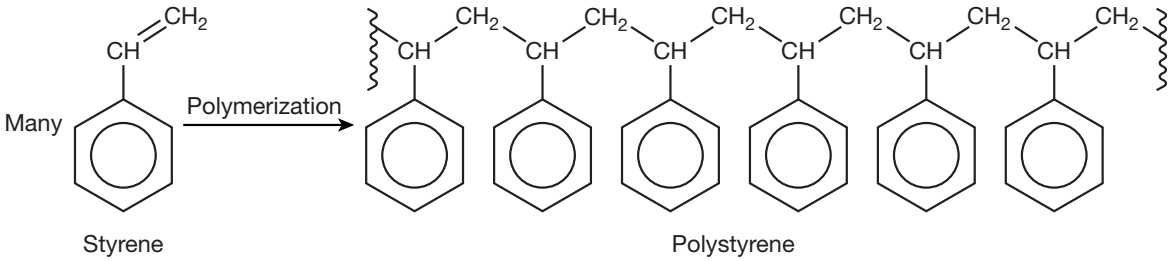


Figure 24: **Polystyrene** is comprised of chains of styrene monomers.

Although the discussion above has focused primarily on synthetic polymers based on a vinyl structure, there also are many other categories. **Acrylate polymers**—often known as acrylics or polyacrylates—consist of monomers that are based on the structure of acrylic acid. Acrylic acid consists of an entity called a **carboxyl group**—a carbon atom with two attached oxygen atoms, one which has a hydrogen atom while the other does not—connected to a vinyl group (fig. 25). As with vinyl polymers, monomers making up acrylate polymers can have a range of substitutions, leading to a variety of properties. Acrylates are known for their resistance to water and weather and often for their transparency, which is why they are often used in polishes and dentistry.

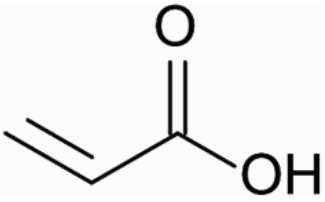


Figure 25: Acrylic acid.

Various tattoo pigments fall within the category of organic polymers. Some of these pigments are aromatic (their molecular structures include a benzene ring). Other organic pigments contain what is called a **diazenyl** group. This functional group consists of two nitrogen atoms connected with a double bond. Since each nitrogen atom can form three covalent bonds, this arrangement leaves each nitrogen atom to form a single bond with another group of atoms. Consequently, each diazenyl group looks like this:

R–N=N–R'

in which:

- R represents a carbon atom connected with other atoms, and
- R' represents a different group of atoms connected to a carbon atom.

Compounds with at least one diazenyl group are called **azo compounds**. Polymers can also be formed with diazenyl groups linking other groups (fig. 26).

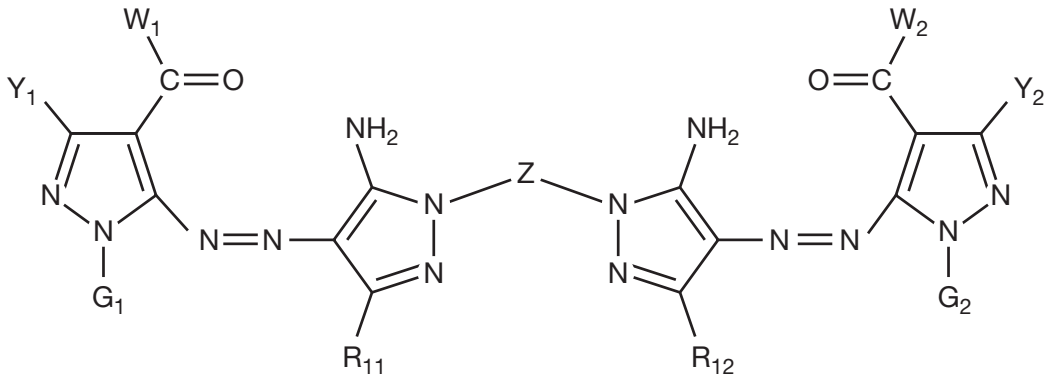


Figure 26: An azo pigment.

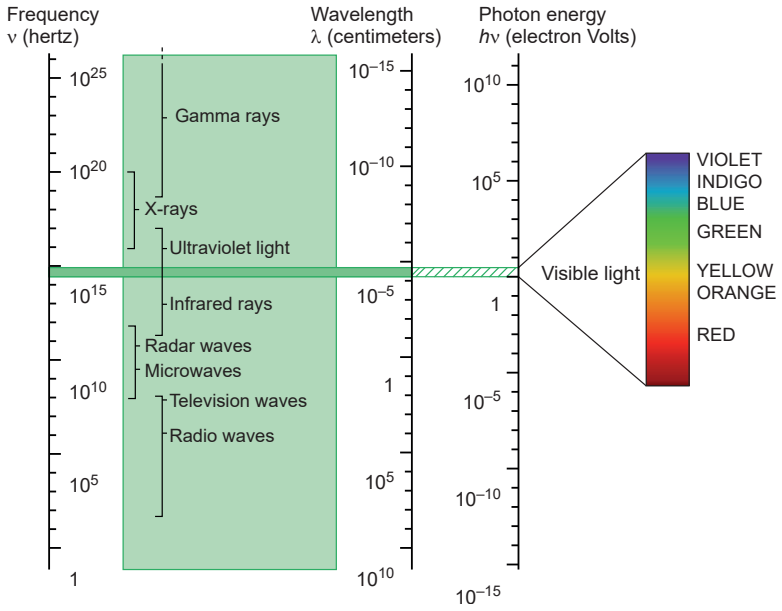


Figure 27: The electromagnetic spectrum, showing wavelength and frequency ranges, with the visible portion of the spectrum expanded.

Why Do Tattoos Fade?

Tattoos fade on account of two mechanisms, which work in concert. One mechanism involves the absorption of electromagnetic radiation (EMR), meaning visible light as well as other invisible parts of the EMR spectrum (fig. 27), particularly ultraviolet (UV) and infrared (IR) radiation. EMR includes sunlight as well as the light that comes from artificial lighting. Sunlight is much more significant to the issue of tattoo fading, as it is much more intense than artificial lighting and emits a great deal more UV radiation (sometimes called UV "light," even though it is not visible to humans). Some lights—particularly

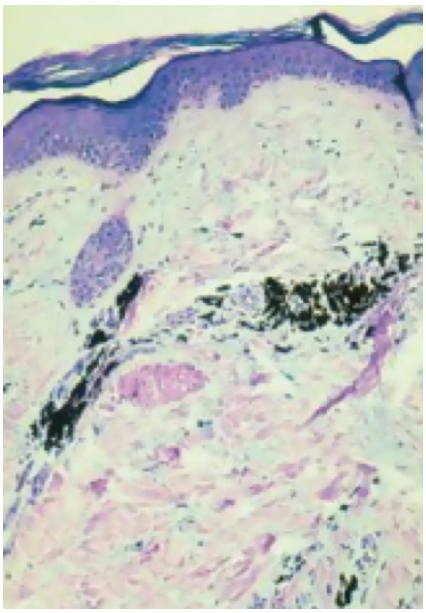


Figure 28: Histological section from tattooed human skin, showing black pigment particles inside fibroblasts. *Image credit: Philosophical transactions. Biological sciences.*

fluorescent lights—emit UV radiation as well, however not nearly as much as the sun. (Serup et al. 2015).

At the same time, approximately 40% of solar radiation reaching the surface of the Earth is IR radiation (Cho et al. 2009). IR radiation is the reason why sunlight feels warm. It is known to penetrate beneath the epidermal layer of the skin and produce various effects on skin cells (Cho et al. 2009; Schroeder et al. 2010; Tanaka et al. 2010). Many of the lasers used in tattoo removal (discussed in Unit V) achieve the task by exposing the tattoo to IR radiation (Choudhary et al. 2010).

EMR is referred to as a *spectrum*, because it exists at a continuous range of frequencies and wavelengths. Frequency and wavelength of light are inversely proportional, meaning that λ increases as *f* decreases, based on the relationship:

$$c = f\lambda$$

where:

- *c* is the velocity of light (approximately 3×10^8 m/s in a vacuum),
- *f* is frequency in Hertz (Hz), and
- λ is the wavelength in meters.

Whether light is in the visible range, in the UV range, or in some other range (such as IR, radio, or gamma ray) depends entirely on these values. Although the radio portion of the spectrum includes wavelengths range in meters (actually from millimeters to a kilometer or more), smaller units (such as nanometers [nm]) are generally employed to express λ values of visible and UV light.

In the visible range, the value of λ indicates the color of the light that the human nervous system perceives, as discussed in Unit III. Humans see light that has a wavelength anywhere from 625 to 740 nanometers (nm) as red, while 625 down to 590 nm is orange. As the wavelength shortens further, light looks yellow, green, cyan, and blue, and the visible light with the shortest wavelength is violet (range 380–450 nm). At λ of approximately 380 nm, the UV spectrum begins, whereas the IR spectrum begins around 740 nm.

It's important to note that there is some variability regarding the wavelengths and frequencies that some people are able to perceive. Some may see up to wavelengths slightly longer than 740 nm, while others can see wavelengths that are shorter than 380 nm. Others may perceive the same wavelength as slightly different colors.

As discussed in Unit III, although humans do not see IR and UV radiation, **EMR of different wavelengths affects various pigments differently**. This phenomenon also expands into visible light, as different pigments absorb and reflect light of different wavelengths, the visible color is reflected by a particular pigment. People don't see the light that the pigment molecules absorb, but the energy from absorbed IR, UV, EMR, and visible light can react with the structure of the pigment, breaking it apart. With sunlight, the breakup of pigment particles occurs over many years, so fading is slow, and a tattoo is unlikely to disappear. In contrast, laser light can produce more dramatic and more rapid fading for the intentional removal of tattoos. This topic will be explored in a later chapter.

The other mechanism related to tattoo fading involves special cells of the immune system called **macrophages** and connective tissue cells called **fibroblasts** (fig. 28). Macrophages and fibroblasts engulf pigment particles, but they have an easier time engulfing smaller particles than they do larger ones. When they engulf large pigment particles, those remain within the cell to produce their designated color. Macrophages typically live longer than fibroblasts, even for periods of many years. After a macrophage dies, the pigments are engulfed by new macrophages (Baranska et al. 2018). Over time, however, sunlight can break down the pigments, and once this happens within living macrophages, the macrophages can break down the smaller pieces.

Known as **photodegradation**, the breakdown of pigments due to EMR varies among different pigments. The ability of a chemical agent, such as a pigment, to resist photodegradation is known as its **photostability**. Photostability relates strongly to particular wavelengths of light, and other aspects of a light source can also affect it.

Cosmetic Tattoo Pigments

Generally, the term **cosmetic tattooing** refers to tattooing that is administered either to make an unwanted marking, scar, or other feature look more natural, or to enhance "beauty" in the way that makeup may be used to achieve the same effect. Cosmetic tattoos are also called **permanent makeup (PMU)**.

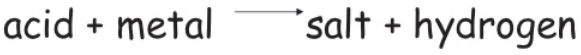
Because this work is performed on sensitive areas of the body like the face, cosmetic tattoo artists take care to select pigments and inks that are chemically

milder than those used on most body tattoos. Often, this means that the coloring agents consist of vegetable dyes. Consequently, these tattoos tend to fade noticeably over time (Serup et al. 2015).

The need for chemical mildness furthermore means that agents are pH balanced: solutions and suspensions for cosmetic tattoos are designed to have particular pH levels. These are **buffered solutions**, meaning that they contain chemical agents that resist shifts in pH in either direction (toward more acidity or more alkalinity). This can be tricky, because pH inside the bloodstream is 7.4 (slightly alkaline), yet the surface of the skin is part of the body's microbiome, home to a community of microorganisms. Skin microorganisms give the surface of the skin a somewhat acidic pH—known as the **acid mantle**—that is typically slightly below 6.0, which helps protect against threats such as fungal infection. Moving down through the epidermis layers, pH gradually increases down to the *stratum germinativum*, the deepest epidermal layer. Although blood throughout the body is generally at pH 7.4, the blood vessels within the dermis tend to have a somewhat lower pH (Ali and Yosipovitch 2013). Consequently, there is a little bit of wiggle room in terms of safe pH levels for cosmetic tattoo ink, but the inks are pH balanced sufficiently to prevent it from going out of the normal range.

Metal Salts

As noted earlier, the coloring agents used to create illustrative tattoos contain pigments that can be metal oxides, metal salts, and/or organic polymers. Metal salts are produced from metal atoms replacing hydrogen atoms (protons) that come from acid molecules.



Depending on the identity of the metal and other aspects of the metal atoms, pigments consisting of metal salts can produce a variety of colors and have a varying range of photostabilities. The same is true of metal oxide pigments, which are molecules consisting of metal and oxygen atoms bound together. In the case of both metal salts and metal oxides, the pairing of certain metals with certain nonmetals depends on the valences of the atoms involved.

The metals used in metal-based pigments are generally heavy metals (metals with high density, high atomic number, and/

or high atomic weight). The atoms of such metals provide electron arrangements that allow for the absorption of certain wavelengths of EMR and reflection and transmission of other wavelengths. In other words, they produce incredibly vibrant colors.

Metal salts and metal oxides used as tattoo pigments can be naturally occurring (sometimes identified with the term "naturally bonded"), or they can be synthesized through chemical industrial processes (sometimes identified with the term "chemically bonded"). The metals in these pigments are *heavy metals*, a term that encompasses metals with high atomic number (many protons), high atomic weight (many protons and neutrons), or high density (the metal weighs a lot per volume); generally, these three properties all occur together. Examples of heavy metals include lead, chromium, mercury, antimony, nickel, beryllium, cobalt, and arsenic. A variety of heavy metals are present in many tattoo pigments, because different metals in combination with other elements produce various desired colors.

9 METABOLISM & LYMPHATIC PROCESSING OF TATTOO PIGMENTS & DYES

While the previous chapter covered the chemistry of pigments and dyes, this chapter takes a closer look at how these materials are metabolized in the body. It also examines the vascular system, particularly the lymphatic drainage and lymphoid organs (especially lymph nodes) in relation to specific kinds of colorants and their breakdown products.

Metal Pigments

Vibrant colors in illustrative tattoos have historically come from inorganic pigments, namely metal salts and metal oxides. For instance, the metal salt cadmium sulfide produces yellow; mercury sulfide produces red; and chromium oxide (a metal oxide) produces green. Generally, inorganic metal pigments are being tattooed less today than in the past (Bäumler 2015). However, it is important to be aware of them in certain settings. In the case of an older, tattooed individual undergoing a lymphoid tissue biopsy or presenting with a history suggesting possible chronic heavy metal poisoning, this ink could give a false positive. The inorganic pigment titanium dioxide, however, is still used widely, as it produces a white color that is often mixed with various color pigments to lighten their tone (Bäumler 2015).

While modern tattoo pigments tend to be organic—rather than inorganic metal compounds—some of these organic pigments exist as organic metal complexes, meaning organic molecules with metal atoms bound to them in some way. Many of the body's most famous molecules are metal complexes. One classic example is hemoglobin, the molecule that carries oxygen and other substances in the blood.

Organic Pigments

Tattoo ink manufacturers are required to avoid certain ingredients and if labeled sterile, they are required to sterilize their product. In the United States, at the time of publication (2019), ink manufacturers were not required by the federal Food and Drug Administration (FDA) to sterilize if their product was not labeled as sterile. A declaration of the ingredients except flavor, fragrance, and trade secret ingredients should be listed in descending order of predominance on a Material Safety Data Sheet (MSDS). Even so, there is no agency holding manufacturers accountable for what is being produced in their product. Consequently, the identity of many colorants can be known only through third-party chemical analysis; however, there is a great deal of variation in the results of third-party chemical analysis. This is due to a lack of validated and consistent analytical testing methodology. When considering how the body processes colorants, it is possible to discuss coloring agents at the categorial level, but much more difficult to speak to the presence of specific chemical structures.

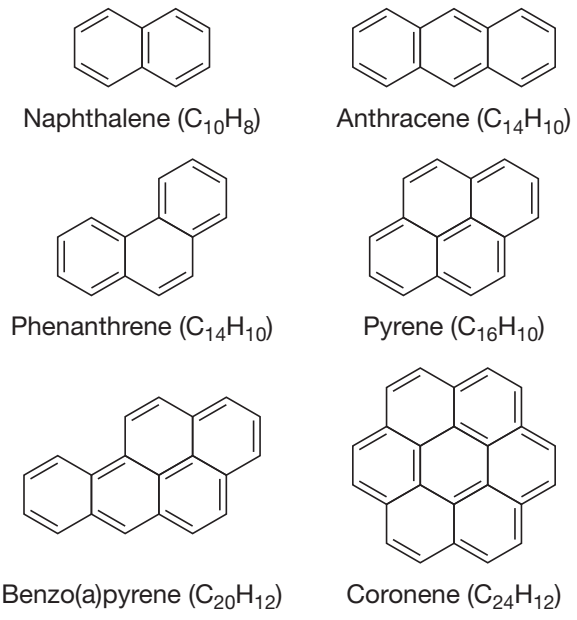


Figure 29: Some examples of polyaromatic hydrocarbons (PAHs).

One example is Carbon Black, the major component in black tattoo coloring. Rather than consisting of one particular structure, the molecules of Carbon Black belong to group of structures, known as **polycyclic aromatic hydrocarbons (PAHs)** (Bäumler 2015) (fig. 29). Known commonly as soot, PAHs result from the incomplete combustion of hydrocarbons (compounds composed of hydrogen and oxygen). PAHs are composed mostly of multiple aromatic rings. These are rings of benzene (C_6H_6), which can be drawn in three different ways (fig. 30), representing that they have six carbon atoms that share valence electrons in a way that the shared electrons belong to the entire ring, rather than to each carbon-carbon bond (Chang and Overby 2019). This phenomenon has

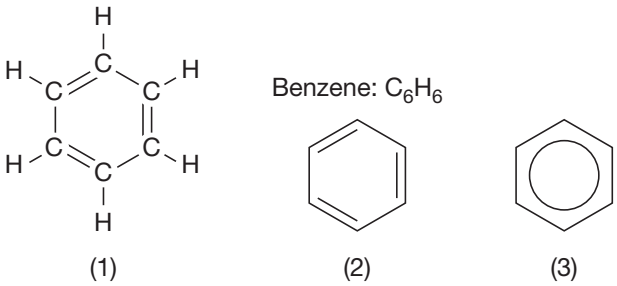


Figure 30: The benzene ring (aromatic ring) consists of six carbon atoms and six hydrogen atoms, all in a plane (left).

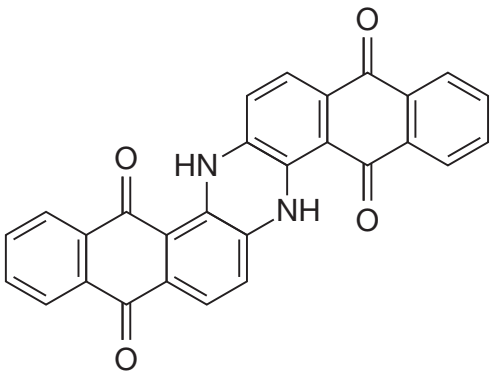


Figure 31: This colorant is *polycyclic*, because it contains multiple rings. It also is polyaromatic, because some of the rings are aromatic (benzene) rings.

a profound influence on the chemistry of the ring and any groups that are attached to it. Consequently, pigments consisting of PAHs and other aromatic pigments may be considered as a **pigment category**.

In organic chemistry, carbon and hydrogen atoms can either be drawn attached to one another, or they can be left out. In the latter case, the unmarked corners represent bonds between carbon atoms with the needed number of hydrogen atoms present. In the case of benzene, each carbon atom uses three of its valence electrons to bond with other carbon atoms, so there is one hydrogen atom bound to each carbon atom at each vertex of the hexagonal ring. One way to represent the carbon-carbon bonds is as three double bonds alternating with three single bonds (fig. 30, middle). It does not matter which C-C bonds are drawn as double and which as single, because all 18 valence electrons connecting the carbon atoms are **delocalized** from their respective carbon atoms. They belong instead to the entire ring. Another shorthand representation of the benzene ring is a circle inside a hexagon (fig. 31, right).

Another term applied to pigments is **polycyclic**. This means that the molecules contain multiple rings of atoms, which may or may not include aromatic rings. All polyaromatic compounds are polycyclic, but not all polycyclic compounds are poly-aromatic (fig. 31).

