

Adaptations to the cold

Water good, ice bad

Staying alive often depends on whether liquid water is available, something which makes Antarctica especially challenging, as water can freeze within seconds. This is especially so during the brief summer when water may change back and forth to ice several times a day. Every time freezing occurs sharp ice crystals advance across a cell, threatening to puncture delicate membranes and kill the cell.

Some large organisms reduce this danger with structural adaptations such as fur, blubber or feathers but the invertebrates (animals without backbones) have no such adaptations and instead rely on their cell chemistry, along with special enzymes, to minimise their risk of ice damage.

They do so in these three main ways:

1. Avoiding freezing

How ice forms

Normally an ice crystal forms when water molecules attach themselves to small particles, then grows as further water molecules attach to the outer surface of this crystal. Known as *nucleators* the first small particles may be dust on the organism, food molecules in the gut, or the proteins between cells.

Invertebrate adaptations

Springtails and mites are two Antarctic land invertebrates that actively avoid freezing right down to -20°C by:

- having a water proof outer layer (cuticle) which stops water entering.
- removing nucleators, by emptying their gut as winter approaches or by removing proteins from their blood

To survive even lower temperatures, some insects also produce

- small molecules such as alcohols and sugars which reduce the chance of ice forming.
- large compounds such as proteins, which act as antifreezes by joining to ice crystals and preventing further water molecules attaching themselves.

2. Tolerating freezing

Arthropods (invertebrates with jointed limbs) and nematode worms are two groups of Antarctic organisms that can even tolerate being frozen solid. They do so by allowing the ice to form slowly over hours or days, often at just below 0°C , something which allows their cells to adjust to presence of ice.

Like the freeze avoiding organisms, some insects also produce alcohols, sugars and proteins which encourages ice to form around their bodies, rather than within it.

3. Dehydrating

Without water ice cannot form, so by losing up to 95% of their body's water and becoming dormant some nematode worms and tardigrades can survive extremely low temperatures.



A Tardigrade or "Waterbear" (1mm high)

So successful is this strategy, that the dehydrated animals may survive for several years, before becoming active again when immersed in liquid water. This enables tiny nematode worms to survive in the McMurdo Dry Valleys, one of the coldest and driest environments on Earth - valleys with an average air temperature of -20°C and a precipitation of less than 100mm (as snow) per year. Within these desolate valleys nematodes can even be found living in the thin film of water between soil particles.

Less is known about how small *Tardigrades* survive Antarctica's biting cold, except that these microscopic 'Waterbears' withdraw their eight legs into their segmented bodies, probably reducing their surface area for water loss to the air and then secrete a waxy covering that appears to inhibit ice formation.

Shallow seas are dangerous.

Generally the more salt there is in water the lower its freezing point. This means that for organisms living in cold seas it pays for them to be salty too, as otherwise they will freeze before the sea around them. Antarctic invertebrates are an example of just such organisms and they have very similar salt concentrations as the sea.

Seawater usually freezes at about -1.9°C and does so from the surface down as its heat escapes into the colder air above the waves. Fortunately for many species in deep water sea ice floats, forming a floating blanket which insulates the water below, stopping the sea freezing to the ocean bottom.

However in shallow water 'anchor ice' may form on the bottom and freezes in an upward direction. In places where the water is less than 15m deep, organisms can be faced with a dangerous situation when anchor ice is growing upwards and sea ice is growing down. The annual death of organisms in this shallow zone, helps to explain why most Antarctic marine invertebrates are found in deeper waters.

Cold sea, cold fish

Antarctic fish are different.

No organism can deliberately change to suit its surroundings, and if conditions in nature get too difficult individuals, or species, simply die out. This occurred millions of years ago when the waters around Antarctica cooled and most of the resident fish species died out, leaving only fish with adaptations for living in deep, cold water.

Today the fish of Antarctica are descendants of fish with these ancient adaptations. One group amongst these are the *Notothenioids* which make up:

- almost all of the shallow water fish,
- about a third of all Antarctic fish
- 90% of the fish biomass.

