National Aquarium AS 3.4 Homeostasis

Thermoregulation

Classroom Resource

Note to teachers: This resource is compiled with questions that will be covered at the National Aquarium, or will be relevant to the program. It consists of ideas rather than fixed activities, as the questions could be used in many ways. For example, as a group activity, worksheet questions or as an end of lesson question to consolidate what has been covered.

AS 3.4 is concerned with demonstrating 'understanding of how an animal maintains a stable internal environment' so is focused purely on physiology, rather than the broader effects of homeostasis. Most of the questions in this resource have been written with this in mind. However, a few were written to appeal to advanced study, with the emphases on how homeostasis affects the environment and an animal's behaviour. These questions have been included to tie in homeostasis with other biology or ecology units you may be running throughout the school year. Such questions will be clearly labelled. Some questions have concise answers and longer answers for concentrated study.

Many of these questions are relatively easy and have short answers. Others are much harder with some answers still under debate by science! I hope that all of them help inspire your students about homeostasis, and how it is part of the bigger picture of life on Earth!

Starter Analogies

This analogy is a useful way of introducing the concept of endothermy and ectothermy to students who have not studied it for a while.

Ask students to think of a bus, but imagine that the air conditioning system has stopped working. We are going to pretend that this bus is an animal, and all of the passengers inside it are muscles. When animals move their muscles, heat is created

through friction, giving the animal some warmth. Whether this heat is harnessed or not depends on the thermoregulation system of the animal.

Back to the bus! Say the driver sets the ventilation system so that air from outside the bus blows in the cabin. If the temperature outside is cold, the inside is cold. If the temperature is warm, the inside is warm. The movement of the muscles (passengers) have little effect. This is exothermic, known as cold blooded.

Now, let's say our driver sets the ventilation system so air inside the bus is recirculated back inside the cabin. Soon, all the heat from the muscles (passengers) heats up the inside of the bus regardless of the temperature outside! This is endothermy, or warm bloodedness.

However, sometimes the temperature outside is so extreme the warm blooded animal feels uncomfortable. Endothermic animals like ourselves can cool ourselves down by sweating (opening a window on the bus) or can keep ourselves warm by shivering (passengers/muscles move about to create more heat). The aim for the human body is to keep the body running at more or less the same temperature. We call this homoeothermic. Our ideal temperature is about 37 degrees Celsius.

This next analogy explains homeostasis by likening it to how a fridge keeps a stable temperature.

Fridge Analogy- Homeostasis

For a fridge to work effectively, it must keep a stable internal temperature

(homeothermic).

A fridge is also well insulated, to keep an internal temperature that is greatly different from the surrounding environment.

However, let's say someone opens the door.

Suddenly, the inside of the fridge heats up with warm air, forcing the temperature away from a homeostatic balance (homeostatic imbalance). Therefore it tries to reverse the rise in temperature (negative feedback) by cooling itself down using cold air from the vents (corrective mechanism). If the door is opened for too long, the temperature will increase beyond control, and the milk will be ruined (homeostatic breakdown).

Tricky Terms

A common mistake made concerns the difference between ectothermic/endothermic and poikilothermic/homoeothermic. Ectothermic and endothermic describe the source of the heat. (For ectotherms this source is external, in endotherms it is internal) while poikilothermic and homoeothermic describe the internal stability of the body temperature. So, it is possible to have an ectotherm who is not poikilothermic, and an endotherm who is not homeothermic!

Level Eight Science Living World

Understand the relationship between organisms and their environment

Why do camels have humps?

(Clues: They live in a hot climate. There is not a lot of food around)

Answer: The short answer is to store energy in the form of fat. How this relates to homeostasis requires a longer answer. Out in the desert there is not a lot of food around, and a camel has to eat, and store, whatever food it comes by. However, storing a lot of fat around your body in a desert is like wearing a thermal jumper on a hot summer's day: you would induce hyperthermia very quickly. The camel stores this fat in an extremity (in this case, a hump) where it has little effect on the core body temperature. The hump has a high amount of surface area, so heat is lost quickly.

Why are animals so large in cold climates?

(Clues: Where do we all lose a lot of heat? Clue: Think surface area)

Animals living in colder climates tend to be very large. Think of polar bears and orca.


The reason for this is that by being large, they have relatively little surface area in relation to their size. This means there is little area for heat to escape, helping these animals to maintain their core body temperature without having a stressfully high metabolism.

Why aren't there many ectothermic land animals in Antarctica?

(Clue: It is very, very cold.)

Short Answer: Antarctica would be so cold, ectothermic animals would hardly be able to move.

