The first homeostatic mechanism that we will examine is thermoregulation, the process by which animals maintain and internal temperature within a tolerable range. Each species of animal has an optimal temperature range. Thermoregulation helps keep body temperature within that range, enabling cells to function optimally even when the external temperature fluctuates.

Internal metabolism and the external environment provide the sources of heat for thermoregulation. Most birds and mammals are ENDOTHERMS, meaning that they are warmed mostly by heat generated by their own metabolism. In contrast, most amphibians, lizards, many fishes, and most invertebrates are ECTOTHERMS, meaning that they gain most of their heat from external sources. Keep in mind, though, that endothermic and ectothermic modes of thermoregulation are not mutually exclusive.
An animal can exchange heat with the environment by four physical processes. CONDUCTION is the transfer of thermal motion (heat) between molecules of objects that are in direct contact, as when an animal is physically touching an object in its environment. Heat is always transferred from an object of higher temperature to one of lower temperature.

CONVECTION is the transfer of heat by the movement of air or liquid past a surface. RADIATION is the emission of electromagnetic waves. Radiation can transfer heat between objects that are not in direct contact, as when an animal absorbs heat radiating from the sun.

EVAPORATION is the loss of heat from the surface of a liquid that is losing some of its molecules as a gas. A lizard loses heat as moisture evaporates from its nostrils.
Thermoregulation involves adaptations that balance heat gain and loss

- Metabolic heat production
- Insulation
- Circulatory adaptations

**METABOLIC HEAT PRODUCTION:**
In cold weather, hormonal changes tend to boost the metabolic rate of birds and mammals, increasing their heat production. Simply moving around more or shivering also produces heat as a metabolic by-product of the contraction of skeletal muscles.

**INSULATION:**
Adaptation in mammals and birds is insulation—hair (often called fur), feathers, or fat layers. Most land mammals and birds react to cold by raising their fur or feathers, which traps a thicker layer of air next to the warm skin, improving insulation. Aquatic mammals and aquatic birds are insulated by a thick layer of fat called BLUBBER.

**CIRCULATORY ADAPTATIONS:**
In COUNTERCURRENT HEAT EXCHANGE, warm and cold blood flow in opposite (countercurrent) directions in two adjacent blood vessels.

**EVAPORATIVE COOLING:**
Some animals have adaptations that greatly increase evaporative cooling, such as panting, sweating, or even spreading saliva on body surfaces.

**BEHAVIORAL COOLING:**
Both endotherms and ectotherms control body temperature through behavioral responses. Some birds and butterflies migrate, other animals such as desert lizards, bask in the sun when it is cold and find cool, damp areas or burrows when it is hot.
Osmoregulation: Involves balancing the uptake and loss of water and solutes, such as salt (NaCl) and other ions. Osmoregulation is based largely on regulating solutes because water follows the movement of solutes by osmosis. (Recall that osmosis is a net movement of water across a selectively permeable membrane from a solution with lower solute concentration to a solution with higher solute concentration.) Some sea-dwelling animals such as most marine invertebrates have body fluids with a solute concentration equal to that of seawater. Called osmoconformers, such animals do not undergo a net gain or loss of water. Osmoregulators, such as freshwater animals, land animals, and marine vertebrates have body fluids whose solute concentration differs from that of their environment. Therefore, they must regulate water loss or gain. A freshwater fish maintains water and solute balance by food that helps supply ions, and its gills actively take up salt. The fish’s kidneys produce large amounts of urine, the waste material produced by its urinary system. By excreting dilute urine, the fish disposes of excess water and conserves solutes.
Metabolism produces a number of toxic by-products, such as the nitrogenous (nitrogen-containing) wastes that result from the breakdown of proteins and nucleic acids. An animal deposes these metabolic wastes through the process of excretion, the third and final homeostatic control mechanism. Most aquatic animals dispose of their nitrogenous wastes as AMMONIA. Among the most toxic of all metabolic by-products, ammonia (NH₃) is formed when amino groups (-NH₂) are removed from amino acids and nucleic acids. Ammonia is too toxic to store in the body, but it is highly soluble in water and diffuses rapidly across cell membranes. If an animal is surrounded by water, ammonia readily diffuses out of its cell and body.

Ammonia excretion does not work well for land animals. Land animals convert ammonia into less toxic compounds, either urea or uric acid, that can be safely transported and stored in the body and released periodically by the urinary system. The disadvantage of excreting urea or uric acid is that the animal must use energy to produce these compounds from ammonia. Mammals, most amphibians, sharks, and some bony fishes excrete UREA. Urea is produced in the vertebrate liver by a metabolic cycle that combines ammonia with carbon dioxide. Urea is highly soluble in water and it is also 100,000 times less toxic than ammonia, so it can be held in a concentrated solution in the body and disposed of with relatively little water loss.

