In the movie *2001: A Space Odyssey*, astronauts were put in a state of suspended animation.

Interest in this idea has resulted in **cryonics**—preservation of bodies by freezing, in hopes they can be brought back to life in the future.

Farfetched? Organisms such as frogs can survive winter in a **completely frozen state**.

Although frogs first evolved in tropical biomes, two species live in the Arctic tundra.

They overwinter in shallow burrows, in a **semi-frozen state**, with **no heartbeat**, **no blood circulation**, and **no breathing**.

Few vertebrates can withstand freezing.

In most organisms, freezing results in **tissue damage** as **ice crystals** perforate cell membranes and organelles.
Organisms have two options for coping with environmental variation: Tolerance and avoidance.

Spruce trees in the boreal forest can not avoid temperature extremes, and so must be able to tolerate air temperatures that drop below –50°C in winter, and reach 30°C in summer.

Concept 4.1: Each species has a range of environmental tolerances that determines its potential geographic distribution.

A species’ climate envelope is the range of condition over which it occurs. It is a useful tool for predicting its response to climate change.
Example: At high altitudes, lower partial pressure of oxygen in the atmosphere results in hypoxia—not enough oxygen is delivered to your tissues.

Hypoxia causes “altitude sickness,” which is physiological stress.

Many organisms can adjust to stress through behavior or physiology—called acclimatization. It is usually a short-term, reversible process. Acclimatization to high elevations involves higher breathing rates, greater production of red blood cells, and higher pulmonary blood pressure.

Over time, natural selection can result in adaptation to environmental stress. Individuals with traits that make them best able to cope with stress are favored. Over time, these unique, genetically-based solutions become more frequent in the population.

Adaptation is similar to acclimatization but it is the long-term, genetic response of a population to environmental stress that increases its survival and reproductive success.
Populations with adaptations to unique environments are called **ecotypes**.

Ecotypes can eventually become separate species as populations diverge and eventually become reproductively isolated.

An example of adaptation: Humans have lived in the Andes Mountains for 10,000 years.

When the Spanish first settled there in the sixteenth and seventeenth centuries, their birth rates were low for 2–3 generations, probably due to poor oxygen supply to developing fetuses.

The indigenous Andean populations were adapted to the low-oxygen conditions by having higher red blood cell production and greater lung capacity.

Adaptations can vary among populations.

Populations at high elevations in Tibet and Ethiopia have different adaptations. Tibetans don’t have higher blood cell counts, but do have faster breathing rates. Ethiopians don’t have higher cell counts, but have higher blood oxygen levels.

**Concept 4.2:** The temperature of organisms is determined by exchanges of energy with the external environment.
Variation in Temperature

Some organisms can survive periods of extreme heat or cold by entering a state of dormancy, in which little or no metabolic activity occurs.

Bacteria in hot springs have enzymes that are stable up to 100°C. Antarctic fish and crustaceans must have enzymes that function at –2°C; and soil microbes are active at temperatures as low as –5°C.

Variation in Temperature

Temperature also affects water availability.

The rate at which terrestrial organisms lose water from their bodies is related to air temperature.

Variation in Temperature

Temperature change in a plant can be expressed by the following equation.

$$\Delta H_{plant} = SR + IR_{in} - IR_{out} \pm H_{conv} \pm H_{cond} - H_{et}$$

SR = Solar radiation
IR = Infrared radiation
$H_{conv}$ = Convective heat transfer
$H_{cond}$ = Conductive heat transfer
$H_{et}$ = Heat transfer by evapotranspiration

Plants can adjust energy inputs and outputs. Transpiration rates can be controlled by specialized guard cells surrounding a pore, called a stomate.

Variation in the size of the opening and number of stomates control the rate of transpiration and thus control leaf temperature.
If soil water is limited, transpirational cooling is not a good mechanism.

Some plants shed their leaves during dry seasons.

Other mechanisms include **pubescence**—hairs on leaf surfaces that reflect solar energy. But hairs also reduce conductive heat loss.