Long Answer: 'Cold bloodedness', known as ectothermy, is a perfect adaptation for many animals. Less food needs to be found as the body conditions do not need to be stabilised, all you need is a bit of heat. However, ectothermy is near impossible in Antarctica, where temperatures are below freezing for months on end. An animal's warmth is an important factor that controls it's metabolic rate. A warm ectothermic animal, like a lizard, has a high metabolism and is fast. A cold lizard is a slow lizard. A lizard in Antarctica would be so slow it would hardly be able to move to escape predators or find food. So, if the cold doesn't kill it, starvation would, eventually. (The metabolism being so slow means the lizard could go for months without food). The only exception is the Antarctic midge. This 6mm long insect is so small only a little heat is needed to keep it active. During the harsh Antarctic winter, it can withstand it's own blood freezing. It has the distinction of being the only entirely terrestrial (land dwelling) animal in Antarctica. All the rest, like penguins, spend some of their time in water.

How do Little Penguins keep warm?

Short Answer: Insulation using fat and feathers

Long Answer: Little Penguins spend much of their day in water. Without some way of keeping warm, they would have to leave the water very quickly, cutting down the time they have to find food such as fish and squid. So, Little Penguins insulate themselves against the cold. If we want to go out on a cold morning, we wear lots of warm clothing, such as a coat. Penguins have a 'coat' on all the time in the form of feathers (around 10,000 of them) and insulation. The feathers are all aligned in the same direction to keep out the water. There are also many layers of feathers from the tightly packed blue outer feathers to the fluffy feathers close to the skin. All of these feathers are coated with waterproof oil. Penguins also have a lot of body fat to insulate themselves against the cold, as well as the ability to constrict their blood vessels to reduce heat loss (vasoconstriction).

What happens if a Penguin gets too warm?

We all think of penguins as creatures huddling together on the ice, but many live in far warmer climates. The Little Penguin, for example, lives in Australia and right here in New Zealand. It is faced with a dilemma, as it has to withstand cold (sometimes less than 9 degrees) water, and hot temperatures on land as part of it's day to day life. As penguins spend most of the time in water that is where they have adapted to live, so quite often overheat on land. If this occurs, they can…

- *Spread out their flippers*
  This increases their surface area, increasing the amount of heat loss.
- *Expand their blood vessels*
  The warm blood is pushed closer to the surface and flows more freely, maximising heat lost through evaporation. This is called vasodilation.
- *Pant*
  By panting penguins can remove hot air from the body and replace it with cool air.
- *Head back to the sea*
  Little Penguins spend almost all their day at sea, returning to land only at dusk, when it is cooler.
- *Shake to spread out their feathers.* This releases heat trapped between skin and feather, useful while swimming but no so useful on land.

  As birds are covered with feathers, they <u>DO NOT</u> sweat. Penguins do not have this corrective mechanism available to them.

Were Dinosaurs homoeothermic, or poikilothermic? (ADVANCED QUESTION)

Level Eight Science Living World

- Understand the relationship between organisms and their environment
- Explore the evolutionary processes that have resulted in the diversity of life on Earth and appreciate the place and impact of humans within these processes.

(Clues: Think size, diversity and climate.)

This one is a tricky question: No one knows the answer. Until recently, we thought we knew and labelled all dinosaurs as ectotherms. However, the latest evidence sheds doubt on this. The main arguments are:

Size and surface area

Many dinosaurs are large. Think of the massive sauropod dinosaurs like diplodocus, larger than 175 feet (53m). Some scientists argue that an animal that size would take so long to heat using the sun's energy it could hardly move. Others contend that if diplodocus was homoeothermic, it would need to have a painfully slow metabolism; otherwise it would overheat, especially as it lacks extremities like a penguin's flipper to cool down with (corrective mechanism). Yet more evidence for poikilothermy in dinosaurs is that the climate was warmer hundreds of millions of years ago, making it easier for large animals to acquire heat. Also, ectothermic animals with a large surface area do take longer to warm, but they take longer to cool as well, meaning that body temperatures remain nearly stable.

Evolution

The Dinosaurs' closest living relatives are birds, which are (technically) dinosaurs themselves. Birds are homoeothermic endotherms, leading many scientists to believe dinosaurs are endothermic as well. However, their second closest living relatives, and the ones visibly closest to dinosaurs, are the poikilothermic (and ectothermic) crocodiles. However, Dimetrodon (an egg laying animal more closely related to mammals than reptiles) pre-dated the dinosaurs and grew to impressive sizes. Crucially, Dimetrodons showed early temperature regulation (probably heterothermy), the first step towards homeostasis. If Dimetrodon possessed this trait, 50 million years before the dinosaurs, could the dinosaurs have this trait too?