Whereas Carbon Black is the prime pigment in many black tattoo inks, colored pigments fall into the chemical category known as azo compounds. An azo compound, as discussed in an earlier chapter,

is a compound containing at least one diazenyl group—two nitrogen atoms connected with a double bond, with each of the nitrogen atoms also connected via a single bond to another group of atoms. The diazenyl group is drawn like this:

$$R–N=N–R'$$

in which:

- R represents a carbon atom connected with other atoms, and
- R' represents a different group of atoms connected to a carbon atom.

In scientific literature, azo pigments are often distinguished from aromatic and polycyclic pigments. It is possible for a compound to be aromatic as well as azo, or polycyclic as well as azo, since there can be benzene rings and azo groups in the same molecule. Nevertheless, as a matter of practicality, pigments are typically assigned roughly into azo and polycyclic or aromatic categories. With that caveat in mind, azo pigments are further classified into the following subgroups (Bäumler 2015):

- **Mono-azo:** These compounds produce green to medium yellow and red-orange- yellow.
- **Dis-azo:** These produce greenish, reddish, and orange red.
- **β-naphthol:** These produce orange to medium red.
- **Naphthol AS:** These produce medium red to violet.
- **Metal complex pigments:** Although these are azo pigments, they also contain heavy metals, such as nickel, cobalt, or copper.

Polycyclic pigments also include a variety of subcategories, two important ones being:

- **quinacridones**, which produce blue-to-red, red, and violet; and
- **phthalocyanines**, which produce blue and green.

In many cases, pigments contain agents to lighten the color, such as titanium dioxide (a metal oxide containing the metal titanium) (Bäumler 2015).

What Happens to Pigments & Dyes after They Are Deposited in the Skin?

Potential harmful effects of pigments and dyes are a concern in the tattoo process. There is a possibility that they

could cause harm locally at the tattoo site, and they may also spread to remote sites in the body. For each 1 cm^2 of skin that is colored, a tattoo artist must inject approximately 2.5 mg of pigment. Studies involving both laboratory animals and human volunteers, however, have revealed that approximately one third of the injected pigment disappears within the first few weeks following a tattoo procedure (Bäumler 2015). This is not surprising, as the dermis contains blood vessels and vessels of the lymphatic system, both exit pathways available to the pigments and dyes. The colorants—and pigments in particular—are large and insoluble. These molecules can be broken down by visible light, infrared (IR) radiation, and ultraviolet (UV) radiation (Serup et al. 2015), as discussed in the previous chapter. Azo compounds—used to produce strong, bright colors—are particularly vulnerable to UV (Bäumler 2015). Tattoo pigments are also consumed by cells called fibroblasts and macrophages. Fibroblasts are produced within connective tissue, including the connective tissue of skin, whereas macrophages are a type of white blood cell produced by the immune system. While these cells contain enzymes that help them break down substances that they consume, they have trouble breaking down large molecules like pigments. Consequently, the pigments tend to outlive the cells that engulf them after they are injected in the tattooing process. Pigments released from dead macrophages are then re-engulfed by new macrophages in the same locations of the dermis. The tattoo thus remains, with successive generations of macrophages as the primary pigment reservoirs (Baranska et al. 2018).

But as noted at the beginning of this section, approximately one third of injected tattoo pigment disappears from the tattoo site within a few weeks. Since this is less than the life span of a macrophage or a fibroblast, much of the loss may involve pigment being photodegraded (broken down by light) and **metabolized** (chemically processed by body cells) before it can be engulfed. Some of the loss also may consist of products of pigments that were photodegraded while inside macrophages or fibroblasts that died soon after a tattooing procedure. Once this happens, they are soluble enough to leave the dermis. In any case, tattooing products do leave the dermis. One third of the pigment administered to create a tattoo covering a surface area of 500 cm^2 of skin would amount to approximately 417 mg of pigment leaving the dermis.

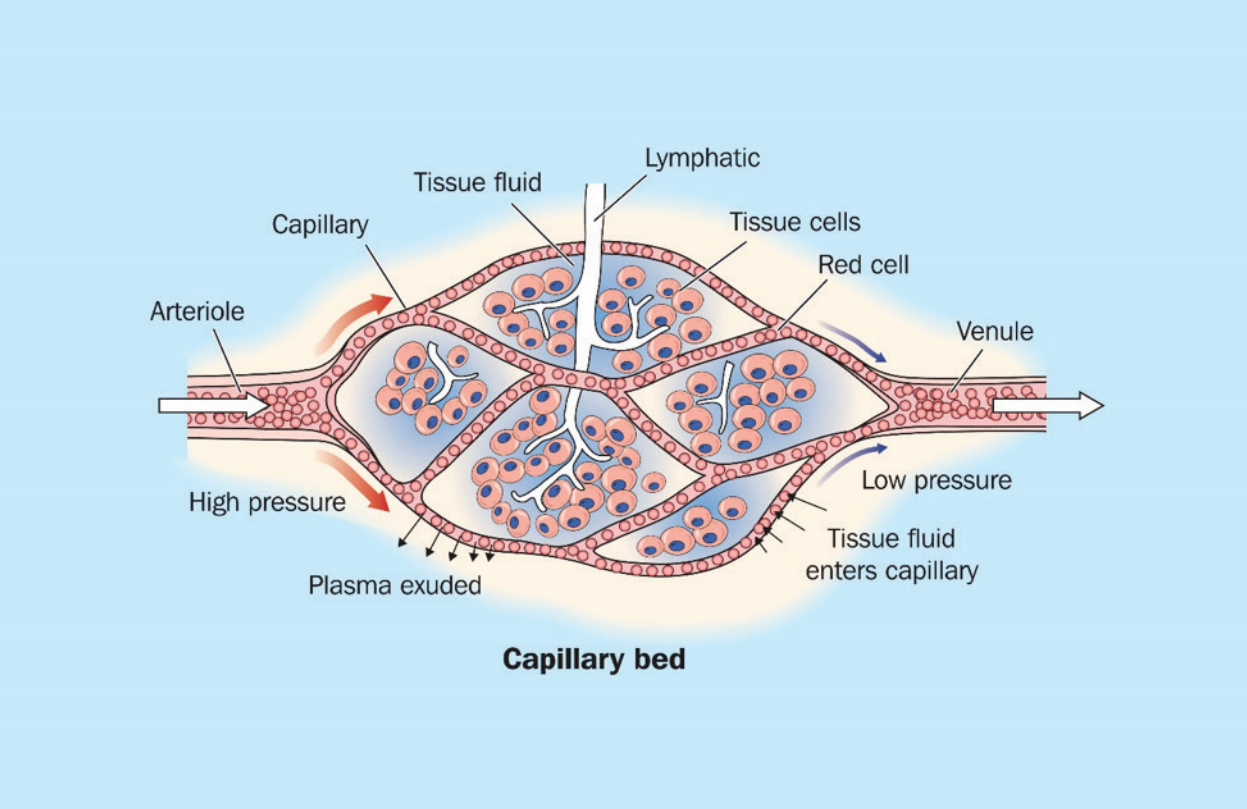


Figure 32: Lymph capillaries and small lymph vessels.

From the dermis, pigment can only penetrate deeper into the body by way of vessels. One such type of vessel are blood capillaries. These microscopic channels deliver blood to venules and veins of increasing diameter. It is difficult for large molecules like pigments to enter them. Large amounts of pigment instead enter a system of vessels known as the **lymphatic vasculature**. Of the fluid that enters body tissues from arterial system, approximately 10% enters lymphatic vessels, moving as a yellowish liquid called **lymph**. Like the venous system, the lymphatic vasculature begins with capillaries that are microscopic (fig. 32), which feed into a system of increasingly wider vessels.

From lymph capillaries, lymph moves through **lymph vessels**, then **lymph trunks**, and finally **lymph ducts**, of which there are two. One duct—the *right lymphatic duct*—receives lymph from the right side of the head, neck, thorax, and arm, and returns the lymph into the right subclavian vein in the lower neck. The other duct—the *thoracic duct*– receives

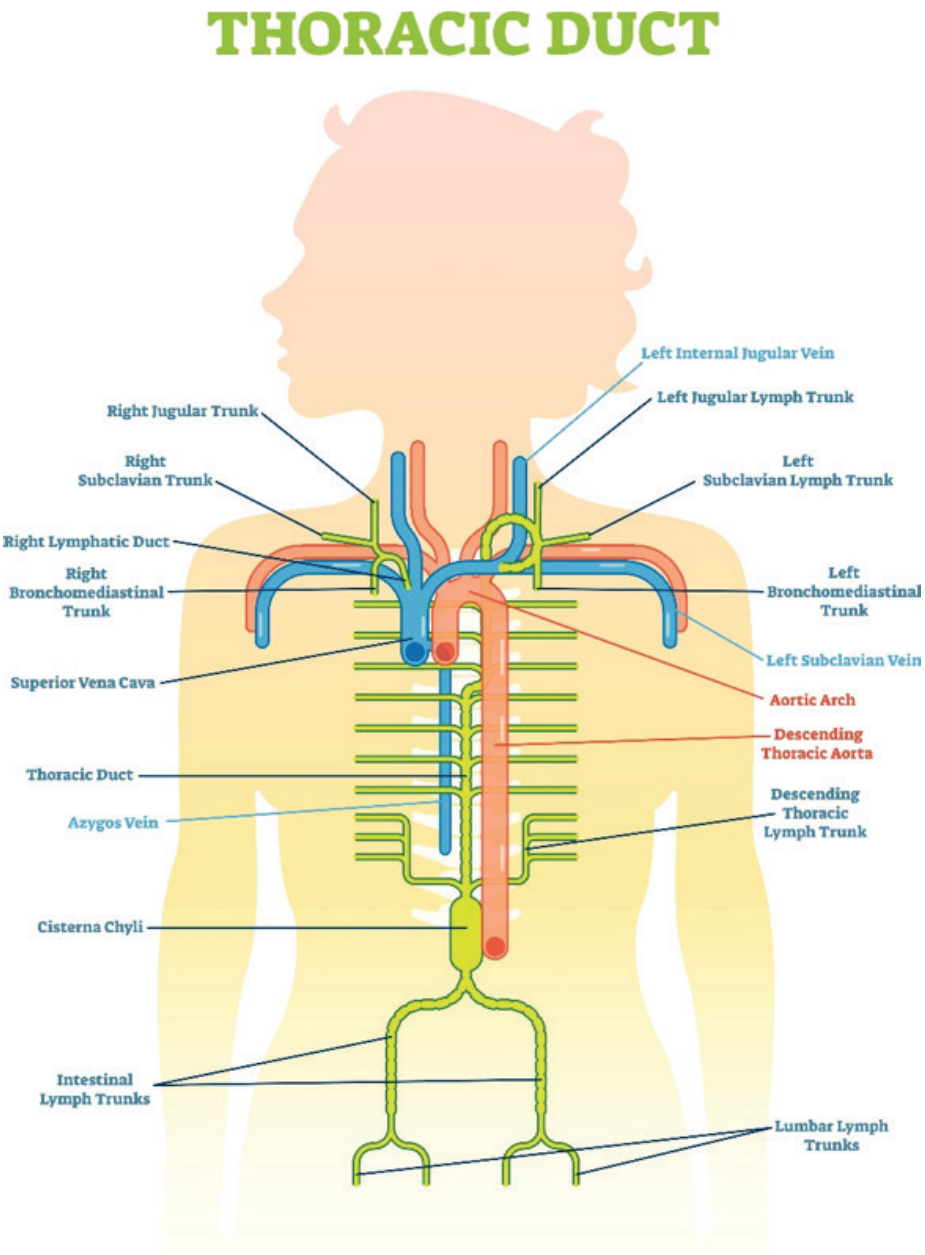


Figure 33: The thoracic duct receives lymph from all but the upper-right portion of the body, which sends lymph into the right lymphatic duct.

a bigger share of lymph, coming from the left arm, left sides of the head, neck, and thorax, both sides of the abdomen and pelvis, and both legs, and dumps the lymph into the left subclavian vein (fig. 33). Upon entering either the left or right

subclavian vein, lymph mixes into blood, which subsequently enters the heart.

Lymphatic vessels act as a detour that avoids much of the venous route, but the vessels constitute just one component of the **lymphatic system** (fig. 34). Other components of the system include bone marrow (located inside bones) and the thymus (located in the chest). These are called **primary lymphoid organs**, where a special kind of white blood cell called **lymphocytes** mature. In addition to being part of the lymphatic system, lymphocytes are additionally integral to the immune system (they defend the body) and part of the circulatory or cardiovascular system (they are also blood cells) (fig. 35). Also belonging to the lymphatic system are **secondary lymphoid organs**, including concentrations of lymphoid tissue in certain parts of the body. Some examples are the tonsils, the vermiform appendix, the spleen, and tiny organs called lymph nodes.

Lymph nodes have lymph vessels feeding lymph into and out of them. All lymph passes through these nodes before reaching the left or right subclavian veins. Filled with two kinds of lymphocytes called **T lymphocytes** and **B lymphocytes**, lymph nodes act as check points for identifying and fighting against infectious agents and filtering out cancer cells and foreign particles. When reacting to an agent that the immune system either knows is dangerous—or thinks might be

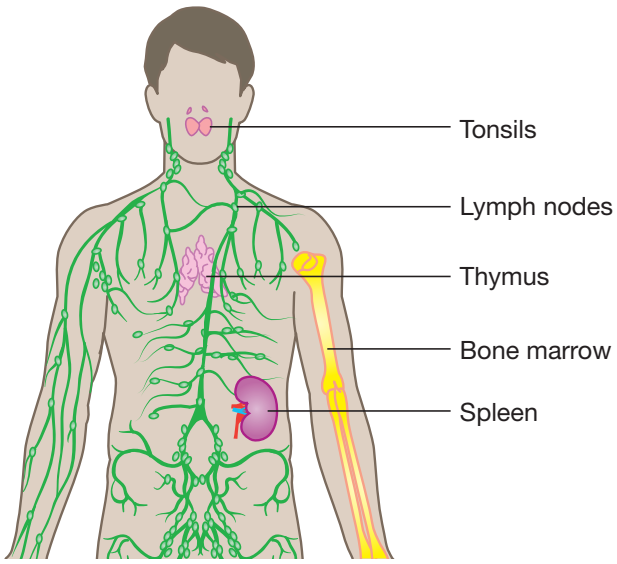


Figure 34: The lymphatic system.

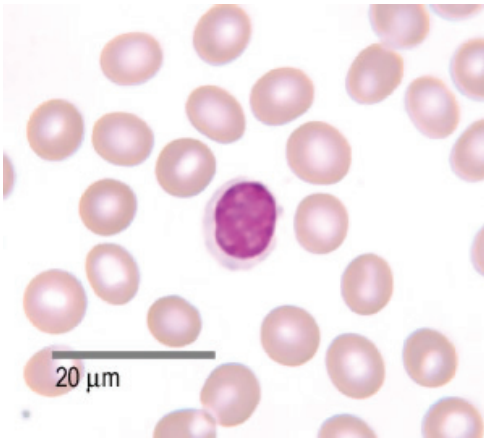


Figure 35: A blood smear, showing a lymphocyte in the center. The other cells are red blood cells. *Image credit: Professor Michelle Peckham, University of Leeds.*

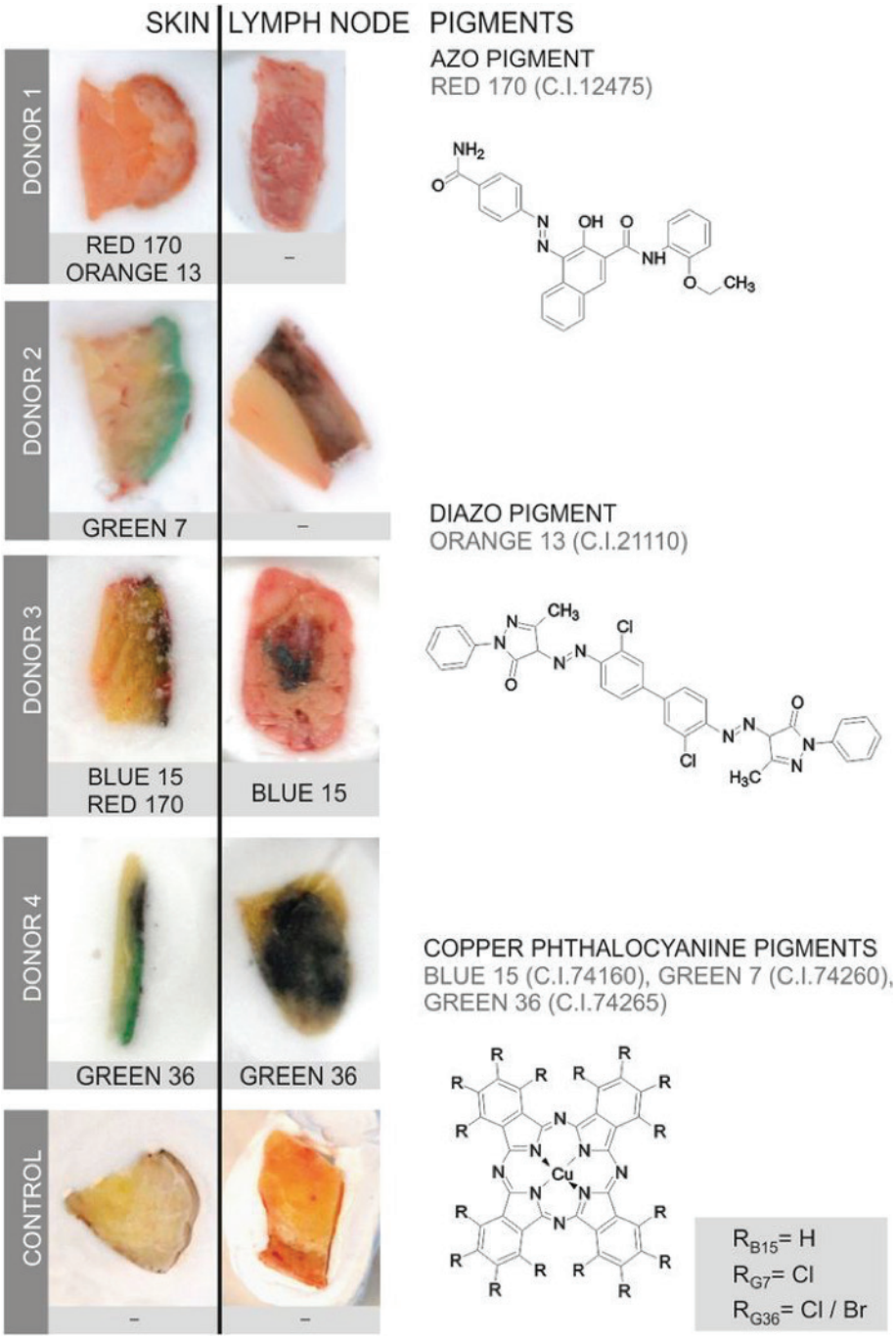


Figure 36: Lymph nodes stained with tattoo pigments. The lower right image is a histological (microscopic) sample from within a node. *Image credit: Smithsonian magazine, Tattoos may stain your lymph nodes.*

dangerous simply because it is foreign to the body—lymph nodes swell. Even when they do not swell up, particles in the lymph are passing through them, and—if they are big particles—getting trapped there.

Lymph nodes are a big part of the answer to the question of where tattoo pigment goes if it escapes from the dermis. The pigments can stain nodes (fig. 36) either soon after a tattooing procedure or, in some cases, due to a reaction occurring years later.

This does not mean that pigments and their broken-down bits leaving the tattoo site go *only* to the lymph nodes. From the tattoo site, they can enter the blood and potentially travel throughout the body, reaching internal organs like the spleen, liver, or kidneys, where they could potentially be stored (Serup et al. 2015). On the other hand, pigments reaching the liver or kidneys could be metabolized into products that are excreted.

Are Pigments Carcinogenic?

Some concern surrounds the cancer-causing potential of certain pigments. PAHs in black inks, for instance, are known carcinogens (Lehner et al. 2014). They are one of the principal carcinogens in tobacco smoke, and the connection between smoking and cancer is unequivocal and well-established. There is also concern about azo pigments, as certain azo compounds are also known carcinogens. There are a great number of new azo pigments these days, and ink manufacturers are not required to identify all details about their pigments nor are they regularly inspected or tested to confirm their product contains the ingredients which are listed on an MSDS.