The survival of these fish in Antarctica is in part due to their having almost twice the levels of ions (mainly as sodium chloride) in their body fluids, compared with fish in warmer waters. However their salty bodies are still only a third as salty as sea around them so their blood freezes at -1°C , creating a very risky situation for an animal in water that is -1.9°C .

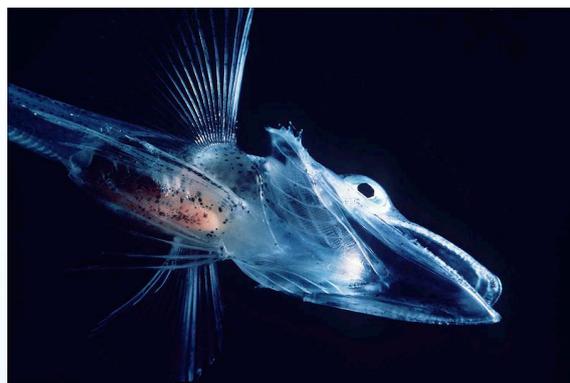
Antifreeze glycoproteins (AFGPs)

Another adaptation that has evolved over millions of years is the presence of natural antifreeze molecules within some fish. These are *glycopeptides* (AFGPs) and are small protein molecules with extra sugar molecules attached. In total there are eight differently sized glycoproteins (numbered AFGPs 1-8) each producing different antifreeze properties. An AFGPs does not prevent freezing starting, but instead stops ice growing further, by disguising the ice crystal.

AFGPs appear to be modified digestive enzymes that are distributed throughout the body and, despite being in very low concentrations, have a remarkable ability to reduce freezing by about 1.5°C . Such a drop is exactly what is required, as this lowers the freezing point of the fish tissues to -2.5°C , which is below the freezing point of the sea.

Ice can also occur in the gut of a fish after ingesting ice-laden water and food. Here in the gut AFGP's go to work allowing the fish to excrete any small ice crystals with waste food. However how such similar ice crystals are excreted from the blood is not understood.

Like much of the chemistry inside cells, producing AFGPs is expensive in terms of materials and energy, so it is not surprising that fish modify how much they produce, with fish in shallow (the coldest) water have the highest levels and deeper water fish having lower AFGP levels.



This young Antarctic Ice Fish is at risk of ice forming inside its body, but has remarkable adaptations that reduce this risk.

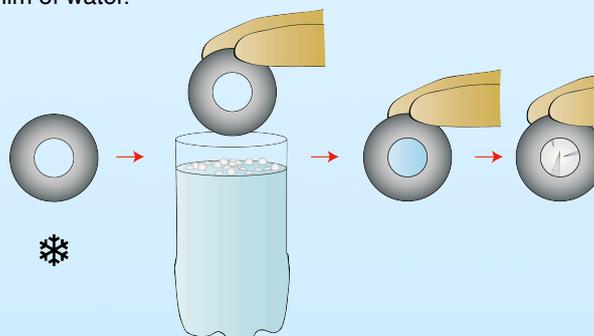
Practical activity: Ice damages cells.

Introduction

The formation of ice inside cells can be both rapid and lethal as advancing ice crystals destroy sensitive cell membranes.

What to do

1. Place any large steel washer in a freezer for at least 20 minutes.
2. With a gloved hand dip the cold washer into cold tap water with a few drops of detergent added. A film of water should form across the hole.
3. Hold the film in the cold air of the freezer for a few seconds and look for ice crystals marching across the film of water.



How it works

The detergent encourages a thin film of water to form. Although the film contains very little water, it still contains billions of water molecules. Within seconds these water molecules park neatly on the advancing ice crystal.

Each time the ice forms from a rough point or dust particle at the edge of the hole where it is coldest. Using a large metal washer (or even a plastic ring) and by wearing a glove, the warming effects of your hand are reduced.

Relevance

- Ice can form rapidly, damaging cells as it advances.
- Just as a thin film of water is at the mercy of cold air in a freezer, so are any organisms living in the large cold masses of Antarctica's land or seas.

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