

on where the animal exists and can range in frequency from seconds to decades. Birds and small mammals use temperature and length of daylight to predict the most optimal time to breed and raise young. Chickens require a certain amount of time exposed to sunlight to produce eggs. Animals that live in the water can use lunar rhythms where they coordinate their behavior based on the phases of the tides controlled by the Moon. Regardless of the length of the rhythm, there are internal mechanisms that regulate cyclical behaviors that maintain the life of the animal.

The Biology of the Internal Clock

The study of biological rhythms is called **chronobiology**. In the 1950s, scientists began studying how animals can determine when to sleep and when to wake up using the model organism *Drosophila* (fruit fly). Fruit flies are prolific breeders and have a short lifespan of about a month, making them easy to breed in laboratory conditions in a short period of time. The ability to breed many generations of animals allows for mutations to occur naturally, enabling researchers to compare differences in behavior. Scientists selected flies that expressed unusual behavior of either sleeping longer or less often than the others and hypothesized that there were differences in their genetics.

By examining their genetic code and comparing it to fruit flies with normal biological rhythms, researchers found several genes that regulate the passage of time. Although fruit flies are much different from mammals, they share a common ancestor with all animals. Further research found that all animals have similar genes that control their circadian rhythm. Early circadian clock genes included period (*per*) in fruit flies and frequency (*frq*) in *Neurospora crassa*; these produce the proteins PER and FRQ, respectively. In mammals, the similar group of genes regulating circadian rhythms are called clock genes.

The biological clock within animals works in virtually the same way in all species. Within the cell, there is a buildup of a protein that increases as the day goes on. The cell then uses feedback to determine if the protein has reached the upper limit threshold or if the cell should continue to produce the protein. Once the cell has made enough of the protein, it halts all production of the protein. Eventually, the cell triggers the production of the protein again when the levels become too low. This cycle occurs within the cell every twenty-four hours, constituting the circadian rhythm.

While every cell in the body maintains the daily rhythm, for animals more complex rhythms need to be maintained. All animals have a central brain region or cluster of neurons that coordinates the sensory information, the circadian rhythm, and all the tissue in the body. In vertebrate animals, there is a small part of the brain called the **suprachiasmatic nucleus** or SCN that acts as the master timekeeper. The SCN is located next to the midbrain in the anterior hypothalamus. The midbrain contains the most basic functions needed to survive that are common to all vertebrate animals.

The SCN is critical to determining more complex passages of time. The SCN uses the visual system to synchronize its rhythm and determine when the start and end of the day occur. Animals without sight who live primarily underground can rely on other cues such as temperature or specialized light-detecting cells to reset their biological rhythm as needed. An external cue that allows an animal to detect and regulate its biological rhythm is called a **zeitgeber**—a German term that translates literally as “time giver.” A zeitgeber allows animals to reset or train their biological clock to match the current environment (Figure 26).