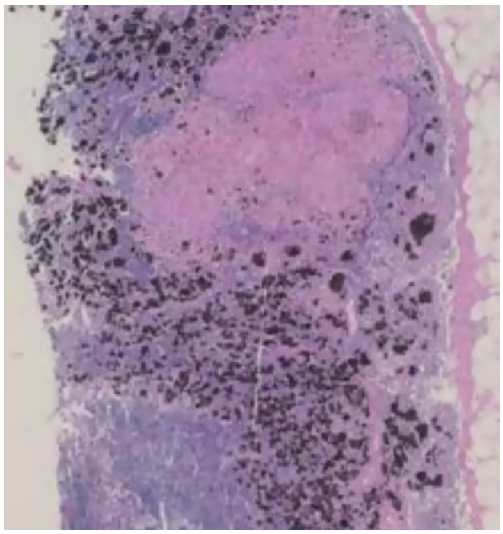


Figure 37: A lymph node showing granulomas and macrophages that were stained with tattoo pigment in a patient who was mistaken to have cancer. *Image credit: Dr. Mark Ferguson. Image reproduced with permission from The Royal Society.*

There are different levels of carcinogenicity, however, and before an agent can be established as a cause of cancer, it must be proven that it causes cancer in the doses in which it is administered and in the situations in which it is used. While epidemiological data demonstrate that PAHs and hundreds of other carcinogens in tobacco cause cancer when inhaled from burning cigarettes day after day, there is not enough data to establish a clear link between tattoo ink the way it is usually used and a particular type of cancer. Perhaps a greater concern at this time is the unintended staining of lymph nodes, which could complicate a workup for cancer, autoimmune diseases, or other conditions. To illustrate the complexity of the scenario, Figure 37 shows a microscopic view of a lymph node sample that had reacted to a tattoo procedure several years earlier and was later mistaken for a cancerous condition. A related concern is that pigmentation of lymph tissue also could make detection of disease more difficult in certain cases.

10 OTHER MATERIALS USED IN THE TATTOO PROCESS

As discussed in the previous chapter, tattoo ink products consist of colorants and water. However, there are other ingredients in the carrier solution of these tattoo inks. A tattooing procedure also includes a variety of other materials that are applied to or come into contact with the skin. These substances include cleansing and antiseptic agents, topical anesthetic solutions, and vasoconstrictor agents. Finally, tattoo ink is injected by way of needles. These are made of steel, of which there are many different kinds. The aim of this chapter is to examine these additional materials, as they come with their own set of potential chemical reactions.

Antiseptic Agents, Lotions, Witch Hazel, & Glycerin

Agents used on the skin for cleansing and antisepsis include **soaps**. One example is Dettol, which contains chloroxylenol—a chemical that is both quite safe and particularly effective against gram positive bacteria (WHO 2015). Discussion is warranted concerning soap products that are marketed as "organic," such as "Green soap" and Dr. Bronner's soap, on the grounds that they are made from vegetable products with minimal processing. Marketing of such products typically emphasizes the fact that they lack synthetic agents, such as detergents. Ironically, detergents are organic compounds, chemicals whose molecules are structured of carbon atoms. The cleaning agents in "organic" products, on the other hand, tend to be inorganic bases such as potassium hydroxide (KOH). While hydroxide bases are fairly effective against certain types of bacteria called **mycoplasmas**—a kind of bacteria that lack the protective cell wall surrounding other kinds of cells—they are only minimally effective against various categories of bacteria and viruses

(CFSPH 2010) that are of concern during a procedure like tattooing.

Alcohol, or products containing alcohol, may also be applied to the skin to resist infection. Generally, the choice is between ethyl alcohol (C_2H_5OH, also abbreviated EtOH; referred to as *drinking alcohol*) and isopropyl alcohol (C_3H_8O, isopropanol; referred to as *rubbing alcohol*). In either case, a solution that is 70% alcohol and 30% water is optimal: lower percentages of alcohol have reduced germ-fighting capability, whereas very high percentages evaporate too quickly and dry out the skin more easily. Alcohols are toxic, but sometimes there is confusion about what this means for wound care. Prior to a puncturing procedure, such as tattooing, alcohol is a very good antiseptic to apply to the skin, as it is effective against potentially dangerous pathogens. Isopropanol is notorious for being more toxic than ethanol, but that concern applies to the ingestion of alcohol, not to its use on the skin. Isopropanol also dehydrates the skin less than ethanol, so isopropanol is the better choice between the two. Often 70% isopropyl alcohol can be added to a carrier solution as a disinfectant.

When there is an open wound with bleeding, neither type of alcohol is the best choice for cleansing. Fragrances or scented products should also be avoided as they also typically contain alcohol. If applied to an open wound, the alcohol will not enter the bloodstream in a quantity that could cause systemic toxicity, in contrast with ingestion. It can, however, interfere with healing. If the procedure area has been cleaned already, it is better not to use alcohol and to use mild soap instead.

Witch hazel is often utilized to thin out ink, whereas tattoo artists will sometimes use an agent called **glycerin** to thicken it. Glycerin and witch hazel are often used as a carrier solution for tattoo pigments. Witch hazel, a common name referring to plants of the genus *Hamamelis* (especially the species *Hamamelis virginiana*), is added as an extract in various products, including gels and soaps and in solutions of water and alcohol. It is marketed by the herbal products industry for use on the skin based on claims that the extract promotes **hemostasis** (stops bleeding). It also acts as:

- an **astringent**, causing the cells of skin and other tissues to contract,
- an **antioxidant**, which protect cells against damage by **free radicals** (molecules with unpaired valence electrons) (fig. 38), and

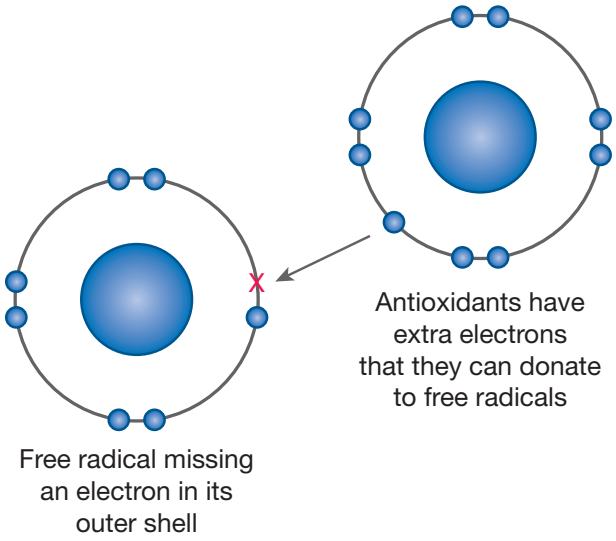


Figure 38: Simplified drawing representing a free radical, which is extremely reactive as it has an unpaired electron and an antioxidant that can quench a free radical.

- an **anti-inflammatory agent**, which minimizes inflammation.

Consequently, witch hazel is sometimes applied to the skin in addition to being mixed into the tattoo ink.

Very limited evidence suggests that witch hazel may exhibit antioxidant properties in skin fibroblasts, notably against hydrogen peroxide (H_2O_2, which is not a free radical, but produces free radicals) (Thring et al. 2011). Overall, there is a scarcity of scientific studies on the molecular, cellular, and clinical effects of witch hazel. Witch hazel is included among herbal products for which there is concern about their potential to act as poisons and cause cancer (Montbriand 2005). On the other hand, witch hazel products are generally considered safe when used topically on adults, according to product instructions (Medscape n.d.; Multum 2019). However, if using witch hazel on the skin, it is wise to use it sparingly until the substance can be studied adequately.

As the skin heals in the weeks following a tattoo procedure, moisture-trapping ointments like petroleum are best avoided, as they also can trap particles and microorganisms that can lead to infection. Instead, water-based, pH-balanced **lotions** are often recommended and used. At the time of publication (2019), there was not yet a consensus on any dermatological guidelines for tattoo aftercare, but it is hoped that such guidelines will be forthcoming in the years to come (Liszewski et al. 2016).

Topical Anesthesia

An **anesthetic** is a substance that reduces, eliminates, or prevents pain. Administration of different types of anesthetic agents and procedures can achieve different types of **anesthesia**, or the insensitivity to or lack of pain. Many types of surgical procedures are performed with the patient under **general**

anesthesia, in which drugs are administered to both prevent pain and to produce unconsciousness at a level deeper than sleep. Using a category of drugs known as **local anesthetics**—which work differently from drugs used to produce general anesthesia—physicians also can induce a range of more mild forms of anesthesia. In these cases, the patient remains awake while pain is eliminated in either large regions of the body or in localized areas.

Administration of general, regional, and local anesthesia, containing more than 5% by volume, requires specialized training. Certain local anesthetics, however, are available in various topical forms for use on the surface of the body. This produces a still more limited form of anesthesia, known as **topical anesthesia**, and the agents to produce it are available over the counter. For instance, anesthetic sprays, creams, and gels come in first aid kits, for instance, so people can apply them on their own minor injuries. Tattoo artists can apply them as well. As with all agents to which a recipient of a tattoo is exposed, the effects of topical anesthetics depend entirely on individual chemistry.

A topical anesthetic product may contain one or more local anesthetics, commonly:

- lidocaine,
- benzocaine,
- tetracaine,
- bupivacaine, and/or
- proparacaine.

These drugs are chemical cousins to cocaine, whose local anesthetic properties made it a choice for eye surgery in

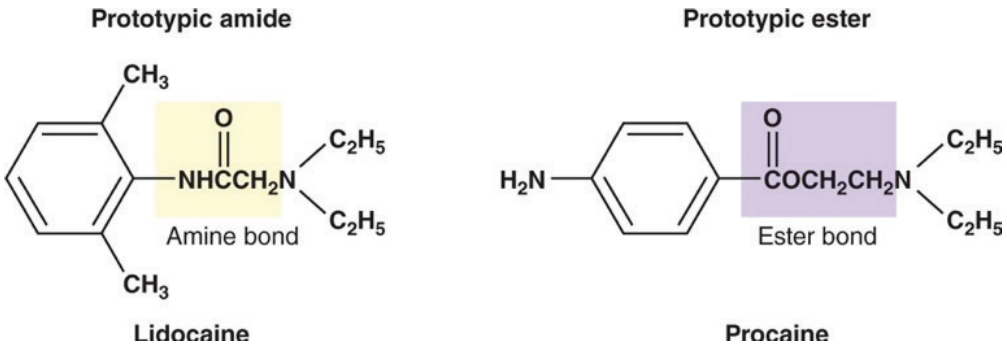


Figure 39: Examples of two classes of local anesthetic. Amide local anesthetics are represented by lidocaine, whereas procaine is an example of an ester local anesthetic. Both types have an aromatic ring.

the late 19th century, before its addictive potential was understood.

Most local anesthetics fall into one of two chemical classes:

- **Aminoamides**, which last longer in the body, since they must reach the liver to be broken down.
- **Aminoesters**, which last for shorter periods in the body, as they can be broken down in the blood.

Both types of local anesthetic have an aromatic ring (fig. 39), which helps the anesthetic dissolve in the cell membrane (fig. 40) surrounding each nerve cell (Becker and Reed 2012). Local anesthetics can reach nerves that are close to the surface of the skin without being injected; they simply need to be applied on the spots where anesthesia is desired.

How Anesthetics Work

As discussed in Unit III, Chapter 2, once inside a neuron, local anesthetic molecules attach to the sodium channels of the membrane. This prevents them from allowing sodium cations to enter the cell when it is stimulated, so no action potentials are generated (Yanagidate and Strichartz 2007).

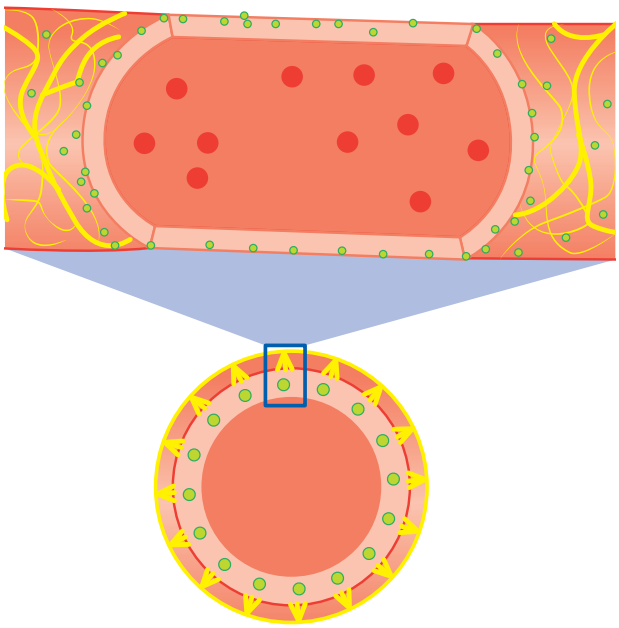


Figure 40: When epinephrine or norepinephrine binds to alpha receptors, specifically alpha 1 receptors of blood vessels, the vessels contract.

Topical anesthetic products also often contain an **alpha-adrenergic receptor agonist**, such as epinephrine or norepinephrine (fig. 40). In binding to alpha receptors on blood vessels in the skin, the alpha agonist causes **vasoconstriction**, which is the narrowing of blood vessels. This increases the time that the local anesthetic remains in the skin, so the anesthesia lasts longer than it would otherwise. One common topical anesthetic gel or spray mixture called **LET**—which stands for lidocaine, epinephrine, and tetracaine—contains 4% lidocaine, 0.1% epinephrine, and 0.5% tetracaine. Another

preparation called Bupivanor contains 0.48% bupivacaine, with norepinephrine at a concentration of 1:26,000 (1 mg per 26 mL of solution). Certain topical anesthetic preparations are proprietary, so the manufacturers reveal only the active ingredients and keep the concentration specifics as a trade secret. In such cases, the manufacturer instructs regarding to the maximum surface area of skin that should be treated. An example is Betacaine-LA, consisting of lignocaine, prilocaine, and the alpha-adrenergic receptor agonist phenylephrine, which is recommended only for adults over an area no larger than 300 cm^2 (Kumar et al. 2015).

Local anesthetics are dangerous when they enter the bloodstream. Recommended limitations—such as maximum surface area that can be covered—exist because anesthetics can get absorbed into the body if applied to the skin or mucous membranes in excessive quantities. Lidocaine can get into the brain and cause confusion, seizures, or coma. In the heart, it can cause low blood pressure and slow the heartbeat to dangerous levels; in fact, it is given intentionally to slow the heart in cases of **ventricular tachycardia** (the heart beating too fast). Local anesthetics—such as lidocaine, bupivacaine, and benzocaine—can also cause **methemoglobinemia (MetHb).** MetHb is a condition characterized by increased quantities of hemoglobin wherein iron of heme is oxidized to the ferric (Fe^{3+}) form, becoming **methemoglobin**. Methemoglobin is useless as an oxygen carrier, particularly in people with certain genetic predispositions (Rehman 2001).

As discussed earlier in this unit, the number of valence electrons an atom has relates to how many electrons the atom can share in covalent bonding, or how many electrons an atom can gain or lose when it becomes an ion. Losing electrons is known as **oxidation**. The degree to which

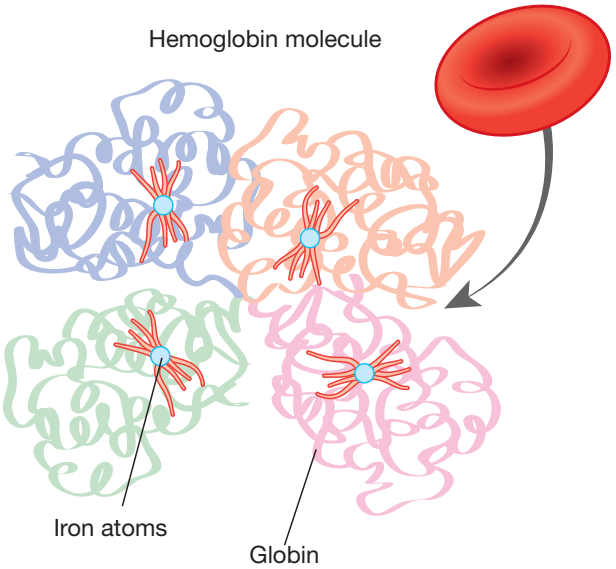


Figure 41: Each hemoglobin molecule has four iron atoms in the ferrous state (Fe^{2+}), which enables the molecule to grab four molecules of molecule oxygen (O_2).

an atom can do this is called the **oxidation state**. In the case of iron, it can have an oxidation state of +2, making it **ferrous** (Fe^{2+}; iron that has lost two valence electrons). Normally, each molecule of hemoglobin includes four iron atoms in the ferrous state, which enables hemoglobin to take a gentle hold of oxygen molecules, carry them through the blood, and then release them wherever they are needed (fig. 41). As noted above, in MetHb, iron atoms of hemoglobin are shifted to the +3 oxidation state, in which iron is called **ferric** iron (Fe^{3+}). Iron is perfectly happy in the ferric form, but it does not work as an oxygen carrier in hemoglobin this way (fig. 42). If a lot of the iron in hemoglobin within a person's red blood cells is ferric rather than ferrous, the red blood cells cannot carry enough oxygen to body tissues. This leads to fatigue, pallor (potentially even **cyanosis**, a blue skin coloring), and shortness of breath, and can be fatal in extreme cases (Rehman 2001).

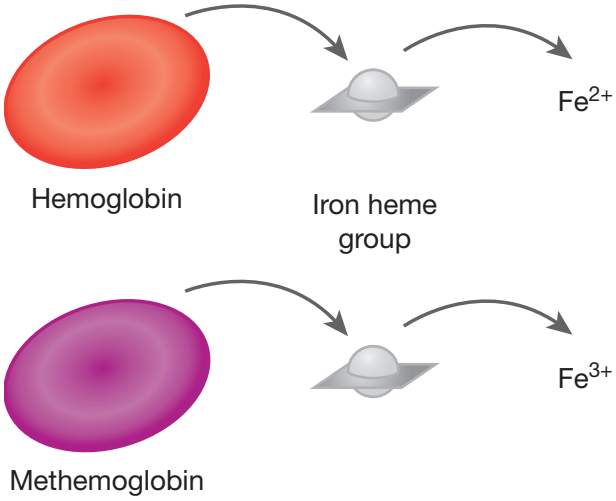


Figure 42: In methemoglobinemia, iron of hemoglobin is in the ferric state, rather than the ferrous state, so hemoglobin cannot carry oxygen.

There is no need to worry about MetHb or complications in the brain, so long as local anesthetic is being dabbed or sprayed on a modestly-sized region of skin. These systemic complications and others generally occur only if the anesthetic is injected into the bloodstream or ingested in large doses. However, during instances of excessive use, such as rubbing the product over a large fraction of the body surface, it is possible that substantial amounts will be absorbed into the bloodstream. As with any medication, it is important to follow the instructions, particularly as they relate to the recommended dose.

Steel Needles

Apart from tattoo ink, the needle that delivers the ink is the most invasive component of the tattoo process. Needle configurations can hold as few as one and as many (if not more) than 30 needles soldered together. Most needles have a diameter of .30-.35mm. With needles

moving in and out through so many points, it is not unrealistic to hypothesize metal molecules rubbing off and entering the body. Moreover, the contact of the needle with the skin can produce reactions related to the composition of the steel. This raises the issue of the different categories of steel and what they contain, a discussion that begins with an overview on what steel is.

Steel is an alloy containing mostly iron, some carbon, and usually various amounts of other metals. To qualify as steel, an iron alloy must contain carbon in the range of 0.08% to 2.1%.

Figure 43: modern steel needles can be purchased pre-packaged sterilized.

To hold desirable properties, steel requires an optimal concentration of carbon, but needs to lack certain other non-metals like phosphorus, nitrogen, and sulfur.

Without knowing the chemistry of what they were doing, ancient iron workers tweaked iron processing by trial and error to produce desirable properties in the finished product. Because some processing methods happened to leave an optimal concentration of carbon in the metal—and also because of a particular ore that had low phosphorus concentrations—people in southern India produced high-quality steel more than 2,000 years ago (Srinivasan 1994).

With the advent of industrial steel making in the 19th century and the growing understanding of chemistry in the same era, metallurgy developed into a precision-based scientific endeavor. Able to control the percentages of different elements within iron alloys, materials engineers have since developed a range of different types of steel, each with properties optimized for specific purposes.