Behaviour

Many experts argue that large dinosaurs would have to have a high body temperature for fast movement. If they were to rely on the outside temperature for thermoregulation, they would be too sluggish to find prey or avoid predators. Others argue that if all dinosaurs slowed down in winter, being sluggish wouldn't matter as

much. Also, herding instincts might help protect smaller herbivores during colder seasons.

This question has been included to demonstrate that there is still a lot to know about thermoregulation. Some questions do not have straightforward answers, some cannot yet be answered at all. There is much to be said over the 'dinosaur debate'.

Here are some websites that explain the arguments in more detail.

http://dinosaurs.about.com/od/dinosaurcontroversies/i/warmblooded.htm

http://www.enchantedlearning.com/subjects/dinosaurs/anatomy/Blood.shtml

Advanced Questions

These questions relate to homeostasis as part of the wider biology of an animal. Although they relate to AS 3.4, they are not directly relevant to the achievement standard criteria.

Why do Antarctic penguins huddle?

They are all trying to minimise their surface area. One penguin would have trouble staying warm all by itself, even with all that insulation. But by huddling with hundreds of others, the surface area around the penguin colony is only that of all the penguins on the outer circle.

One penguin has a lot of surface area compared to thousands in a huddle. To make sure the penguins at the edge of the colony do not freeze, penguins change positions regularly.

Level Eight Science Living World

- **Explore the evolutionary processes that have resulted in the diversity of life on Earth and appreciate the place and impact of humans within these processes.**

The first mammals developed endothermy. How did this help them to survive?

(Clues: First mammals evolved around 210 million years ago. Dinosaurs evolved 230 million years ago. Early mammals were very small.)

Early mammals evolved during the reign of the reptiles. Dinosaurs were the ruling group of animals and our ancient ancestors had to do the best they could to stay out of their way. For most, that meant being very small, and being nocturnal. Being small meant heat is lost very quickly, so endothermy (and later homeothermy) helped them to keep active at night. Around 150 million years ago, mammals had all the features they have today, including hair and homeothermy.

How will Climate Change effect thermoregulation?

(Clue: How would we feel in a warmer world?)

Many scientists predict that our climate will alter substantially over the next hundred years. Almost all of these scientists say our planet will get warmer. How would thermoregulation be affected by this rise?

Ectothermic animals will increase their metabolisms, driven by the higher temperature. Although this will mean they can run faster to evade predators and chase prey, their faster bodies will require more food, putting pressure on resources and the food web. Also, even ectothermic animals have a maximum temperature and if the temperature keeps rising many may die.

The change for homoeothermic animals would be more immediate. Core body temperatures would shift away from homeostatic levels more often, meaning lots of energy would be spent on corrective mechanisms (bringing the body temperature back down to 'normal') so more food would be needed. All homoeothermic animals would undergo a lot of stress as well.

Although natural selection would increase the numbers of animals best suited to withstand these new temperatures, a change in homeostasis would takes millions of years, not hundreds. We can already see the effects on the global ecosystem as animals and bacteria who live in warmer climates now find themselves suited to other areas of

the world that, once colder, are now in their temperature range. On the flipside, animals like polar bears that require cold climates now find their habitat shrinking.

Useful websites to refer to:

http://dinosaurs.about.com/od/otherprehistoriclife/a/earlymammals.htm

http://www.think-bank.com/iwb/flash/homeostasis.html (Great resource for human homeostasis)

http://www.bio.davidson.edu/Courses/anphys/1999/Horak/thermoreg.htm

Osmoregulation

Overview Question

Would you like salt with that?

If you dropped a freshwater carp into the sea would it live? What about if you dropped a saltwater blue cod into the local stream? As for sharks, can they really swim up rivers? If so, how to they tolerate the change in water?

A lot of fishy questions! What everyone can agree on is that freshwater and salt water are different. Objects float more easily in salt water. More oxygen can be held in fresh water. But, what concerns fish is their osmotic balance. Osmosis works to balance the concentration of water on either side of a semi permeable membrane, like fish skin.

Saltwater fish are always losing water to their environment through osmosis. As they lose water they lose salt, threatening their homeostasis. So, saltwater fish drink a lot of water to gain back what they are losing to the surrounding sea. Any excess salt is lost through the gills.

For freshwater fish the problem is the complete opposite. They are always gaining water from their environment. To combat this, they always excrete water, while trapping all the salt they can get.

So, all these fish need to keep their salt content balanced. The ideal amount of salt is between that of freshwater and saltwater. To do this they must always drink or excrete, depending on where they live.

What does all this mean for our carp and cod? Well, if you were to put a cod in freshwater it would 'explode'. Not like in the movies, but it's insides would rupture as it would be gaining water from the environment and be drinking water. If you were to put a carp into the salty sea it would drown. Not only would it be losing water, but it would be excreting it's precious water out of it's body.