Pubescence has been studied in *Encelia* (plants in the daisy family) (Ehleringer and Cook 1990).

Desert species with high pubescence were compared with non-pubescent species in moister, cooler environments.

Plants of all species were grown in both locations.

In the cool, moist location, the three *Encelia* species showed few differences in leaf temperature and stomatal opening.

In the desert, the species with no hairs maintained leaf temperature by transpiration; the pubescent species leaves reflected about twice as much solar radiation.
Natural selection has acted on populations (ecotypes) of *E. farinosa*. In drier environments, leaves had more pubescence, and absorbed less solar radiation than populations from moister environments (Sandquist and Ehleringer 2003).

If air temperature is lower than leaf temperature, heat can be lost by convection, dependent on speed of air moving across the leaf surface. Moving air encounters more resistance close to the surface of an object; the flow becomes more turbulent, forming eddies. The zone of turbulent flow is the boundary layer.

The boundary layer lowers convective heat loss. The thickness of the boundary layer on a leaf is related to its size and its surface roughness. Small, smooth leaves have thin boundary layers and lose heat more effectively than large or rough leaves.

Animals, especially birds and mammals, can generate heat internally. The energy balance equation for animals is shown below.

\[ \Delta H_{\text{animal}} = SR + IR_{\text{in}} - IR_{\text{out}} \pm H_{\text{conv}} \pm H_{\text{cond}} - H_{\text{evap}} + H_{\text{met}} \]

*H*$_{\text{evap}}$ = Heat transfer by evaporation

*H*$_{\text{met}}$ = Metabolic heat generation
Variation in Temperature

**Ectotherms**: Primarily regulate body temperature through energy exchange with the external environment.

**Endotherms**: Rely primarily on internal heat generation, mostly birds and mammals.

Some other organisms that generate heat internally include **bees**, some fish, such as **tuna**, and even some **plants**.

**Skunk cabbage** (臭菘) warms its flowers using metabolically generated heat during the spring.

Variation in Temperature

*Fig. 4.13 Internal Heat Generation as a Defense*

Ectotherms generally have a higher tolerance for temperature variation than do endotherms.

In exchanging heat with the environment, the surface area-to-volume ratio of the body is a factor.

Variation in Temperature

Larger surface area allows greater heat exchange, but makes it harder to maintain internal temperature.

A smaller surface area relative to volume decreases the animal’s ability to gain or lose heat.

As body size increases, surface area-to-volume ratio decreases, and large ectotherms are thus improbable.

This had led to speculation that large **dinosaurs** may have had some degree of endothermy.
Variation in Temperature

Many terrestrial ectotherms can move to adjust temperature. Many insects and reptiles bask in the sun to warm up after a cold night. Because this increases risk from predators, many are also camouflaged.

Variation in Temperature

Endotherms can remain active at subfreezing temperatures. The cost of being endothermic is a high demand for energy (food) to support metabolic heat production.

Variation in Temperature

Metabolic rate in endotherms is associated with the external temperature and rate of heat loss. Rate of heat loss is related to body size due to surface area-to-volume ratio. Small endotherms have higher metabolic rates, and require more energy and higher feeding rates than large endotherms.
Variation in Temperature

**Thermoneutral zone**—constant resting metabolic rate over a range of environmental temperatures.

**Lower critical temperature**—when heat loss is greater than metabolic production; body temperature drops and metabolic heat generation increases.

Small endotherms have high demand for metabolic energy below the lower critical temperature, low insulation values of their fur, and low capacity to store energy.

How can they survive in cold climates?

By altering the lower critical temperature by entering a state of dormancy known as **torpor** (冬眠).

Variation in Water Availability

**Concept 4.3:** The water balance of organisms is determined by exchanges of water and solutes with the external environment.
Variation in Water Availability

In variable environments cells must alter their osmotic potential to maintain water balance—osmotic adjustment.