The concentration of carbon is one factor that affects steel properties. As noted above, an iron alloy is called *steel* if it contains between 0.08% and 2.1% carbon. Iron alloys with carbon present from 2.1%

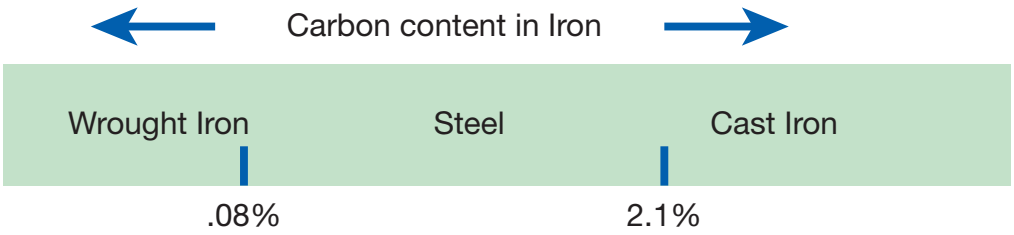


Figure 44: Carbon content and iron type. Steel has an iron content between .08% and 2.1%. Wrought iron has less than .08% carbon, while cast iron has more than 2.1%.

to 4% are called **cast iron**. This type of iron is very hard and strong; by the mid-19th century, it was being used for bridges. The high carbon content, however, also makes the metal brittle, so cast iron bridges often collapsed.

At the opposite extreme, metal that is almost all iron with less than 0.08% carbon is called **wrought iron** (fig. 44). It is much more **ductile** (flexible, able to be deformed or stretched without breaking) than cast iron and is not at all brittle. By optimizing the carbon concentration and methods utilized in the mass production of steel and devising methods for making steel quickly—in large quantities and at low cost—the problem of the bridges was solved, enabling skyscrapers and a range of surgical instruments.

As noted above, in addition to carbon and iron, steel includes metals that enhance various properties. For instance:

- Nickel (Ni) increases the strength.
- Manganese (Mn) increases hardness.
- Chromium (Cr) decreases corrosion.
- Molybdenum (Mo) enhances wear.
- Tungsten (W) adds both strength and resistance to high temperature.
- Vanadium (V) adds toughness (Chemistry Encyclopedia n.d.).

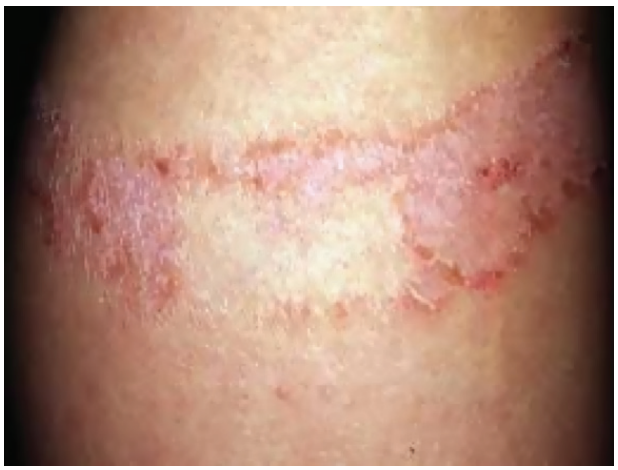


Figure 45: Allergic contact dermatitis due to nickel. *Image credit: DermNet NZ, allergic contact dermatitis.*

In addition to metals, the metalloid element silicon (Si) is often present in steel. Silicon is used in processing of steel to help remove oxygen, which can leave silicon in the alloy, usually at levels below 0.2%. Sometimes, the process can leave silicon content as high as 1%, in which case it tends to strengthen the metal and improve resistance to oxidation. This can also reduce ductility, making it easier for the metal to crack. In higher concentrations, silicon also can add certain electrical properties to steel.

Among the metals in steel, nickel warrants additional mention because—although it improves steel qualities—it is common cause of an itchy rash called **allergic contact dermatitis** (fig. 45; Butler and Mowad 2013). Alloys containing high concentrations of nickel should be avoided.

Other desirable needle qualities include high strength and resistance to bending, but without brittleness that could result in a needle break. Needles also must not rust.

The breakthrough that has enabled these properties for needles and, for that matter, other sharp, narrow devices that go into the body, is the advent of **stainless steel** in the early 20th century. The innovation of this category of steel was the presence of chromium in high concentrations. To produce a layer of chromium oxide that inhibits corrosion, steel must contain at least 10.5% chromium. However, the first stainless steel—introduced in 1913—had 12.8% chromium, and today there are various types of stainless steel with much higher concentrations. In addition to corrosion resistance, stainless steel also performs well both at high and very low (or **cryogenic**) temperatures.

The term **surgical (also known as surgical-grade) steel** refers to a very high-quality stainless steel. Along with chromium, surgical steel contains other metals, including some amount of nickel. If it is categorized as surgical grade, then the alloy—despite the presence of some nickel—is considered to be hypoallergenic (Mayo Clinic n.d.). Consequently, sterile needles that are labeled either as nickel-free stainless steel or surgical-grade stainless steel are more acceptable for use in administering a tattoo. Currently, at the time of this book 2019, there is no regulation on needle content in the US. All Metals used in medical procedures must be surgical grade steel, this is not the case for tattooing. More research needs to be conducted involving steel content and related allergies from microscopic fragments of metals, like nickel, during the tattoo process.

UNIT

3

MEDICAL CONSIDERATIONS FOR TATTOOING

By Dr. David Warmflash

Unit 3: Overview & Inquiry

Topics Covered

- Methods for removing tattoos, including various types of lasers.
- Potentially adverse effects of getting a tattoo, including immunological and allergic reactions.
- Various diseases and conditions that suggest someone should take precautions when getting a tattoo or avoid getting one altogether (contraindications).

Questions to Keep in Mind

- What are the different ways of removing a tattoo? Why is laser removal considered to be the most effective at this time?
- What is an allergic reaction? What kinds of allergic reactions are common following tattoo procedures?
- What is a contraindication? What diseases and conditions warrant further study with regards to how they may contraindicate a tattoo procedure?

What medical considerations need to be taken before getting or administering a tattoo?

Everyone's body is different, inherently each one will heal from a tattoo in its own way. This opens up the possibility of a wide range of reactions, including infections, allergies, or simply no longer wanting the tattoo. Some people also live with health conditions, such as diabetes, which make them more prone to adverse effects from getting a tattoo. These conditions are key for tattoo practitioners to be aware of, for doctors and physicians to study, and for potential tattoo clients to consider before receiving a tattoo.

This unit is devoted to these considerations, starting with an overview of tattoo removal methods. It also covers many of the possible adverse effects of tattooing, including some that can happen even in the most disinfected environments. The unit closes with a discussion of the many medical conditions and treatments that may cause unwanted issues for tattoo recipients. These are known as contraindications.

It's important to note that the research available for this subject, particularly

contraindications, is rather limited. Indeed, a key motivation for writing this book is to point out the limited research and call upon the medical and academic communities to engage in further study. Many of the studies that do exist are included in the pages that follow, which have been compiled for the benefit of the entire tattooing and medical communities, as well as every person who is considering getting a tattoo. If nothing else, the hope is that the reader may be left with curiosity about how much more there is to learn about this art and science.

11 TATTOO REMOVAL

Although the decision to receive a tattoo is usually based on a desire to have the body art present for the remainder of one's life, people do change their minds. This chapter focuses on various tattoo removal techniques—one of many medical considerations to contemplate before getting a tattoo.

Non-Laser Tattoo Removal Methods

As discussed in the previous unit, tattoos eventually fade over time, primarily due to infrared (IR) radiation, ultraviolet (UV) radiation, and visible light breaking up pigments. However, the same processes that make a tattoo persist also make it exquisitely difficult to remove. Consequently, perhaps for as long as tattooing has been around, people have gone to great lengths to remove an unwanted tattoo. Many of these methods are not only less effective than treatment with the newest lasers—covered in the next section—but are also quite painful.

Surgical excision: The most obvious way to remove a tattoo is to cut out the region of skin where the tattoo is located. While this is very straightforward, it is only a viable option for small tattoos, as skin can only stretch so much. To excise any more than a very small area, a **skin graft**—consisting of skin taken from other areas of the body—must be put in to fill in the hole. Often, this can leave the person with a scar, although cosmetic surgeons have developed increasingly effective methods of avoiding or hiding them. Given the rapid advances in laser treatment, however, the value of the surgical approach is now questionable, even for small tattoos.

Cryotherapy: This term applies to the use of very cold temperatures to destroy unwanted tissue. The idea is that it can

destroy pigments, but it is not adequately effective and also tends to produce scarring.

Abrasion techniques: The term abrasion refers to wearing away a surface by way of scraping. In a tattoo removal context, this means getting into the dermal layer and forcefully scraping away the pigments from where they are embedded into the dermis, usually within cells that have engulfed them (dermal macrophages and fibroblasts). This can be done using a salt-based solution to remove pigment in the dermis, in which case the technique is called **salabrasion**. Salabrasion may be one of the oldest tattoo removal techniques, if not the oldest. Another equally crude method called **dermabrasion** accomplishes removal utilizing a rotating mechanical tool. In both cases, the overlying epidermal layer is removed, and the dermis is damaged in the process of removing pigment. These techniques effectively replace the unwanted tattoo with a scar.

Injection of anti-tattoo solutions: Another old method aimed at removing tattoos is through subcutaneous (under the skin) injection of a solution—such as glycolic acid solution—that can degrade or dislodge pigment molecules. In addition to questionable efficacy, this tactic leaves scars and/or burn marks.

Tattoo removal cream: This tactic is marketed for its low cost, simplicity, and lack of pain. They have limited effectiveness because such products do not have much effect on tattoo pigments in the dermis. To be sure, they can fade tattoo ink that has been injected into the epidermis, due to the needle not entering deeply enough into the skin. Such "epidermal tattoos," however, are not permanent anyway, as the epidermal cells are constantly replaced.

Removal by replacement (cover-up): This option involves hiding a tattoo by putting another one in the same spot or adding to the undesired tattoo in a way that makes it different. For instance, the addition of a little more ink can change the number 3 into the number 8. If the unwanted tattoo is a light color, it can be covered with a darker tattoo. On the other hand, to replace a tattoo that is dark, generally, the tattoo must first be lightened by using a laser. In such cases, if the goal is not to have any tattoo in that part of the body, the laser method can be repeated for the requisite amount of sessions needed to fade the tattoo to the point of removal.

Laser Tattoo Removal

Although usually written in lowercase letters, the word **laser** is an acronym that stands for **l**ight **a**mplification by **s**timulated **e**mission of **r**adiation. To appreciate laser tattoo removal, it is helpful to know how laser light differs from other kinds of light.

Light consists of **photons**, which act as particles of energy under some conditions and as waves in others (fig. 1). Behaving as waves, photons have wavelength (λ), frequency (*f*), and velocity (*c*). These values are related by the equation $\boldsymbol{c = f\lambda}$.

Whereas *c* (the velocity of light) is constant, λ and *f* are inversely proportional to one another. When λ increases, *f* decreases. Gamma rays and X-rays (at the high frequency end of the electromagnetic spectrum) have short wavelengths, while radio waves (at the opposite end of the spectrum) have long wavelengths and low frequency. Between gamma/X-rays and radio waves lie all the other types of electromagnetic radiation (EMR), including visible light. The color of this light depends on its wavelength and frequency (fig. 2).

Because photons act as waves, they oscillate in different directions as they travel. Different photons can be in different phases of oscillation, just like two different singers can be in different phases of *Row, Row, Row Your Boat*, hopefully producing a nice harmony (but maybe not).

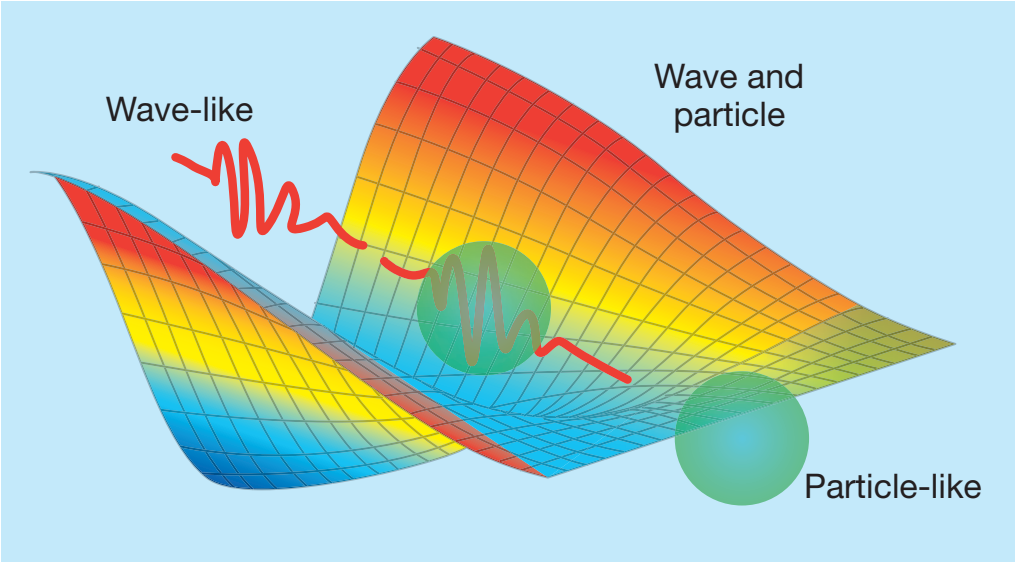


Figure 1: **Photons** act both as particles and as waves.

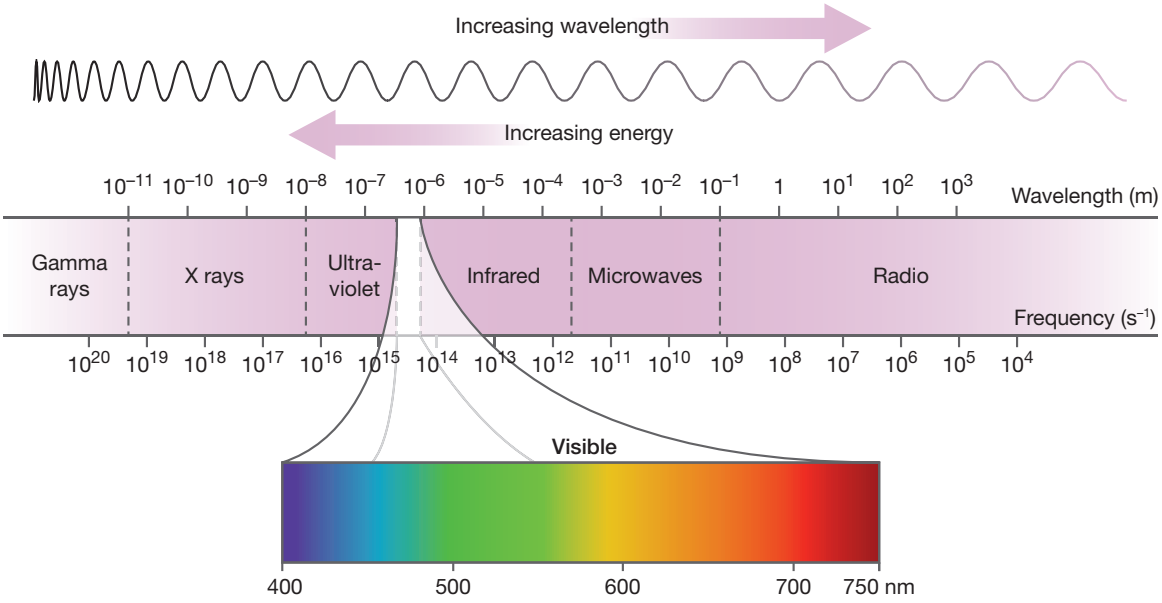


Figure 2: The electromagnetic spectrum.

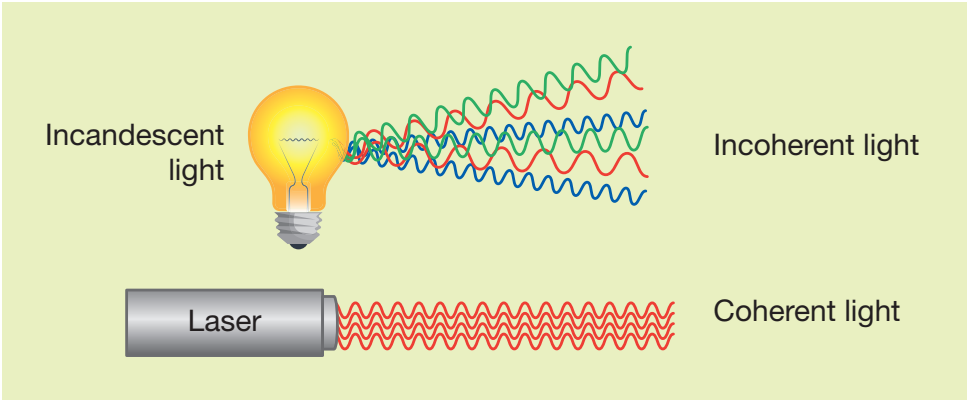


Figure 3: The photons of incoherent light have numerous wavelengths, all out of phase and oscillating in numerous directions. Coherent light, by contrast, is of a single wavelength with all waves in phase.

Light from a flashlight, a cell phone, or the sun is consists of gazillions of photons with many different frequencies and wavelengths that are not oscillating in unison. This kind of light is called **incoherent light**. By contrast, a laser beam consists of photons all with an identical wavelength and frequency, all moving in unison. This kind of light is called **coherent light**. Consequently, unlike incoherent light, laser light does not spread out as it moves (fig. 3).

Lasers can thereby deliver huge amounts of energy to concentrated areas over concentrated periods of time. This makes them extremely useful in medical applications, where they can produce changes in tissues at the molecular level. They can literally change molecules, including both pigments in the dermis and the proteins in hair follicles that produce hair. In fact, the process and equipment involved in hair removal and tattoo removal are very similar.

Pulse Lasers & Continuous Wave Lasers

While all lasers are coherent light, and while different effects can be achieved with lasers of different wavelengths and power, lasers are also categorized based on whether they produce light continuously or in a series of very short pulses. Although laser physicists began working with **pulse lasers** as early as the 1960s, until the early 1990s most applications of lasers to tattoo removal involved **continuous wave lasers**, which caused scarring (Sardana et al. 2015). Since the 1990s, it has been very clear that pulsed lasers enable tattoo removal more effectively than continuous wave lasers, with minimal damage to skin and underlying tissue (Choudhary et al. 2010). The constant energy spread by a continuous wave laser causes a photothermal effect, heating the tissue surrounding the target area and resulting in damage. In contrast, while the pulse laser delivers more energy than its continuous wave counterpart, the intervals between pulses allow for that energy to dissipate safely into the tissue. This reduces the amount of heat in

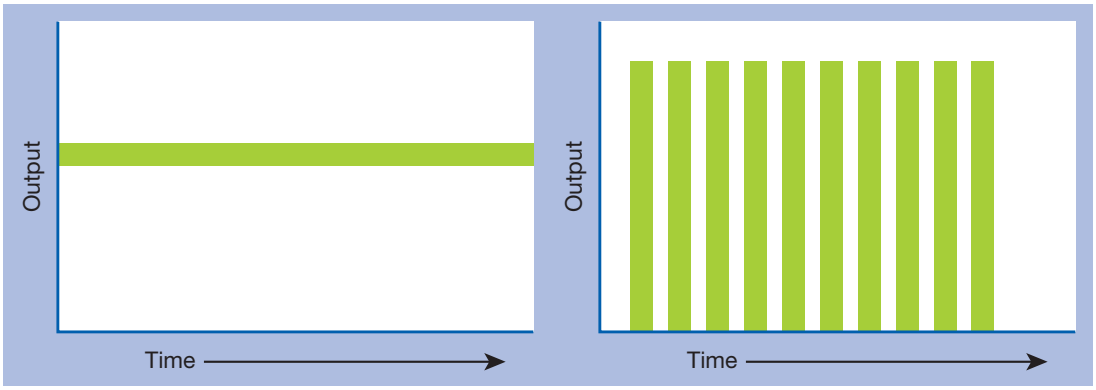


Figure 4: Continuous lasers deliver constant energy output (left), whereas pulsed lasers deliver intermittent bursts (right) that can be of greater output. These outputs can be higher, as dissipation of heat between pulses reduces the amount of tissue damage.

the surrounding areas, as well as the risk of damage (fig. 4)

Consequently, if the energy is high enough, at a wavelength that can be absorbed by a pigment, and is delivered in an appropriately short burst, a pulse laser can successfully heat a portion of a large molecule and leave the rest of the molecule unheated. This stresses the covalent bonds of the molecule, causing it to break into smaller pieces. The lymphatic system can then remove the pigment more easily (fig. 5).

Since roughly the turn of the century, the gold standard instruments for laser tattoo removal have included a handful of laser types that pulse using a technique known as **Q-switching (QS)**. This technique enables pulsing on the order of nanoseconds, billions of times per second, so fast that the laser will appear as though it is not pulsing at all.