Land animals that excrete URIC ACID (birds and many other reptiles, insects, land snails, and few amphibians living in deserts) avoid the water loss problems almost completely.
The URINARY SYSTEM plays a central role in homeostasis, forming and excreting urine while regulating the amount of water and ions in the body fluids. In humans, the main processing centers of the urinary system are the two kidneys. From this enormous traffic of blood, our kidneys extract a fluid called FILTRATE, consisting of water, urea, and a number of valuable solutes, including glucose, amino acids, ions, and vitamins. Blood to be filtered enters each kidney via a renal artery: blood that has been filtered leaves the kidney in the renal vein. Urine leaves each kidney through a duct called a URETER and passes into the URINARY BLADDER. Periodically, the bladder empties during urination. Urine leaves the body through a tube called the URETHRA, which empties near the female vagina or through the male penis. The kidney has two main regions, the RENAL CORTEX (outer layer) and the RENAL MEDULLA (inner region). From the medulla, urine flows into a chamber called the renal pelvis, and from there into the ureter. Each kidney contains about a million tiny functional units called NEPHRONS. A nephron consists of a tubule and its associated blood vessels. Performing the kidney’s functions in miniature, the nephron extracts a tiny amount of filtrate from the blood and then refines the filtrate into a much smaller quantity of urine. The receiving end of the nephron is a cup-shaped swelling, called BOWMAN’S CAPSULE. At the other end of the nephron is the COLLECTING DUCT, which carries urine to the renal pelvis. Bowman’s capsule envelopes a ball of capillaries called the GLOMERULUS. The glomerulus and Bowman’s capsule make up the blood-filtering unit of the nephron. Here, blood pressure forces water and solutes from the blood in the glomerular capillaries across the wall of Bowman’s capsule and into the nephron tubule. The rest of the nephron refines the filtrate.

The tubule has three sections:
1.) The PROXIMAL TUBULE
2.) The LOOP OF HENLE, a hairpin loop carrying filtrate toward- and in some cases, into- the medulla and then back toward the cortex.
3.) The DISTAL TUBULE (called distal because it is the most distant from Bowman’s capsule).
Our urinary system produces and disposes of urine in four major processes. First of all, during FILTRATION, water and virtually all other molecules small enough to be forced through the capillary wall enter the nephron tubule from the glomerulus. Two process then refine the filtrate. In REABSORPTION, water and valuable solutes, including glucose, salt, other ions, and amino acids, are returned to the blood from the filtrate. In SECRETION, substances in the blood are transported into the filtrate. Finally, in EXCRETION, urine - the product of filtration, reabsorption, and secretion - passes from the kidneys to the outside via the ureters, urinary bladder, and urethra.
1.) The proximal tubule actively transports nutrients such as glucose and amino acids from the filtrate into the interstitial fluid to be reabsorbed into the capillaries. NaCl (salt) is reabsorbed from both the proximal and distal tubule. As NaCl is transported from the filtrate to the interstitial fluid, water follows by osmosis.

The loop of Henle and the collecting duct have one major function: water reabsorption.

2.) The long loop of Henle in the figure carries the filtrate deep into the medulla and then back to the cortex. The presence of NaCl and some urea in the interstitial fluid maintains the high concentration gradient in the medulla, which in turn increases water reabsorption by osmosis. Just after the filtrate rounds the hairpin turn in the loop of Henle, water reabsorption stops because the tubule there is impermeable to water. But as the filtrate moves up to the cortex, NaCl leaves the filtrate, first passively and then actively as the cells of the tubule pump NaCl into the interstitial fluid.

3.) Final refining of the filtrate occurs in the collecting duct. By actively reabsorbing NaCl, the collecting duct is important in determining how much salt is excreted in the urine. Our kidneys also maintain a precise balance between water and solutes in our body fluids. When the solute concentration rises above a set point, a control center in the brain increases the blood level of ANTIDIURETIC HORMONE (ADH), which signals the nephrons to step up water reabsorption.
A person can survive with only one functioning kidney, but if both kidneys fail, the buildup of toxic waste and the lack of regulation of blood pressure, pH, and ion concentrations will lead to certain death if untreated. Knowing how the nephron works helps us understand how some of its functions can be performed artificially when the kidneys are damaged. DIALYSIS means “separation” in greek. Like the nephrons of the kidney, the machine sorts small molecules of the blood, keeping some and discarding the others. The patient’s blood is pumped from an artery through a series of tubes made of a selectively permeable membrane. As the blood circulates through the tubing, urea and excess ions diffuse out. Needed substances, such as bicarbonate ions, diffuse from the dialyzing solution into the blood. The machine continually discards the used dialyzing solution as wastes build up.