Solute concentration in a cell can be increased by synthesizing solutes, or by taking up inorganic salts.

Not all microorganisms can do this; some can adjust to extreme saline conditions.

Variation in Water Availability

Plants have rigid cell walls of cellulose, fungi have cell walls of chitin, and bacteria have cell walls of peptidoglycan (肽聚醣).

Cell walls allow development of turgor pressure—when water moves into a cell, the expanding cell presses against the cell wall.

Variation in Water Availability

Terrestrial plants take up water through their roots, and by beneficial fungi called mycorrhizae (菌根菌).

Older, thicker roots have a waxy cuticle that limits water uptake.

Mycorrhizae (菌根菌) provide greater surface area for absorption of water and nutrients, and allow exploration for these resources. The fungi get energy from the plant.
Variation in Water Availability

For aquatic animals, the water can be:

- **Hyperosmotic**—more saline than the animal’s cells.
- **Hypoosmotic**—less saline than the animal’s cells.
- **Isoosmotic**—have the same solute concentration as the animal’s cells.

Marine animals tend to be isoosmotic to seawater.

Invertebrates capable of osmotic adjustment do so by exchanging solutes with the environment.

For example, jellyfish have Na⁺ and Cl⁻ concentrations similar to seawater, but their SO₄²⁻ concentrations may be one-half to one-fourth that of seawater.
Variation in Water Availability

In marine cartilaginous fishes (e.g., sharks and rays) the blood is isoosmotic to seawater.

Marine bony fishes evolved in freshwater and their blood is hypoosmotic to seawater.

Fish exchange salts across the gills, and by eating and drinking.

Salts that enter bony fishes must be continually excreted through urine or across the gills, against an osmotic gradient (requires energy). Water is replaced by drinking.

Marine mammals do not drink seawater, and produce urine that is hyperosmotic to seawater.

Freshwater animals are hyperosmotic to the water—they tend to gain water and lose salts from the skin or respiratory surfaces.

Solute are taken up in food or across gills, against the osmotic gradient.

Excess water is excreted as dilute urine.

<table>
<thead>
<tr>
<th>TABLE 4.1</th>
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<tbody>
<tr>
<td><strong>Tolerances for Water Loss in Selected Animal Groups</strong></td>
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<tr>
<td>Group</td>
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<tr>
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</tr>
<tr>
<td><strong>INVERTEBRATES</strong></td>
</tr>
<tr>
<td>Molluscs</td>
</tr>
<tr>
<td>Crabs</td>
</tr>
<tr>
<td>Insects</td>
</tr>
<tr>
<td><strong>VERTEBRATES</strong></td>
</tr>
<tr>
<td>Frogs</td>
</tr>
<tr>
<td>Small birds</td>
</tr>
<tr>
<td>Rodents</td>
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<tr>
<td>Human</td>
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<td>Cane</td>
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Source: Wingate et al. 2005. Note: Values are maximum percentages of body weight lost as water that can be tolerated, from a range of exemplary species in each group.
Three problems must be overcome for an organism to withstand freezing:

- Water forms needle-like ice crystals that can pierce cell membranes.
- Oxygen supply to tissues is restricted due to lack of breathing and circulation.
- When ice forms, it pulls water from cells.

In animals that withstand freezing, the freezing water is limited to the space outside the cells.

Ice-nucleating proteins (冰核活性蛋白) outside cells serve as sites of slow, controlled ice formation.

Additional solutes, such as glucose and glycerol inside cells lower the freezing point.

Winter burrows covered with layers of leaves and snow keep temperatures above −5°C (the lower limit for their survival).

Freezing occurs over several days to weeks, but thawing can be rapid.
Arid conditions are a more widespread challenge for organisms. Some tolerate dry conditions by going into suspended animation. Many microorganisms do this, as do some multicellular organisms.

As cells dry out, the organisms synthesize sugars that form a glassy coating over the cellular constituents. When moisture returns, metabolic functions are regained rapidly.