Generally requiring 6 to 10 treatment sessions spread over a period of several weeks (fig. 6), the QS lasers that constitute the gold standard for tattoo removal therapy are categorized based on two factors. One factor is its **laser gain medium**. This is the part of the laser where the "**l**ight **a**mplification by **s**timulated **e**mission of **r**adiation" takes place. When energy is put into the medium, electrons are boosted to higher energy states than they usually exhibit. The boosted electrons then fall to their normal, lower energy states. In the process, they release energy that comes out in the form of photons of coherent light at a particular wavelength (fig. 7). Laser gain media can be:

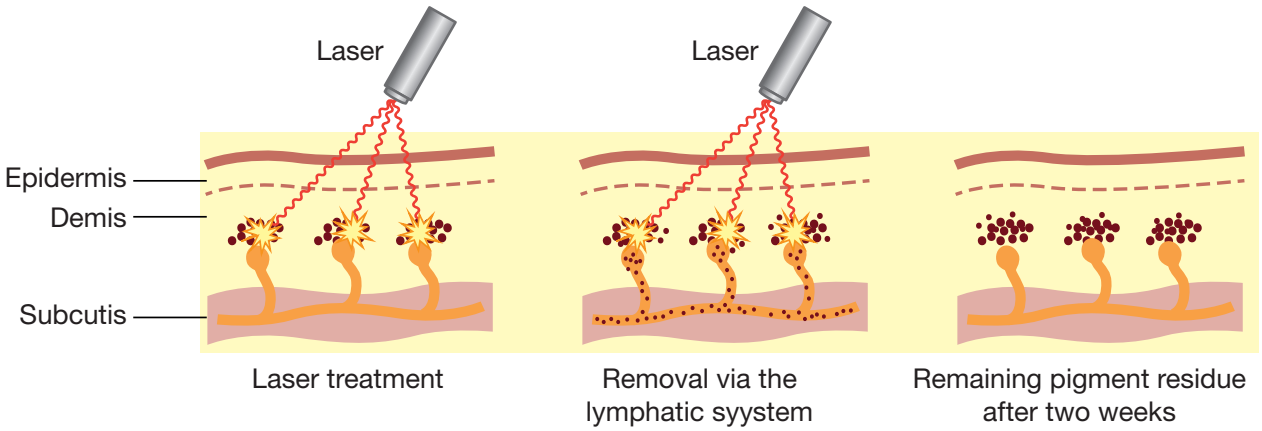


Figure 5: Laser light can break pigment molecules into smaller pieces that can be more easily removed from the site via the lymphatic system.

- **gases**, such as carbon dioxide, argon, or xenon;
- **crystals** or special kinds of glass; or
- **solid alloys** that include **semiconductors**—elements (generally metalloids and certain metals that are almost metalloids) that conduct electricity, but not as well as metals do.

The other factor considered when categorizing a laser is the **wavelength of coherent light** that it emits. This is an

Figure 6: Laser tattoo removal works progressively over several sessions. Not all tattoos fade as completely as this one. *Image provided courtesy of Katie Hester from Fade Out Laser Removal.*

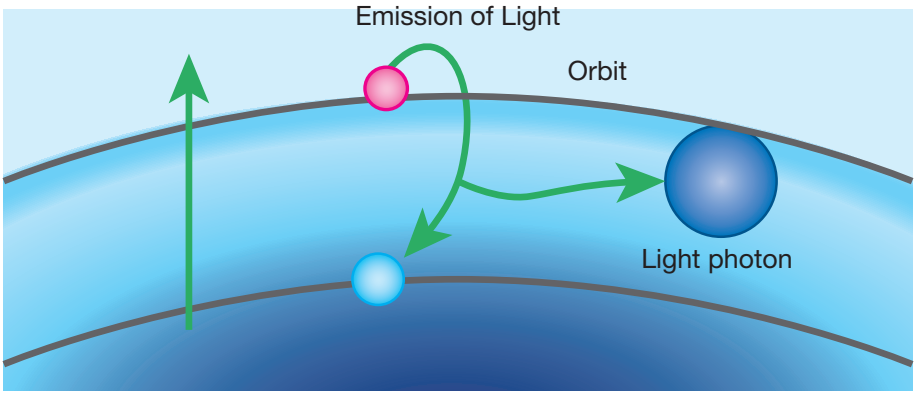


Figure 7: When energy is pumped into a laser gain medium, electrons are temporarily boosted to higher energy levels. When they drop back down to lower energy levels, energy is released as photons of coherent light of a particular wavelength, and viewed as a particular color.

important consideration in tattoo removal, since different colors and shades absorb different ranges of wavelengths. Black pigments absorb just about everything shined on them. This is why black looks black, why people feel hot when wearing black on a sunny day, and why black tattoos heat up in sunlight more than lighter colored ones do. It is also why laser removal has always worked best on black tattoos and tends to be more challenging for lighter colors and shades like yellow, orange, and white.

QS Lasers Used in Tattoo Removal

The following QS lasers are very common in tattoo removal procedures:

QS ruby laser (694 nm): This laser uses a special kind of ruby as the gain medium and emits laser light at 694 nanometers (nm), which falls into the red part of the EMR spectrum. This laser reportedly works to remove black, blue, violet/purple, and green pigments (Sardana et al. 2015). Historically, removal of green pigments has been challenging. This may be because green pigment molecules are often smaller than others, making it harder to stress them enough to break them apart (Siomos et al. 1996).

Q-switched Nd:YAG laser (1064 nm/532 nm): Ng:YAG stands for neodymium-doped yttrium aluminum garnet ($Y_3Al_5O_{12}$), which forms a crystal that has been doped with the element

neodymium. In this case, **doped** means that something has been added as an impurity to alter the properties of the substance into which it is added. Within the electromagnetic (EMR) spectrum, the wavelength of 1064 nm belongs to the **near IR spectrum**, the part of the spectrum that is closer to visible red than it is to microwaves (the smallest kind of radio waves) (fig. 2). At 1064 nm, light from this laser is thought to be very effective for black, blue, and brown tattoo pigments, plus it penetrates deep into the skin (Sardana et al. 2015). In QS mode, the Ng:YAG can also produce a second beam at 532 wavelength (green), which does not penetrate as deeply (fig. 8) yet has been reported to be particularly effective for removing red, red-brown, orange, and rose-colored pigments (Gómez et al. 2010; Levine et al. 1995; Sardana et al. 2015). A potential difficulty with this wavelength is that hemoglobin—the oxygen-carrying molecule that fills red blood cells—is basically a red pigment that can absorb light in the 532 nm range. This is also true for the skin pigment melanin, the levels of which determine the darkness of an individual's skin tone. By absorbing the laser energy, hemoglobin and melanin can reduce the effectiveness of lasers whose wavelengths they absorb (Shah and Aurangabadkar 2015).

Q-switched alexandrite laser (755 nm): Alexandrite is a type of Chrysoberyl crystal whose normal color is green, although it can change to red when exposed to light. At 755 nm, the light from this device is in the near IR range. Normally, most people

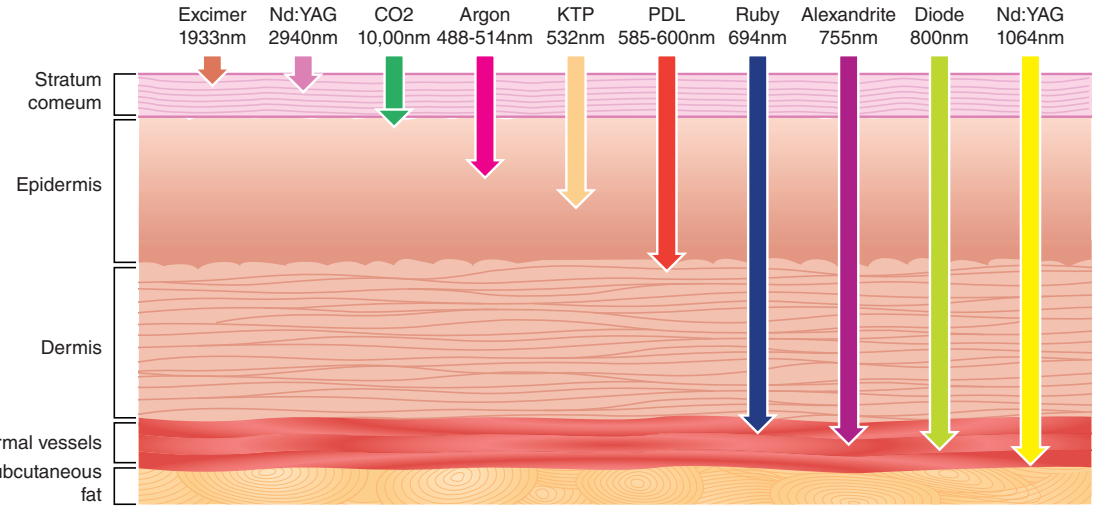


Figure 8: Skin penetration depth of various types of lasers.

cannot see light with a wavelength much longer than about 740 nm at the transition between red and IR. With some pulsed laser light, and under certain conditions, people can see up to 1050 nm into the IR spectrum. Consequently, the alexandrite laser will look red to the eye. It is actually considered to be a red laser, in contrast with the 1064 nm Ng:YAG laser, which is unequivocally an IR laser. The Q-switched alexandrite laser is reported to work well for removing black and blue, as well as green pigments. It is also reported to remove naturally occurring pigments in skin (**dyspigmentation**), so often other lasers are preferred for removing tattoos on pigmented skin (darker skin types) (Sardana et al. 2015).

In sum:

- the QS ruby laser (694 nm) successfully removes black, blue, violet/purple, and green pigments;
- the Q-switched Nd:YAG laser (1064 nm/532 nm) successfully removes black, blue, brown, red, red-brown, orange, and rose-colored pigments; and
- the Q-switched alexandrite laser (755 nm) successfully removes black, blue, and green pigments.

It is important to note that yellow and white pigments are not listed above. Again, lighter colors are more difficult if not impossible to remove.

Considerations & Complications for Laser Tattoo Removal

The issue of altering skin pigmentation—as is a risk with both the Q-switched Nd:YAG and Q-switched alexandrite lasers—raises the point that the selection of lasers for tattoo removal is influenced by a variety of factors in addition to the color of the pigments that need to be removed. One clear factor is skin color (pigmentation). Other factors can include the anatomic location of the tattoo, the age of the tattoo, and any immune system problems affecting the individual seeking its removal.

In addition to dyspigmentation, potential complications of QS laser treatment include:

- allergic reactions
- hyperpigmentation (increased skin darkening)
- hypopigmentation (increased skin lightening) (fig. 10)
- blisters

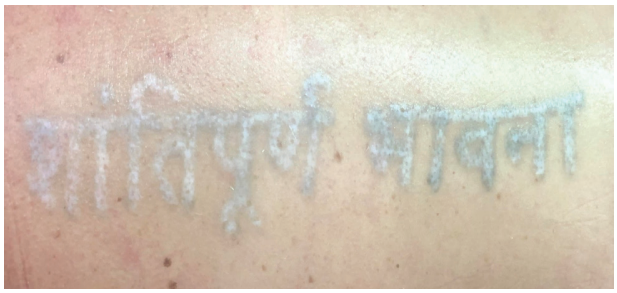


Figure 9: A case of hypopigmentation in areas where tattoo pigments have been removed by laser treatment. *Image provided courtesy of Katie Hester from Fade Out Laser Removal.*

- edema (swelling)
- transient erythema (redness)
- pinpoint bleeding (Reiter et al. 2016)

This treatment can potentially leave debris remaining in the epidermis, but generally this complication can be minimized by tweaking the laser procedure in various ways (Choudhary et al. 2010). Notably, recipients of nanosecond laser treatment report that the treatment is painful, often more painful than getting the tattoo itself (Lorgeou et al. 2018; Reiter et al. 2016). Use of topical anesthetics can reduce the pain somewhat, but not completely (Greveling et al. 2017).

Picosecond Lasers

Whereas the QS method enables pulsing on the order of nanoseconds, there are lasers that pulse faster, namely in the picosecond (trillionth of a second) range. **Picosecond (PS) lasers** include the picosecond alexandrite laser, which—like its QS counterpart—emits laser light at 755 nm (Cho et al. 2018). They also include the picosecond Nd: YAG, which—also like its QS counterpart—can emit a 1064 nm IR pulsed beam and a 532 nm green pulsed beam (Kasai, 2017; Reiter et al. 2016). Some PS lasers produce light at 758 nm and 795 nm (Reiter et al. 2016).

While QS nanosecond lasers are the current gold standard for tattoo removal, the relaxation time for heated pigment particles is less than 10 nanoseconds (Reiter et al. 2016). Consequently, there is a rationale that picosecond lasers may be able to provide even more effective treatment than nanosecond laser devices (Reiter et al. 2016; Sardana et al. 2015), potentially clearing away more pigment in fewer sessions compared with QS lasers. However, many variables can contribute to the efficiency of the tattoo removal process. An individual's physiology, the machine and experience of the technician all play a part in how effective each session can be. There is still no concrete evidence which shows picosecond lasers are more efficient than QS nanosecond.

In this regard, a systematic review of studies published through 2016 found that many of the studies on this subject had not been adequate. This was due to a high risk of bias and/or a lack of comparison between the two methods specifically for tattoo removal. The systematic review did find, however, some evidence that picosecond lasers are more effective in clearing black-blue ink compared with their nanosecond counterparts (Reiter et al. 2016).

More recently, in 2018, a study involving 49 patients reported picosecond lasers work better for tattoos overall, although with no advantage over QS lasers for clearing multicolored tattoos. The same study reports no differences in side effects between the two laser categories, but significantly less pain with picosecond lasers than with QS lasers (Lorgeou et al. 2018).

An even more recent review of 27 papers published up to the year 2019 found picosecond laser treatment to be generally quite effective and safe for tattoo removal, as well as in the treatment of other skin conditions like acne scarring, skin aging, and pigmented lesions and disorders (Torbeck et al. 2019). Consequently, while more studies are required to adequately compare the two laser types, picosecond lasers may be poised to replace QS lasers for tattoo removal.

Emerging Tattoo Removal Methods

Research using tattooed chicken breast tissue suggests the possibility of combining laser treatment with high intensity focused **ultrasound**—sound waves administered to disrupt tissue—to remove unwanted tattoos and potentially treat other skin conditions (Hazlewood and Yang 2019). Other research has highlighted the major role that dermal macrophages play in the persistence of tattoos, as they re-engulf tattoo pigments when older macrophages die (Baranska et al. 2018). This same research also suggests a potential for immunotherapy agents that could target immune system cells in ways that would block this type of macrophage activity. Such a treatment would make it more difficult for tattoo pigments to remain in the dermis, particularly if administered in concert with additional established methods such as laser treatment.

12 ADVERSE EFFECTS OF TATTOOING

An episode of the once popular television series *M*A*S*H* highlighted infection, particularly with hepatitis virus, as a notorious complication of tattooing. First airing in 1977, the episode linked potential medical complications to a tattooing culture that was connected mostly with soldiers and sailors receiving tattoos from artists whose procedure, instruments, and ink were reputed to be substandard. Such a concern was accurate for the early 1950s, during the Korean war, the era in which the series intended to portray. The concern, unfortunately, is still valid in connection with unprofessional tattoo facilities that do not follow sanitary procedures and use unsterilized materials. Unfortunately, risk of infection also applies to procedures performed by tattoo artists who *do* follow all the correct procedures.

Challenges to Sterility

In the United States, tattoo inks are not required to be sterile, although many manufacturers market a sterile product. When a manufacturer claims sterility on a label, their product must maintain that claim. Sanitation is often achieved by way of gamma irradiation. In this procedure, the ink is exposed to radiation from a gamma-emitting source, such as cobalt-60 (an isotope of cobalt that emits gamma radiation). The rays kill mature bacteria, viruses, and other potential pathogens (fig. 11). Gamma irradiation has its limits, it kills live pathogens, but it does not kill spores. Spores are a product of the pathogen's reproductive process. These are a variety of dormant cells including bacteria, fungi, protozoans, algae and fauna. When these spores germinate, the

material is contaminated. This means that tattoo ink, although "sterilized" upon leaving the manufacturing facility, may still pose a risk for a pathogen reaction.

Additionally, a US report describing analysis of 85 unopened stock bottles of tattoo inks, discovered that although labeled as sterile by their manufacturers, 49% were in fact not (Journal of Applied Microbiology, 2018). 33 inks were contaminated with bacteria, 2 with fungi and 7 with both fungi and bacteria. This leaves enough doubt to make the risk of infectious complications quite real, even when all needles, equipment, and agents applied to the tattoo site are sterile. It also underscores a need for ink manufacturers and tattoo artists to adhere to standards that place sterility at a level of the utmost importance.

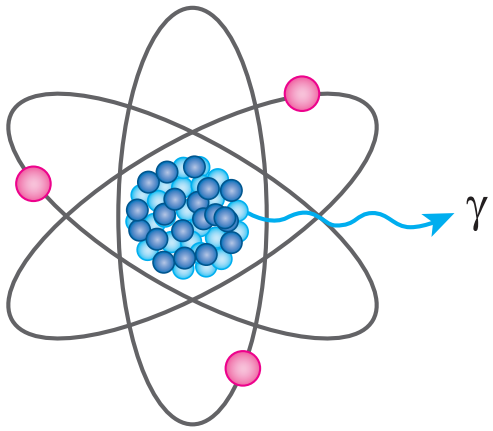


Figure 10: Cobalt-60 is an isotope of cobalt (Co) that emits gamma (ɣ)rays and is used commonly as a source of gamma rays to sterilize materials.

Like inks, tattoo needles are not required to be sterile unless a localized jurisdiction regulates body art. Although this requirement reduces the risk of infection dramatically, receiving a tattoo still poses inherent risks. This is because the same needle penetrates the skin many times. Compared to procedures where a needle only penetrates the skin once, tattooing greatly increases the risk of transferring organisms from the surface of the skin to its interior. (Begolli Gerqari et al. 2018). This makes cleaning the skin critically important prior to a tattooing procedure.

Moreover, while the characters on the aforementioned *M*A*S*H* episode named hepatitis as a potential complication, this is now referred to as hepatitis A virus (HAV), which causes fairly limited disease. These days, known dangers of contaminated ink and instruments now extend to:

- hepatitis B (HBV) and hepatitis C (HCV) viruses, which easily kill or require liver transplantation
- human immunodeficiency virus (HIV)
- an enormous range of pathogen infections

Viral Infections

While HIV is notorious for causing Acquired Immune Deficiency Syndrome (AIDS), infection with HBV or HCV can actually occur with much smaller viral doses than infection with HIV (Serup et al. 2015,). In tattooing, the hepatitis viruses pose a statistically greater danger.

Medical literature also includes some concern that a tattoo procedure might trigger a latent herpes simplex virus (HSV) infection. The body can carry HSV for a long time, sequestered within but not eliminated by the immune system (Begolli Gerqari et al. 2018). As with the human papilloma virus (HPV), existing medical literature is limited to case reports of lesion-like warts (verrucae planae) known to be caused by various HPV subtypes that have appeared on tattoo sites following a tattoo procedure (Kirchhof and Wong 2019).

Additional viral diseases that warrant investigation for their potential spread in tattooing settings include:

- cytomegalovirus (CMV)
- Epstein-Barr virus (EBV)
- Zika virus

The latter is not common outside of tropical climates. It is nevertheless a concern because of serious consequences when it infects pregnant women.

Bacterial Infections

Similar to a viral infection, bacterial infections can also result from getting a tattoo. This can be the due to contaminated ink or improper sanitary procedure, or because the tattoo site becomes infected before the wound has healed (Serup et al. 2015). Infection with **mycobacteria**—bacteria of the genus *Mycobacterium*, which includes the organisms that cause tuberculosis and leprosy—can generally be avoided (Serup et al. 2015).

Potential bacterial infections also include certain disease-causing species of *Streptococcus* and *Staphylococcus* (fig. 11). Both of these genera include species that can **necrotize** tissues or organs. In other words, they kill cells, causing extreme damage and dysfunction, even to the point of requiring amputation of a limb (fig. 12). Some of these species can cause **sepsis**—the spread of microorganisms in the blood and other body tissues—which itself can be fatal (Serup et al. 2015). Among these organisms is the notorious methicillin (a synthetic form of the antibiotic penicillin) resistant *Staphylococcus aureus*.