There are some fish that can osmoregulate in salt water or fresh. These are called euryhaline fish and include salmon and some eels. These fish survive because of their kidneys rapidly adjusting to the different salinity.

Most sharks don't even osmoregulate at all. They are osmoconformers so don't have to waste energy by balancing their body conditions. However, this means that they cannot survive the same range of water as most fish. Some sharks like the bull shark are euryhaline, and can swim many hundreds of kilometres upstream.

Just when you thought it was safe to go back into the river…..

Salt and Fresh Water

Why is the sea salty?

Answer: An important, but little thought about, question in osmoregulation. Sea salt comes from the weathering of continents (coastal erosion or carried by rivers), underwater volcanoes and underwater vents. Over millions of years the salt concentration has stabilised to what it is today.

Why are rivers not salty?

Answer: This may come as a shock but, freshwater is not entirely fresh. As the water erodes rock, tiny pieces of minerals enter the water. Even rain is not entirely mineral free. However, we cannot taste the minerals because the concentrations are so small. However, think about all the river water flowing into the ocean right now- Amazon, Mississippi, Waikato and your local creek. Combined, these waterways form a major source of salt for the ocean.

What challenges would an animal in a rock pool face regarding osmoregulation?

(Clues: Tides and hot summer days.)

The short answer: When the tide goes out the rock pool is cut off from the sea. When it rains it loses salinity through dilution. If it is a hot day, water evaporates and salinity increases. Most animals cannot tolerate such changes.

The long answer: As far as marine environments go, the rocky shore is one of the harshest on our planet. Even in the deep sea the water is there all the time. Twice a day on the rocky shore, the tide flows and recedes, changing the conditions on the rocky shore. Consider a rock pool, cut off from the sea. If the day is really warm with direct sun, lots of water would evaporate, leaving the salt behind. This increases the salinity, or salt concentration, of the water that is left in the rock pool. This is bad news for many animals who cannot adjust to normally unheard of levels of salt. (A

marine fish, for example, would lose more water to it's environment than it is compensating for by 'drinking'.)

However, now imagine the very same rock pool in a rainstorm. A lot of fresh water would enter the rock pool, causing a decrease in salinity. This means a salt water fish would be drinking too much water, as the fish is losing less to it's environment.

There are many animals affected by this dilemma from fish to sea snails, star fish to crabs. Studying them all shows how fragile life at the rocky shore can be.

What are the advantages of being an osmoregulator?

Answer: They can tolerate a greater range of salinity conditions than osmoconformers. However, they need to use a lot of energy to maintain this balance.

What are the advantages of being an osmoconformer?

Answer: Although they cannot tolerate a wide range of salinity, they use less energy as they don't have to worry about balancing their fluid concentration.

What sorts of animals are osmoconformers?

A range of animals are osmoconformers including sea anemones, jellyfish, sea squrits, and squid. Some animals with backbones are osmoconformers too, namely hagfish and most sharks.

Why can sharks swim up rivers?

Most sharks are osmoconformers, in other words their fluid concentration is the same as the surrounding environment. However, a few sharks can adjust their concentration using their kidneys to survive in a wide range of environments. These sharks are considered osmoregulators by many scientists. One such shark, the bull shark, has been found hundreds of kilometres up rivers.

How has osmoregulation affected evolution? (Very advanced question!)

The short answer: Populations of fish who live in fresh water cannot get to salt water to breed or compete with salt water fish.

The long answer: Evolution is all about genetics being handed down from generation to generation, with slight changes along the way. Competition with other species can affect evolution, as traits that will help you find resources such as food become valuable as both species compete. This brings us to this example. Imagine a river mouth.

Upstream is freshwater, the sea is salty marine water. In the fresh water lives the giant kokopu.

On the saltwater side lives the olive rockfish. 

If they lived in the same place, these fish would compete for the same food and hiding places. However, the change in the salt concentration on the river mouth forms a barrier that cannot be crossed. So, osmoregulation has affected their evolution by,

Preventing competition between the species, allowing each to evolve their own particular features.

So this enabled each species to become suited to their particular environment

However, both fish bear a striking similarity to each other, despite being from different families (the kokopu is from the same family as whitebait.) This is because they have a similar lifestyle, or niche. Both live near the bottom of the river/sea. Both hide amongst and in cracks so have long bodies. They eat similar food. Therefore they have evolved similar features to suit how they live. This is called convergent evolution. If it were not for the need to osmoregulate, we may have had a single species for freshwater and saltwater, or two who are much more related (same family or genus).

Another way this effects evolution is by stopping populations interbreeding. This is not the case with our study with the kokopu and rockfish. However, in the case of very similar species interbreeding, or hybridising, can occur. The change in salinity can prevent this from happening.