Various bacteria can produce infective **endocarditis**, a heart infection that is fatal if not recognized quickly and treated (fig. 13). These bacteria include:

- *S. aureus*
- various Streptococci (especially of the viridans group)
- coagulase negative Staphylococci
- Enterococci (Cahill and Prendergast 2016) (fig. 11)

Consequently, the possibility of endocarditis as a tattoo complication is on the list of concern (Serup et al., 2015).

Other Adverse Effects

Whereas viruses and bacteria are the principal categories concerning infectious organisms in connection with tattoos, medical literature includes a scattering of case reports of fungal infections (Gathings et al. 2018; Kluger et al. 2014; Oanţă and Irimie 2016). Upon further review, insufficient data were provided to implicate getting a tattoo as being causative of the infections. Adverse effects of tattooing also include psychiatric, social, and occupational complications (Serup et al. 2015). As much as a tattoo can positively affect an individual's self-esteem and body image

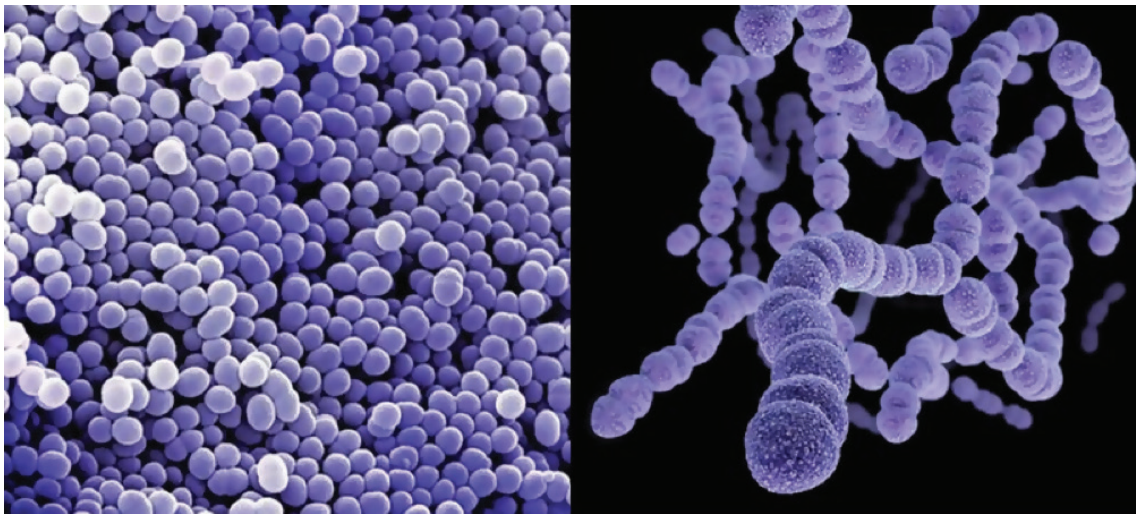


Figure 11: ***Staphylococcus*** **(left) and** ***Streptococcus*** **(right) both consist of cocci (spherical-shaped cells), but they group together in different ways.** Whereas Staphylococci form clumps, Streptococci form chains. *Images made available through the Centers for Disease Control and Prevention (CDC); image credit to Jennifer Oosthuizen - Medical Illustrator.*

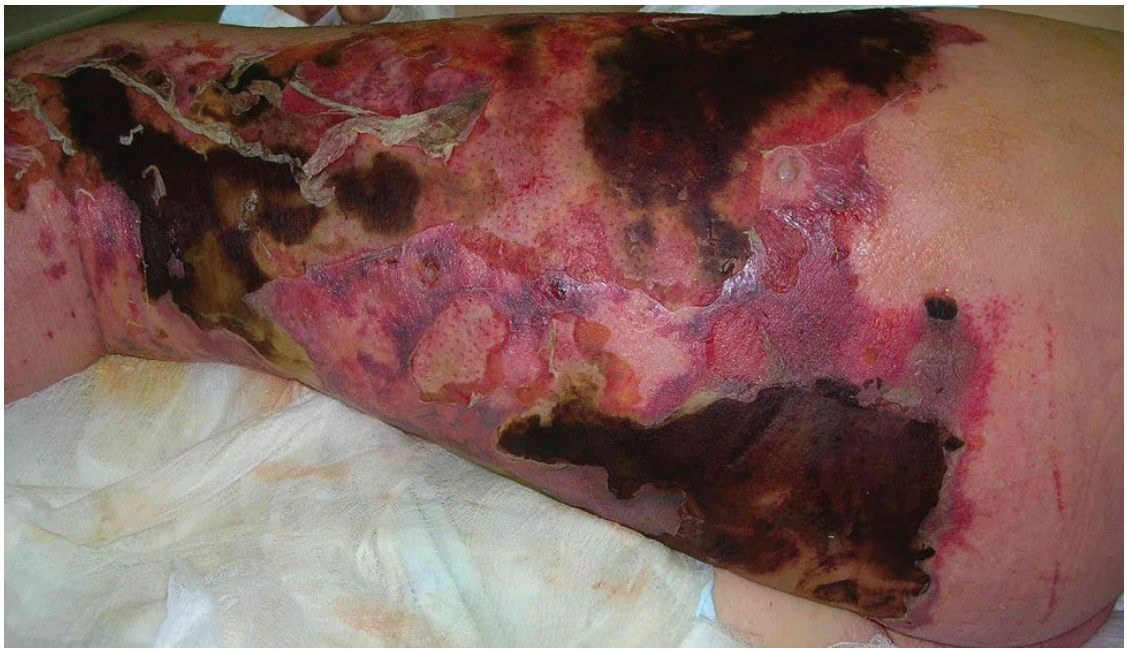


Figure 12: Necrotizing fasciitis, caused by a mixture of necrotizing (flesh eating) bacteria, including a type of *Streptococcus*. Note that the case above was not caused by a tattoo. *Image credit: Piotr Smuszkiewicz, Iwona Trojanowska, and Hanna Tomczak. Image license: Creative Commons Attribution 2.0 Generic.*

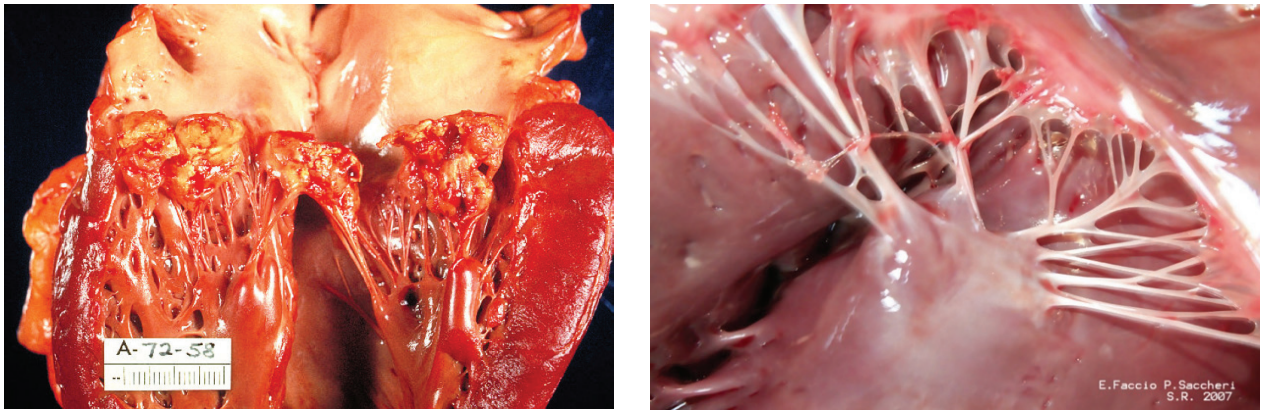


Figure 13: A bicuspid (mitral) valve, Damaged due to infective endocarditis (above). Healthy valve (below).

it can also have a negative effect. A poorly done, or not well thought through tattoo, can be an ugly daily reminder of a bad choice. In modern culture, an individual's choice for appearance and lifestyle are generally accepted by society. However, visible tattoos still carry a stigma in some realms. In the recent past, tattoos were associated with insidious individuals like criminals and drug addicts. Having visible tattoos should always be an occupational consideration, as some employers prohibit any visible body art.

An Assessment of Adverse Reactions

The possibility of a contaminated ink batch and inadequate antiseptic procedures notwithstanding, the likelihood of developing a fatal infection from a tattoo procedure is quite low. In contrast, mild adverse reactions—especially swelling, itching, and photosensitivity (sensitivity of the tattoo site to sunlight)—are extremely common, affecting about 20% of tattoo recipients (Serup et al. 2015). Fortunately, such effects are generally temporary. It is not uncommon for people with tattoos to complain of burning, pain, or other sensations in tattooed body parts during magnetic resonance imaging (MRI), as the procedure employs a magnetic field so powerful that it can affect metals within tattoo pigments.

Although it would be preferable to be able to link the risk for every known complication to factors that could be avoided, epidemiological data on tattoo complications is very limited. Nevertheless, a retrospective review published in 2016 assessed 493 tattoo complications present in 405 patients. Here is what they found:

- 37% (184 people) presented with allergic complications, which represent one category of immune-mediated reactions (discussed in the next section).
- 32.2% experienced **plaques**, which are raised lesions more than 1 cm wide. The tattoo likely exacerbating an existing condition.
- 11% of the group (53 people) suffered bacterial infections.
- 9% (46 people) experienced complications that were considered psycho-social. In these cases, the tattoo bothered them personally or caused difficulties in their relations with other people or in work situations.

- 3.7% experienced extreme **hyperkeratosis**, the abnormal thickening of the epidermis.
- 1.4% experienced **ulceration** (sores).
- 30% (144 people) suffered various other reactions, including photosensitivity, pain, and swollen lymph nodes.

Such effects were reported predominantly in red and reddish tattoos, a phenomenon that is thought to be related to chemical aspects of red pigments.

Additional complications were found in association with black tattoo ink (carbon black):

- 13% (66 people) **experienced Papulo-nodular reactions**—raised, lumpy areas on skin. This is thought to be the result of clumping together of the black pigment molecules rather than an allergic reaction, as black pigments are thought to be **hypo-allergenic** (do not cause allergic reactions).
- 5% of the complications were cases of **sarcoidosis**, which features enlarged lymph nodes and the appearance of concentrated areas of inflammation called **granulomas** on particular parts or all over the body. The tattoo likely exacerbating an existing condition.

Allergies, sarcoidosis, and a plethora of other conditions that have been, or may be, associated with tattoos are different kinds of immune reactions.

Immune-Mediated Reactions

While mild reactions at the tattoo site are common but not life threatening, and while systemic infections from blood-borne pathogens are potentially deadly but rare, somewhere in between are a range of **immune-mediated reactions**. These conditions arise because something triggers the immune system to initiate a process that is harmful to the body, either throughout the body or in a localized area. In some cases, such complications can be exacerbations of preexisting skin conditions (Islam et al. 2016). In other cases, however, immune reactions are new to the individual, stimulated by the tattoo procedure itself.

Allergic reactions and **granulomatous reactions** fall into this category. **Granuloma annulare**—a chronic condition that features yellow or red firm

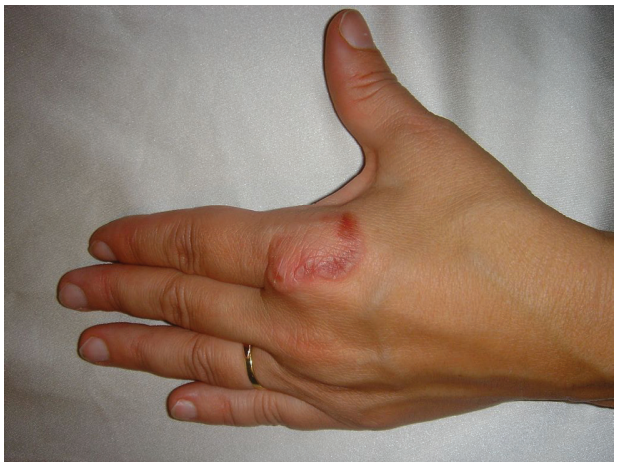


Figure 14: Granuloma annulare, not caused by a tattoo.

nodules or **papules** (small bumps) forming a ring on the skin—has been reported to flare up following a tattoo procedure (Bagwan et al. 2007; fig. 14). **Necrobiosis lipoidica** –a problem with collagen that is best known for occurring in diabetic patients—has also been reported with a possible tattoo connection (Babin-Muise et al. 2012).

A common allergic reaction to tattoos is called **allergic contact dermatitis**. This kind of allergic reaction is triggered by something coming into contact with the skin and manifesting itself in the location of contact (fig. 15). This kind of localized response is in contrast to allergic reactions that manifest systemically (throughout the body). Systemic symptoms may occur far away from the provoking agent, such as in the respiratory system. In the case of tattoos, the triggering agent in the skin can be one or more agents in the ink or another agent that contacts the skin such as if an artist uses latex instead of nitrile gloves.

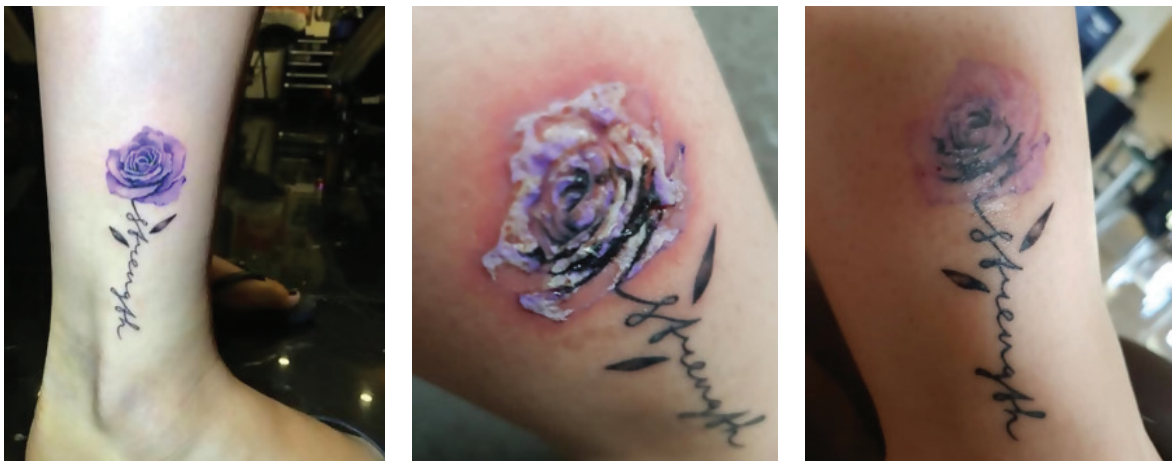


Figure 15: Dermatitis reaction immediately after tattoo procedure (left), 3 days post-procedure (middle), and 3 weeks post-procedure (right).

The Immune System & Tattoo Procedures

The immune system consists of the various organs, tissues, specialized cells, and specialized proteins that act to defend the body against disease-causing microorganisms and other agents that can harm the body. Although the **skin**—the largest organ in the body—figures prominently as the location of tattoos and associated complications, the skin also comes into discussion in that it is the physical barrier against anything potentially entering the body. In a very real sense, the skin is part of the immune system due to its role as the first obstacle that a potentially harmful agent must overcome. The skin also contains cells and processes that change themselves to combat organisms and molecules that are foreign to the body. These changes result from some element of the immune system being exposed to such foreign entities.

The "soldiers" of the immune system consist of **white blood cells (WBCs)**. There are many types of WBCs. Depending on the type, these are produced, matured, and/or stored in bone marrow, the spleen (located in the abdomen), the thymus gland (located inside the chest), and lymph nodes (fig. 16). WBCs circulate constantly in the blood, creating a great deal of overlap between the immune system, lymphatic system, and circulatory system. While there are many different types of WBCs, for the purposes of this discussion they are categorized into two big groups: phagocytes and lymphocytes.

Immune system **phagocytes** are big WBCs that engulf—and usually break up and digest—entities that the immune system considers to be foreign to the body. Phagocytes include **monocytes**. One type of monocyte is the macrophage (discussed in an earlier chapter). Macrophages can engulf—or **phagocytize**—small organisms, such as bacteria and viruses. They can also engulf individual molecules, which they can often digest, but not always. For instance, large pigment

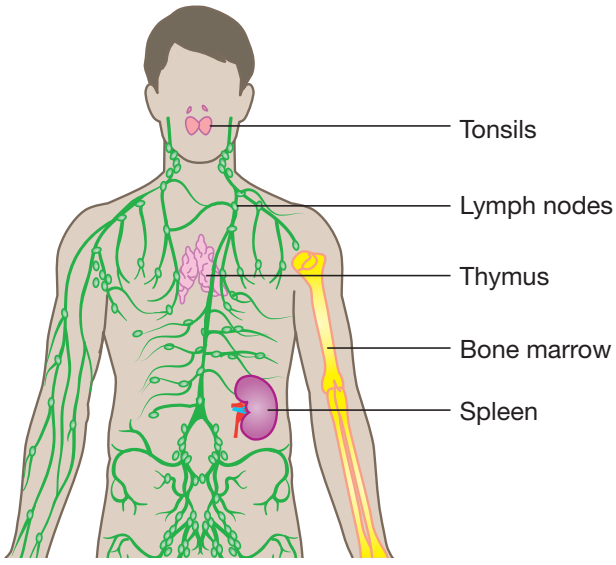


Figure 16: Some organs of the immune system.

molecules are difficult for **dermal macrophages** to break down. This keeps the tattoo visible, even as the pigments are passed through successive generations of macrophages (Baranska et al. 2018). Monocytes also include dendritic cells, which engulf foreign material and then display parts of that material, called **antigens**, to another type of immune system cell. This process enables the immune system to learn to recognize and respond to the foreign body. Phagocytes of the immune system also include neutrophils, eosinophils, and mast cells (fig. 17).

Lymphocytes are WBCs that recognize, remember, and help to destroy entities that the immune system considers foreign. Lymphocytes include **T lymphocytes**, which are presented with antigens of foreign material by **dendritic cells**. Lymphocytes also include **B lymphocytes**, whose job is to make special proteins called **antibodies**. Antibodies

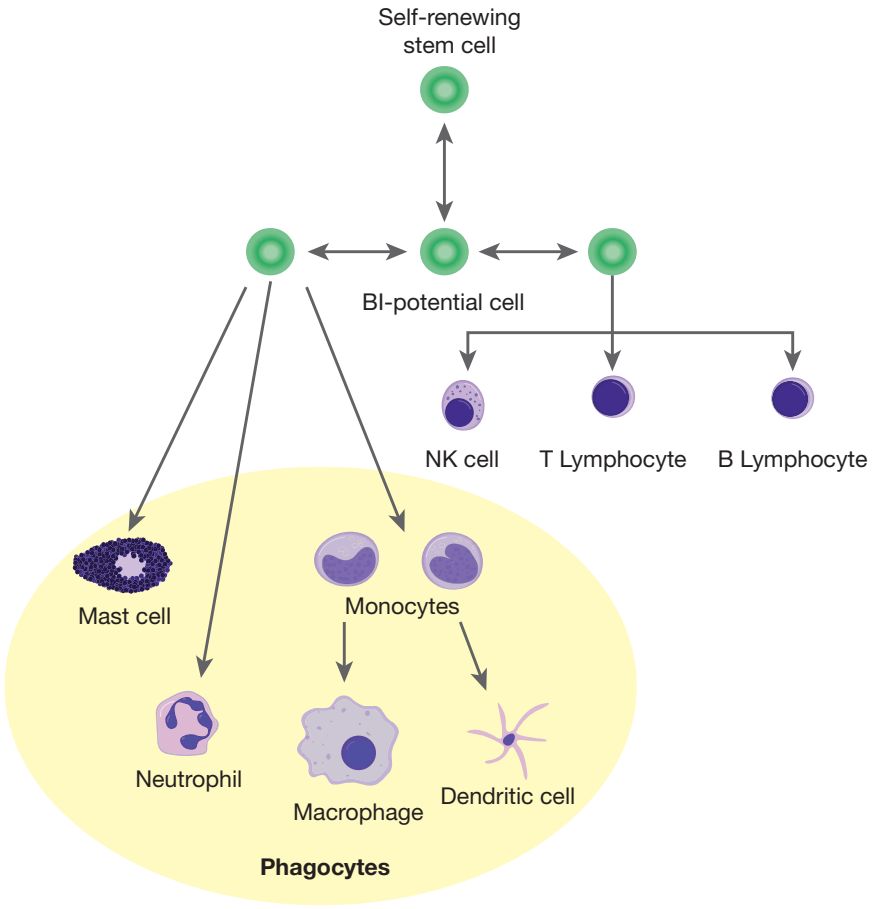


Figure 17: Some types of phagocytes and lymphocytes.

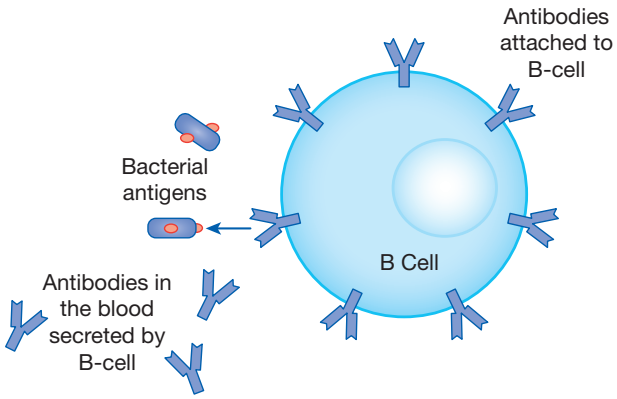


Figure 18: B lymphocytes produce antibodies.

attach to antigens to aid in the destruction and removal of their associated foreign agent (fig. 18). In a sense, antigens are like fingerprints unique to each substance that enters the body, whereas each antibody is like a key that recognizes a particular antigen fingerprint.

Allergic Reactions

Although the immune system can learn to make billions of different antibodies, there are five classes of antibody:

- IgA (immunoglobin A)
- IgD (immunoglobin D)
- IgE (immunoglobin E)
- IgG (immunoglobin G)
- IgM (immunoglobin M)

Each of these has a particular function. An allergic reaction is a type of immune reaction in which antibodies against the foreign entity—the allergen—fall into the **immunoglobin E (IgE)** class. In many cases, the body learns to mount an immune response that has negative consequences, rather than protecting the body. An allergy is an example of such a negative immune reaction.

In an allergic reaction, IgE antibodies that have been created to recognize a particular allergen find it. IgE antibodies attach to **mast cells** (a cell filled with basophil granules, found in numbers in connective tissue), causing the cell to release various substances. These substances include:

- histamine (fig. 19)
- heparin
- cytokines
- granulocyte macrophage colony-stimulating factor (GM-CSF)
- leukotrienes
- various proteases (enzymes that break proteins into smaller pieces)

Known as **mast cell mediators**, these substances cause the familiar features of an allergic reaction—such as swelling, redness, and itching—at the site where

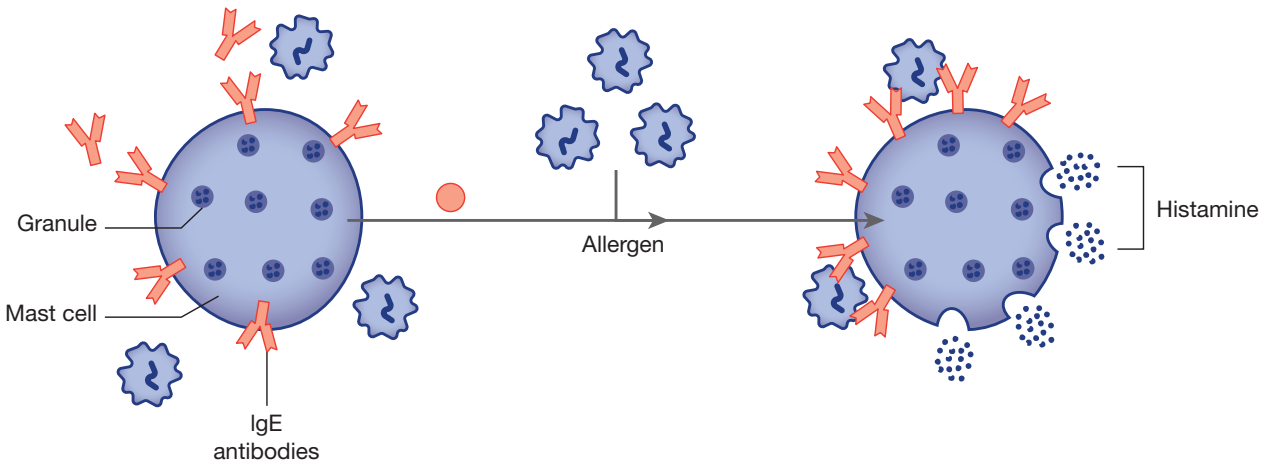


Figure 19: The allergic response is mediated by an allergen bound to IgE, causing mast cells to release mediators like histamine.

an allergen contacts the skin. If severe, an allergic reaction also can develop throughout the body as an **anaphylactic attack**. Anaphylaxis is a sudden severe hypersensitivity reaction resulting in a mass release of mast cells through the mucosal and epithelial tissue. This reaction typically creates bumps called **urticaria** (known commonly as hives) (fig. 20). It may also cause swelling, itching, and flushing, as well as itchy, teary, red eyes, and a congested, runny nose; sometimes with a metallic taste in the mouth. When severe, anaphylaxis can affect the digestive symptoms (nausea, vomiting, diarrhea, cramps) and to the brain (causing anxiety or confusion). It can also include cardiovascular signs and symptoms—low blood pressure, fainting, **syncope** (loss of consciousness), **arrhythmia** (rapid, slow, or irregular heartbeat)—and present in the respiratory system with coughing, breathing difficulty, wheezing, mucous secretion, voice change, throat itching and swelling, or a tight, choking sensation in the throat. Many of these effects can be fatal if the person is not given immediate

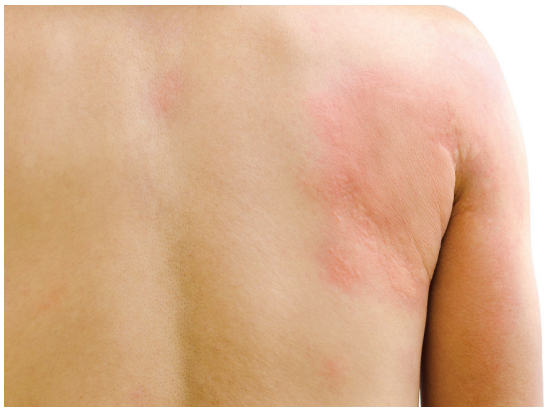


Figure 20: Urticaria (hives), signifying the onset of an anaphylactic reaction. *Image © Can Stock Photo / tinglee1631.*

Figure 21: Allergic (dermatitis) reaction in and around tattoos, featuring erythema (redness of the skin).

treatment with **epinephrine**, such as with an epinephrine auto-injector (EpiPen®).

In contact allergic dermatitis, release of mast cell mediators occurs locally in the area where there has been an allergen. The effects generally remain local, but anaphylaxis is always a possibility. In the setting of tattoo administration, it is theoretically possible for metal in the steel needle—such as nickel—to provoke an IgE response, but this is thought to be extremely rare (Serup et al. 2015). On the other hand, allergic reactions to ink are fairly common (fig. 21), particularly with red inks (fig. 22). This does not necessarily mean, however, that there are often allergens in the ink. Rather, the mechanism

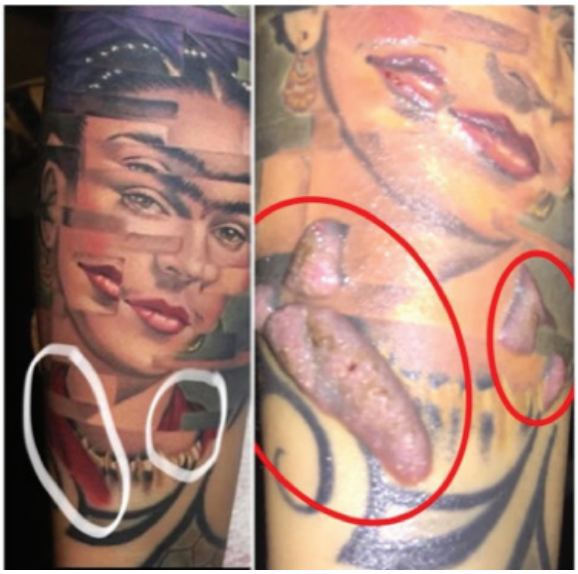


Figure 22: Allergic reaction to red ink.

may involve **haptens**, small molecules that combine with other molecules. In doing so, they become **antigenic** (able

to stimulate the immune system to make B lymphocytes with antibodies against them) (Serup et al. 2015). As there are so many different molecules in tattoo ink that can be broken up in a myriad of methods, it is quite difficult to predict who will develop an allergic or other type of immune reaction after receiving a tattoo, even in cases where there is a prior/pre-existing history of allergies.

Other Immune-Mediated Conditions

The list of conditions for which there are reports of a connection or possible connection with tattooing is extremely long; addressing all of them is out of scope for both this chapter and this book. Nevertheless, apart from the allergic and granulomatous conditions mentioned earlier, some other conditions warrant brief mention. Tattoos do not cause immune-mediated conditions, but these preexisting conditions can be exacerbated by the tattoo process.

Like sarcoidosis, **lupus** is an autoimmune condition. This disease is caused by the immune system seeing particular substances of the body as if they were foreign and then attacking those substances. **Subacute (cutaneous) lupus** is a form of lupus that affects the skin primarily (Wang et al. 2019). In tattooing, attacks of this type of lupus can occur in context with the Koebner (or Köbner) phenomenon. Also occurring with other autoimmune skin diseases, notably psoriasis, the **Koebner phenomenon** refers to an otherwise unaffected region of skin developing the characteristic features of a disease stimulated by trauma of that region of skin (Kluger et al. 2017). For example, if an individual has a history of psoriasis, receives a tattoo in a previously unaffected area of skin, and then has a characteristic psoriatic outbreak at the tattoo site, this would be an example of the Koebner phenomenon (Serup at al. 2015).

Inflammation of small blood vessels in the skin, called **cutaneous vasculitis**, has also been reported as an adverse effect of the tattoo process. This usually resolves within days to weeks (Serup et al. 2015). Further reports have been published suggesting tattoo procedures as a cause of various other skin conditions, including:

- **reactive perforating collagenosis,** a collagen-related problem (Escudero-Góngora et al. 2017)

- **morphea,** in which skin becomes discolored and hardened (Mahalingam et al. 2002)
- **pyoderma gangrenosum**, which is characterized by big, painful sores and may be the result of red tattoo ink (Litvinov and Sasseville, 2014; fig. 23)

Finally, the Koebner phenomenon may produce reactions in individuals with various other conditions that will be discussed in the following chapter, which deals with potential tattoo contraindications. These include:

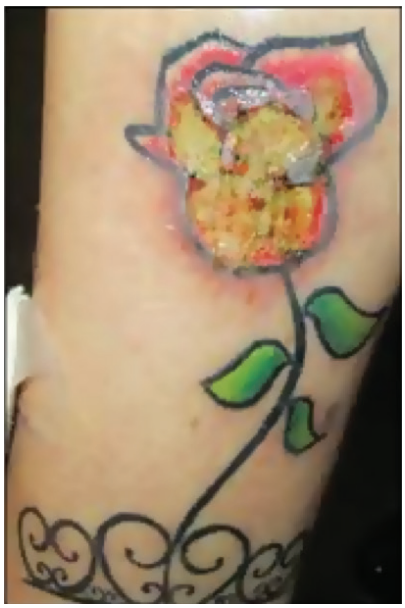


Figure 23: Pyoderma gangrenosum. *Image credit: Canadian Medical Association Journal, Pyoderma grangrensosum triggered by red tattoo dye.*

- Darier disease
- lichen planus
- lichen sclerosus
- lichen atrophicus

Other Complications Arising from the Tattoo Process

Folliculitis (inflammation of hair follicles) (fig. 24) is another complication that can develop after receiving a tattoo. It can be the result of infection, pigments, or other tattoo materials entering the follicles (Serup et al. 2015). Birthmarks (also called **nevi**) and other hyperpigmented regions can become irritated when tattoos are injected

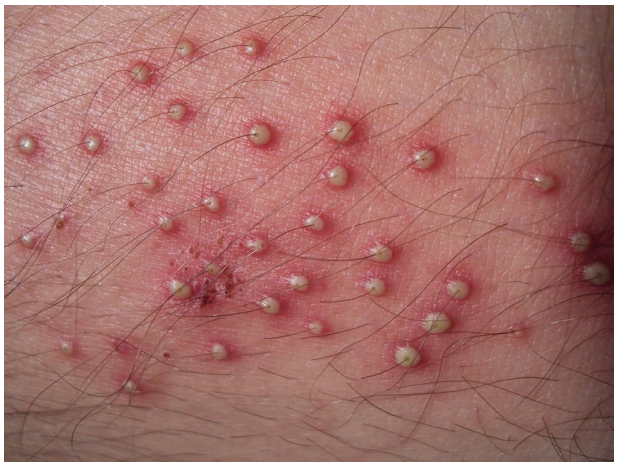


Figure 24: Folliculitis. This kind of reaction can result following tattoo procedures, either via infectious or noninfectious mechanisms.

in them or nearby. It is recommended that tattoo artists avoid tattooing within a centimeter of such spots (Serup et al. 2015).

Tattoos & Malignancy

As noted in the Chemistry of Tattoo Pigments and Dyes chapter (Unit IV), certain groups of pigments in tattoo ink are known carcinogens. A notable example is Polycyclic Aromatic Hydrocarbons (PAHs) that comprise carbon black pigment (Lehner et al. 2014). The fact that PAHs are also present with other carcinogens in tobacco smoke—an agent whose cancer connection is unequivocal—highlights the concern about tattoo pigments as potential risk factors for malignancies, such as **cutaneous malignant melanoma** (**CMM**, an aggressive type of skin cancer) and other cancers of the organs and skin. Regarding malignancy and tattoos, new data are constantly changing the perspective and level of concern, but the issue is complex for a few reasons.

First, while there have been several studies showing carcinogenic tattoo pigments causing malignancies in laboratory animals, such studies involved continuously exposing the animals to the agents in question. This is generally not a good model for the tattoo setting, in which pigments are injected into a person's skin just once (Serup et al. 2015). The model might be more accurate, however, in reflecting the scenario of an individual receiving numerous tattoo procedures over many years. Another reason for the challenge is that the bulk of tattoos are present among individuals in roughly the 20–40-year-old age group, whereas the period from first exposure to a carcinogen to the actual appearance of clinical cancer typically spans from several years to decades. Another reason why the issue is difficult to study is the presence of seemingly endless confounding factors: people generally possess a range of risk factors for various malignancies, and it is challenging to design epidemiological studies that control for them in order to assess one particular factor of interest.

The aforementioned challenges notwithstanding—including the carcinogenic status of PAHs in black ink—medical literature includes other certain malignancies, such as squamous cell carcinoma (SCC), resulting from tattoos (Junqueira et al. 2017; Shrout et al. 2019), particularly those with red pigments (Shrout et al. 2019). SCC is a cancer that usually develops on sun-exposed areas of the skin. It can, however, occur virtually anywhere throughout the body and is connected with other risk

factors, notably human papilloma virus (HPV) and UV light. The UV light factor is highly relevant to the issue of tattoos and SCC, based on finding SCC in laboratory mice. This may possibly be triggered by red tattoos containing the pigment 2-anisidine and UV together, but not by red tattoos alone (Lerche et al. 2017). Given that SCC is a form of skin cancer that is notable for having multiple risk factors, the combined effect on carcinogenesis of tattooing with UV light and other factors is an issue that warrants much more investigation. Alongside the possibility of malignancy, evidence also has emerged connecting tattoos with certain nonmalignant **neoplasia**, such as **keratoacanthoma (KA)** (Junqueira et al. 2017). This kind of tumor has similarities with SCC but is **low grade** (histology appears close to normal) and benign.

13 CONTRAINDICATIONS TO TATTOOING

As this book has covered, the process of tattooing introduces no shortage of opportunities for allergic responses, infections, and other reactions. How a body responds depends on an entire world of environmental factors, as well as infinite factors that are unique to each individual. Some of these individual factors can be invisible and hard to predict. Others—such as known medical conditions—may be more easily screened for, which can help to prevent unwanted responses. This chapter is devoted to outlining these factors, which are known as contraindications. Given the limited research available on contraindications and tattooing, however, most if not all of the contraindications listed require further study.

What are Contraindications, and Why do They Require Further Study with Regard to Tattoos?

The term **contraindication** refers to a medical condition, treatment, or circumstance specific to an individual that suggests that they should avoid a particular procedure, technique, treatment, or activity. In medicine, contraindications are categorized as absolute or relative. An **absolute contraindication** is a contraindication that applies all the time. For example, administration of an anticoagulant (blood thinning) medication is *absolutely contraindicated* in a person

with an actively bleeding gastric ulcer, in someone with a low platelet count, or in someone with a severe blood loss injury. On the other hand, a **relative contraindication** is a contraindication for something whose benefit-versus-risk depends greatly on the situation. As an example, agents that suppress the immune system—such as corticosteroids—are contraindicated in people with immune disorders, since the treatment puts them at greater risk than other people for infections. However, there are situations when an immunosuppressive treatment is mandatory to avoid death, so these agents are only *relatively contraindicated* in people with immune disorders.

Both for therapies and for recreational activities, professional medical specialty associations publish and regularly update clinical practice guidelines that include absolute and relative contraindications. There are all sorts of guidelines contraindicating various treatments for cardiac and cerebral conditions, as well as for activities like SCUBA diving or piloting an aircraft. Relevant to this, data have been published by the Divers Alert Network (DAN) showing that approximately 1.1% of the US population participated in diving in 2014 (DAN 2014). However, there also are data suggesting that some 10–29% of the world population is tattooed, although most of the data comes from Western countries (Kluger 2019). In any case, it is safe to say that the number of people with tattoos is at least in order of magnitude larger than the number of people who participate in SCUBA diving. Yet, there are simply no guidelines on tattoo contraindications. Only a handful of authors currently publish on the topic, and they are all based in Europe. While their papers are insightful, their suggestions regarding what and when to contraindicate come down to mere opinion. This book can do no better, but it can lay the groundwork for future discussions—and hopefully research—on the matter.

Consequently, what follows in this chapter are suggestions regarding conditions that should be discussed as candidates for relative and absolute tattoo contraindications, whenever formal clinical practice guidelines are drafted. Primary care physicians and dermatologists certainly are encouraged to consider the perspective of this chapter (and the previous chapter), as well as the information contained within it, when confronted with patients who are considering tattoo procedures.

These considerations come with two caveats. First, the reader should be aware

that the information is incomplete; a discussion of every possible disease and drug contraindication for tattoos and a full discussion of those conditions and drugs mentioned would be too extensive for this chapter. It would also be out of scope with this book, whose purpose is to provide an overview of multiple issues of science and medicine *vis-à-vis* tattooing. Second, although peer-reviewed to assure accuracy, this book was not conceived to serve as a set of clinical practice guidelines. The drafting of such guidelines would require a series of discussions among carefully-selected specialists representing relevant clinical fields, such as dermatology, cosmetic surgery, and infectious diseases. It is the hope of the authors that this book will stimulate such a project.

The above discussion notwithstanding, the one solid recommendation that the authors shall make is that individuals who are considering tattoo procedures should discuss the matter with their primary care physicians. Additionally, tattoo artists will be well served to be aware of how their practice may interact with the conditions and treatments listed, and to encourage potential clients exhibiting them to speak with their physician before getting a tattoo.

A recent survey conducted in Poland of 1,199 university students revealed a shockingly insufficient level of knowledge regarding tattoo-related health issues. When asked about the sources of that information:

- 79% had consulted with tattoo artists
- 73% had consulted the internet (with a great deal of overlap, as many had consulted both)
- 5% had consulted physicians
- 8% had consulted relevant medical literature

Furthermore, 49% reported that tattoo artists failed to inquire about medical conditions and medications prior to the procedure. In comparing responses between medical students versus students at other types of universities, the study found that while 86% of medical students were aware of the hepatitis C virus (HCV) risk associated with tattoos, only 34% of the other students knew of this risk (Rogowska et al. 2018). The need for the kind of information presented in this chapter—and the discussions and research that will hopefully follow its publication—is great.

THESE CONTRAINDICATIONS/ COMPLICATIONS INCLUDE BUT ARE NOT LIMITED TO...

Cardiopulmonary Conditions

Consideration for absolute contraindication should be given to numerous cardiopulmonary conditions, due to the risk of a tattoo procedure causing syncope (loss of consciousness) or an exacerbation of the condition. These conditions include **acute coronary syndrome (ACS)** and all of its manifestations. Any workshop that is arranged to develop guidelines on tattoo contraindications, however, must consider where to draw the line for people with a history of ACS who have been treated without recurring attacks.

ACS now comprises two broad categories:

- non-ST elevation acute coronary syndrome (NSTE ACS)
- ST elevation myocardial infarction (STEMI)

It excludes stable angina (chest pain or discomfort caused when the heart muscle doesn't get enough oxygen-rich blood), as a group of clinical opinion leaders may have divided opinions regarding contraindication of tattooing for patients in that category.

When it comes to **severe or late stage cardiac disease**, such as heart failure, the decision on contraindicating tattoo procedures seems clear. The same goes for **emphysema** of a severity that requires the individual to carry an oxygen tank; any given tattoo parlor is unlikely to accept such a client.

In utter contrast to the scenario of an obviously ill person who shows up seeking a tattoo, people with certain cardiopulmonary conditions can look and feel normal most of the time and then suffer a sudden attack of their condition that can be life threatening. Here are some examples:

- a young adult with asthma (fairly common)
- a young adult with arrhythmogenic right ventricular dysplasia (much less common)
- people with other cardiomyopathies (such as hypertrophic cardiomyopathy)
- people with various arrhythmias

Some additional conditions must be discussed in the development of guidelines

regarding cardiopulmonary contraindications. These include:

- uncorrected valve disease
- a history of infectious endocarditis (IE) or a known risk for IE
- axis deviations and their various underlying causes
- various congenital abnormalities and shunts
- pulmonary hypertension

In many cases, it may be reasonable to permit a tattoo procedure, provided that the tattoo candidate is given a full cardiovascular workup and appropriate treatments, such as antibiotic prophylaxis in the case of an individual with a history of IE.

Neurological Conditions

Numerous neurological conditions can additionally result in syncope, notably epilepsy. Also falling in this category are people with a history of **cerebrovascular accidents (strokes)** and of **transient ischemic attack** (a stroke risk factor), as well as **atrial fibrillation**. In many of the stroke risk cases, the medication that the patient is taking will be the prime consideration in the decision on contraindication of tattooing (as referenced in the discussion below on blood thinning medications).

The discussion must also extend to range of **movement disorders** that often have an insidious onset. These include:

- myasthenia gravis (as it can lead to myasthenia crisis)
- Parkinson's disease
- amyotrophic lateral sclerosis

This list is not intended to be complete, but with these and many other neurological conditions, the severity of the disability is likely to make a big difference in terms of a decision on whether tattoo contraindication is warranted. This, in turn, means a great deal of discussion is required in the course of developing guidelines.

Also pertinent to the neurology discussion are a host of conditions in which an individual could suffer attacks that are not life threatening but are painful or otherwise disturbing. People with these conditions could potentially be triggered by the pain or stress of a tattoo procedure. Top among these are: **vascular headache disorders**, namely **migraine disorder** and **cluster headaches**.

On the list of non-painful but disturbing conditions are disorders that

feature attacks of **vertigo**, a disturbance in balance. **Ménière disease** affects both balance and hearing; it is possible that noises from the tattooing machine could trigger an attack. More common is **benign paroxysmal positional vertigo (BPPV)** wherein an attack of vertigo is triggered by the head being placed in certain positions. From a tattooing standpoint, this can happen when the individual is inclined backward in order to have the tattoo procedure. Such attacks while lying down are not dangerous, but if severe can result in vomiting. It is reasonable at least to discuss BPPV as a possible relative contraindication for tattooing, depending on the level of the patient's response to treatment and the patient's will to tolerate the discomfort in order to receive the tattoo.

Diabetes Mellitus

Diabetes mellitus (DM) falls high on the list of conditions that must be discussed, primarily due to its high prevalence. Each day there is a very good chance that any given tattoo parlor will receive multiple candidates who are diabetic. Approximately 30 million Americans—roughly 10% of the US population—suffers from DM, with 90–95% of cases being type 2 or adult onset. Prevalence is particularly high in people above the age of 45, but due to rising obesity in the population, there is growing prevalence among younger age groups.

Diabetics are of particular concern because common complications of DM include the body's compromised ability to fight off infection. Diabetics are 21% more likely than those without DM to contract an infection (Shah et al. 2013). Another major concern is that complications are not controlled for **diabetic neuropathy** (malfunctioning peripheral nerves). This leaves the individual prone to ulcerations on extremities that can easily become infected. Diabetics also have an increased risk of granuloma annulare (Alirezaei and Farshchian 2017; fig. 16), which has also been documented as a tattoo complication.

When diabetes is not controlled or controlled inadequately, the diabetic is prone to cardiovascular disease, which may lead to the use of a plethora of medications. These may include aspirin, which—on account of being an anti-platelet drug—increases the bleeding risk.

A discussion of diabetes could go on for many pages, but the bottom line is that it is a systemic, chronic disease with widespread effects. Sores, infections, and

bleeding figure prominently as potential complications. Consequently, it seems reasonable that any case of uncontrolled DM should be considered an absolute contraindication for a tattoo procedure. Similarly, it seems reasonable that the patient's physician should contraindicate the tattoo procedure in cases when:

- diabetes has come under good clinical control as assessed based on hemoglobin A1c (HbA1c) values, and yet the patient suffers from diabetic neuropathy due to previously uncontrolled disease, or
- there is a history of sores.

Cancer

Patients who are suffering from any **cancer** that extends beyond a localized position—from which it can be cured by way of surgical excision alone—are typically receiving numerous medications, potentially including blood thinners. Patients undergoing chemotherapy have an inhibited capacity to fight bacteria, resulting in an elevated risk for infection. Individuals undergoing chemotherapy are absolute contraindication. They are subject to a range of complications of their disease, such as **clot formation**. Consequently, it is reasonable to consider contraindicating

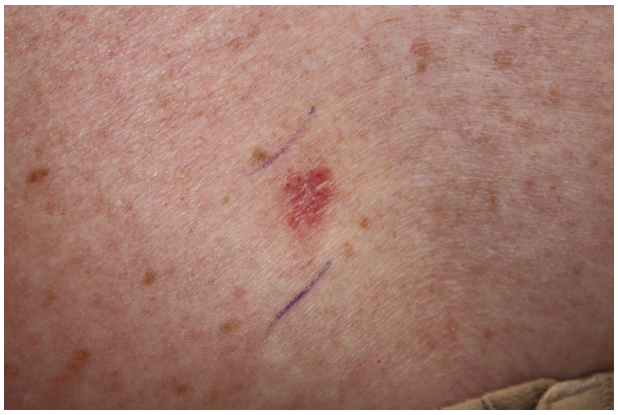


Figure 25: Basal cell carcinoma. *This image has been made available by the Creative Commons CC0 1.0 Universal Public Domain Dedication.*

tattoo administration in such settings. The exception is when there is a **neoplasm**, a cancer with such a low risk of metastasis that all treatment occurs at the site of the tumor. The prime example of this is **basal cell carcinoma (BCC)**, the most common type of skin cancer, which is treated and cured by a variety of removal techniques (fig. 25). If an individual arrives at a tattoo parlor with a BCC that has yet to be treated, there is no reason to avoid a tattoo procedure, so long as the tattoo is not to be placed anywhere near the BCC.

Bleeding Diathesis & Anti-Clot Medications

Some people with bleeding disorders and people who are taking anticoagulants

(blood thinners) could experience uncontrolled bleeding. There are many different bleeding disorders, ranging from **hemophilia A** and **hemophilia B** (which are uncommon but potentially severe) to **von Willebrand disease (vWD)** (which is extremely common but can be quite mild). Bleeding disorders can be either inherited or acquired. In some cases, they can be controlled by supplying a deficient clotting factor. **Clotting factors** are special proteins that are needed in the process of forming blood clots to stop bleeding.

Hemophilia A and hemophilia B are examples of bleeding disorders that are usually inherited. A person with inherited hemophilia A is deficient in a particular clotting factor called **factor VIII**, whereas inherited hemophilia B is a deficiency in **factor IX**, also called the "Christmas factor." While the presence of at least one normal gene for the needed factor prevents the condition, the factor VIII gene and the factor IX gene are both carried on the X chromosome, of which females have two and males have one. Consequently, it is much easier for a male to inherit hemophilia A or hemophilia B than for a female to inherit either of these conditions. However, a female with an abnormal gene on one of her X chromosomes is a carrier for the condition; each time that she conceives a son, there is a 50% chance that he will be a hemophiliac.

Hemophilia has a range of severities, characterized as mild, moderate, and severe based on the percentage of the deficient clotting factor that the person makes compared with how much is needed for normal clotting. People with severe hemophilia A, for instance, produce less than 1% of the normal amount of factor VIII, whereas someone making 6–49% of the normal amount is said to have mild hemophilia, as 50% or more is generally enough for normal clotting.

There are other types of hemophilia that are **autosomal** (not related to sex chromosomes). One example is hemophilia C, a deficiency of clotting factor XI. It affects Ashkenazi Jews in particular but is quite rare. Most of the time, however, the setting of inherited hemophilia involves a male with hemophilia A or hemophilia B.

While inherited hemophilia results from a person lacking at least one good gene for the needed clotting factor, these conditions also can develop as acquired conditions, due to the immune system making antibodies that inhibit the factor. In acquired hemophilia A, for instance, there are antibodies against factor VIII.

Hemophilia A can be treated by giving the person factor VIII, with the goal of increasing the person's levels of factor VIII to above 50% of normal. Since giving a patient too much of the needed clotting factor can be dangerous, there are protocols for adjusting the dosage. The treatment is imperfect, and there are usually ups and down in the person's clotting ability. In cases like these, the objective of the treatment is to allow the patient to engage in normal day-to-day activities like shaving without fear that they will bleed to death.

Because hemophilia is a tricky disease to manage, it is reasonable to consider contraindicating tattoo procedures in hemophilia settings. However, with gene therapy emerging as a pathway for permanent cure of individuals with hemophilia A and B, many hemophiliacs for whom tattooing should be contraindicated at present could easily find themselves in a different situation in the years to come. Even then, though, things will be tricky. Giving the patient their own ability to produce clotting factor through gene therapy also means aiming to increase the levels of clotting factor in the blood. Overshooting this target level would replace a condition that causes too much bleeding with a condition in which the person clots too easily. Even when it comes to hemophilia cases cured by gene therapy, the necessity to contraindicate tattooing may come down to each individual case.

Similar reasoning is likely to apply to a plethora of other bleeding disorders. Examples include:

- Glanzmann thrombostemia (a problem with platelet aggregation)
- Bernard-Soulier syndrome (also a platelet abnormality)
- von Willebrand disease (vWD)

Being the most common bleeding disorder—affecting both males and females in roughly equal amounts—vWD could be the most important bleeding diathesis to discuss in connection with tattoos. As with virtually all clotting disorders, vWD is divided into various types and subtypes. Many of the cases are what's called **type 1 vWD**, which can be mild, but also is notorious for striking in particular circumstances. It is not uncommon for women with type 1 vWD to feel the effects in the form of **menorrhagia**, for instance (excessive menstrual bleeding, or an exceptionally long duration of their menstrual period), or to be diagnosed with vWD, only after frequent

menorrhagia triggers a hematological workup to investigate the cause of the bleeding. Similarly, with both genders, a dental procedure could lead to the discovery of the disease. Consequently, a tattoo procedure could just as easily be the event that causes unanticipated excessive bleeding in an individual who, up to that point, had not known that they suffered from a bleeding diathesis.

Blood Thinning Medications

Apart from bleeding conditions, one can also become prone to bleeding on account of medications that are given to thin the blood on purpose. These are often used to treat blood clots or the tendency to clot, or to help to prevent clots in conditions that can trigger them, such as atrial fibrillation. Blood thinning medications given on a long-term basis include Warfarin, Eliquis, Plavix, Aspirin, and a range of newer drugs. Medications given against clots for rapid action and for shorter-term issues include various types of heparin, as well as thrombolytic (clot busting) agents like streptokinase, r-tPA, and urokinase. Consumption of alcohol also interferes with clotting, thereby making the individual bleed more easily.

Although this chapter is presented merely as a conversation starter for the eventual development of clinical guidelines, it seems reasonable that tattoo procedures should be absolutely contraindicated in those who are on long-term blood thinning therapy, whereas people who are taking anti-clot medication on a short-term basis should be directed to wait until their status has returned to normal. Alternatively, a professional group directed to develop guidelines might also set limits based on laboratory values for relevant tests—such as aPTT or INR—depending on the drug in question.

Anemia

Anemia is not a disease per se, but an inadequacy of healthy **red blood cells (RBCs)**, resulting from some underlying cause (fig. 26). Types of anemia include:

- iron deficiency anemia (very common, particularly in females)
- anemia due to various vitamin deficiencies
- anemia due to cancer
- anemia of chronic disease
- aplastic anemia, which occurs when stem cells in bone marrow are

damaged and don't make enough RBCs

Genetic conditions causing or manifesting anemia include:

- thalassemia (either the alpha or the beta chain of hemoglobin is abnormal, or is produced in inadequate amounts)
- sickle cell disease (SCD)
- hereditary spherocytosis
- Fanconi anemia

Apart from other aspects of a person's disease that could contraindicate tattooing, the main relevant issue with anemia is the possibility of blood loss. The ability of the person to receive a tattoo safely depends on the level severity of the anemia and the degree of success of the treatment they are receiving.

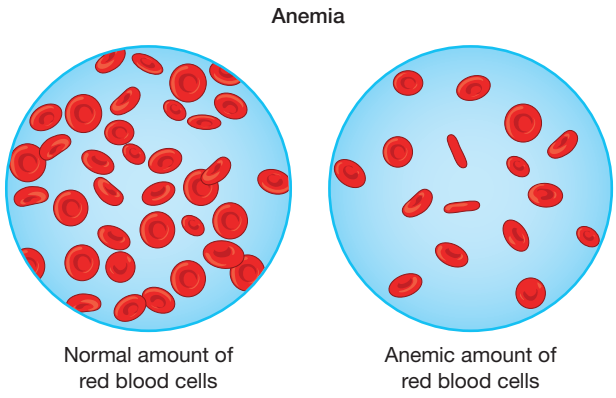


Figure 26: One parameter that defines anemia is the number of red blood cells (RBCs) per unit volume of blood. However, other parameters, such as RBC size and amount of color versus paleness also factor into play.

Infectious Conditions & Immunosuppression

Clinical guideline development projects may encounter a dilemma when it comes to infectious diseases. On the one hand, tattoo artists in most North American states and provinces are required to employ universal precautions and undergo blood borne pathogen training. On the other hand, the prospect of patients with potentially life-threatening viruses present in the body getting procedures that are not medically necessary always raises concern.

When an individual has a chronic infectious disease—such as HIV, hepatitis B (HBV), or hepatitis C (HCV)—tattoo artists require the individual to consult with a physician before undergoing a tattoo procedure. If cleared for the procedure, the tattoo artist agrees to it and uses universal precautions. A guideline development group commissioned to address tattooing must decide whether it is acceptable to leave such cases to the discretion of primary health care providers, whether

to require that the tattoo candidate be assessed by a board-certified infectious disease specialist, or whether to list particular parameters for clearance of such individuals, such as CD4 count and amount of time symptom-free. Discussions also must consider the fact that a significant number of people carrying such infections do not know about their infection, raising the question of whether every tattoo candidate should be required to undergo screening for HIV and hepatitis viral antigens.

Things are much clearer regarding infections that the body easily heals. Whereas somebody with an active hepatitis A (HAV) infection certainly should not get a tattoo—as this virus produces a self-limiting infection that a person with a healthy immune system fights off—the mere history of an HAV infection is not likely to be chosen as a contraindication for a tattoo procedure.

As noted in the Adverse Effects of Tattooing chapter, there is concern that a tattoo procedure might trigger a latent herpes simplex virus (HSV) infection to an active HSV infection (Begolli Gerqari et al. 2018). Consequently, in the development of guidelines on tattoo contraindications, HSV status should be discussed, along with human papilloma virus (HPV), cytomegalovirus (CMV), Epstein-Barr virus (EBV), and Zika virus.

Given reports of various bacterial infections emerging as tattoo complications (Serup et al. 2015), a contraindications guideline development should consider histories of infection with *Mycobacterium* (Serup et al. 2015) and necrotizing *Streptococcus* and *Staphylococcus* (fig. 13).

Given the risks of infection as a complication of a tattoo procedure, any workshop or panel on tattoo contraindications should consider contraindicating tattoo procedures for those who are immunocompromised, due to hereditary or acquired conditions, or due to therapy with immunosuppressive medications.

Skin & Autoimmune Conditions

Both skin and autoimmune conditions were discussed as tattoo complications in the previous chapter. Here, the subject is broached merely to point out that all such conditions need to be at center stage in a discussion regarding tattoo contraindications. When considering diseases that manifest with skin changes and that are systemic, a tattoo procedure

is one of many skin-traumatizing events that can potentially trigger the Koebner phenomenon. This is when an otherwise unaffected region of skin develops the characteristic features of the disease stimulated by trauma of that region (Kluger et al. 2017; Serup et al. 2015). For instance, if an individual with a history of psoriasis receives a tattoo in a previously unaffected area of skin and then has a psoriatic outbreak at the tattoo site, this would be an example of the Koebner phenomenon (Serup at al. 2015).

The Koebner phenomenon has been reported in settings of tattoo procedures on individuals with:

- vitiligo
- lichen planus
- lichen sclerosus
- lichen atrophicus
- psoriasis
- Darier disease

All of these must be on the list for considering the contraindication of tattoo procedures.

Darier disease features wart-like, generally yellowish lesions on the skin, particularly on the forehead and scalp, as well as behind the ears and the torso and extremities. **Lichen sclerosus** and **lichen atrophicus** (*lichen sclerosus et atrophicus*) lesions appear as areas of white, patchy, thin skin. Although lichen sclerosis and atrophicus occur most often in the genital and anal region, these conditions have also been reported on tattoos (Serup et al. 2015).

Various other skin conditions, as well as systemic diseases with skin manifestations, also warrant discussion. These include:

- sarcoidosis (an autoimmune disease)
- discoid lupus and subacute lupus
- cutaneous vasculitis
- granuloma anulare
- necrobiosis lipiodica
- perforating collagenosis
- morphea
- pyoderma gangrenosum (Serup et al. 2015)

In certain other skin pathology settings —such as **keloids** (raised scars)—the rationale for contraindicating tattoos is not very strong (Serup et al. 2015). This is

also true for **atopic dermatitis (eczema)**. While this chronic condition should be discussed, the case for allowing tattoo procedures on areas of the body where the dermatitis has never occurred is quite sound.

Similarly, for people with a history of allergic contact dermatitis, if a region of skin is clear, there is little reason to avoid tattooing the area—unless the individual is known to be allergic to a particular agent that will be used on or injected into the tattoo site.

History of an allergic reaction to a tattoo is a good reason for contraindicating a tattoo procedure. If it is known that the reaction was to a particular ink component—such as red pigment—then the contraindication need apply only to that component.

Pregnancy, Lactation, & Menstruation

In many locations, women who are pregnant or breastfeeding are unlikely to request a tattoo, although a European researcher has reported some cases of pregnant and breastfeeding women insisting on tattoo procedures (Serup et al. 2015). Although there are no known fetal and neonatal complications of maternal tattoo procedures, there is also very little data published on this matter, perhaps because it is rare for women to get tattooed during pregnancy and lactation. To be sure, although women are asked about their pregnancy status on medical screening forms at tattoo parlors, many women receive tattoos before knowing that they are pregnant. It would be quite challenging to design a prospective study investigating whether tattoo procedures early in pregnancy cause harm, that is both informative and ethical.

Menstruation is not likely to be considered a reason for contraindication of a tattoo procedure, unless the woman suffers from high blood loss due to excessive bleeding or menstruation for a very long period (menorrhagia).

Alcohol & other Drugs

A high blood alcohol content can inhibit a successful tattoo endeavor. Alcohol can temporarily thin an individual's blood, decreasing clotting ability. Additionally, alcohol impairs judgment and may interfere with the ability to make a conscientious decision for a permanent alteration of appearance. Alcohol can also hamper the body's ability to heal and

alcoholics are prone to infection. Alcohol, when abused over long periods of time, can lead to liver disease and nutritional deficiencies. These, in turn, can lead to a variety of complications that could contraindicate tattoo procedures.

Similarly, tobacco can lead to cardiovascular and pulmonary conditions that can also comprise settings where contraindication of tattoo procedures may be warranted. Smoking can contribute to Buerger's disease, in which blood vessels constrict, which reduces blood flow and slows or hampers the ability of infection fighting blood cells to reach injured tissue. Like smoking and alcohol, heavy drug use affects the decision process and can affect the body's ability to properly heal and is, therefore, a contraindication.

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