Hi, this is Janet for Cheap Astronomy, www.cheapastro.com. This is SISS, Science on the ISS – and today's episode is *Heat pipes.*

Heat moves by conduction, convection or radiation. However, in space, convection becomes mostly irrelevant. In the cold vacuum of space, there's no air, or anything else, that can absorb heat from a surface and then carry it away. And, even in a pressurised cabin, like on the ISS, air won't carry heat away from a surface since hot air has no reason to rise in microgravity. The heated air will just hang there. Of course, the ISS has lots of little fans to blow air around, but those little fans have little motors that get hot as they work – so their work in moving air around the cabin ends up adding more heat to the cabin.

This is all a bit of a worry since the ISS is full of fans and motors and computers and people – all of which generate heat and all of which need to stay cool to operate effectively. Ultimately, the only way you can cool an entire spacecraft is to conduct heat to its outer surfaces and let that heat radiate away into the cold vacuum of space.

The ISS has an Internal Active Thermal Control System, which involves networks of tubing running through the crewed compartments of the US segment. Water is continually pumped through that tubing, absorbing heat as it goes. The heated water is then pumped past the Interface Heat Exchangers, which transfer the heat absorbed from the cabin to the External Active Thermal Control System. This external system pumps liquid ammonia through networks of tubing, past the Interface Heat Exchangers, but also past most of the external electronic systems that are on the ISS. The heated ammonia then circulates through the ISS's extendible radiator panels which provide a large surface area to help radiate heat away quickly. Separate to all that, there's the Photovoltaic Thermal Control System which pumps liquid ammonia through the ISS's huge solar panel arrays to keep them cool.

And here let's take a quick SISS tangent to discuss solar panel cooling. The ISS's solar panels are thin and flat and so can radiate heat away quite quickly. On each 90 minute Earth orbit the panels get hot in the Sun for about 45 minutes and then they cool right back down again during the 45 minutes when they're out of the Sun. So, the reason why the ISS' solar arrays need an active cooling system is not because we're worried they'll melt, it's because of operating efficiency.

If you listen to a lot of science and technology podcasts you are probably aware that if you make some materials very cold, they can become *super*conductors – or, to put it another way, they develop very low electrical resistance. So, it shouldn't come as a surprise to learn that if you make some materials very hot, they can become *totally-crap* conductors because they develop very high electrical resistance.

While hot photovoltaic cells can still absorb photons – and in doing so raise the electron of a first incident atom up to a higher energy shell – all the other atoms in a hot photovoltaic cell are jumping around like crazy, which makes it harder for that first incident atom to pass its quanta of absorbed energy on to an adjacent atom. In a cold material, atoms hardly move at all, so they can easily conduct quanta of energy – as though they are all lined up in a Newton's cradle.

Of course, the ISS Photovoltaic Thermal Control System consumes energy to actively cool the ISS solar panels, but the energy gained through improved photovoltaic cell efficiency far outweighs the energy used by the cooling system.

But now, back to the main story. As well as all those active cooling systems, the ISS also has a Passive Thermal Control System, which doesn't require any energy to run. It includes the thermal blankets, which insulate the ISS modules from the temperature swings which come from moving in and out of the sun every 90 minutes – and it includes heat pipes.

Heat pipes are long thin cylinders that have a small volume of fluid vacuum-sealed within them. If you put one end of a heat pipe against something hot and the other end against something cold, the fluid at the hot end will boil away into vapour – and, since that vapour will occupy a larger volume, some of it will come into contact with the cold end of the pipe where it will condense back into a liquid again. That phase change back into a liquid releases latent heat which warms the cool end of the pipe and the condensed fluid flows back to the hot end of the pipe again. That fluid return is either enabled by gravity or, in the case of heat pipes working in microgravity, it's enabled by capillary action which draws the fluid back thorough tiny grooves engraved on the inner surface of the cylinder.

A heat pipe is about as close as you'll get to a perpetual motion machine. The nett effect of fluid evaporating at the hot end and condensing at the cold end and flowing back to the hot end again – is that heat is continually shifted from the hot end to the cool end and it's shifted much faster than normal conduction could manage. There are no moving parts and the fluid within the pipe doesn't lose any appreciable volume in its perpetual cycling between evaporation and condensation. No laws of thermodynamics are breached since energy is neither created nor destroyed, it's just shifted from point A to point B – and entropy is increased as most of the shifted heat dissipates away into the wider Universe.

The obvious advantage of heat pipes is that they don't draw power like active cooling systems do – and with no mechanical or electronic parts they don't need any maintenance either. Heat pipes are an example of space technology we'd like to have more of. A piece of vital infrastructure that just keeps on working without anyone having to think twice about it.

So, now aboard the ISS is the Advanced Research Thermal Passive Exchange experiment, which is investigating different heat pipe designs to determine what design works best in different conditions.

There are two main problems with heat pipes. Firstly, if they get too hot, the liquid within will remain in an evaporated state and eliminate most of the pipe's heat transfer capacity. So, you'll need different heat pipes containing different fluids with different boiling points to work across different heat gradients. Secondly, after the fluid in a heat pipe has evaporated and then condensed again, the condensed fluid has to return to the hot end if the process is to continue.

The capillary action, that returns fluid to the hot end via grooves on the inner surface of each heat pipe, is mostly driven by fluid tension. But different fluids have different fluid tensions – so particular kinds of internal grooves that encourage capillary movement for one fluid may not work so well for another.

The Advanced Research Thermal Passive Exchange experiment is investigating all these various parameters to determine which kind of heat pipe best fits what kind of heat gradient.

And where is all this going? On the ISS in low earth orbit where the sunlit surfaces are exposed to 120 degrees Celsius, what you want to do is shift as much excess heat back into space as you can. Out past Pluto though, where temperatures are below minus 200 degrees Celsius, you might want to delay that radiative heat loss to space. You will still have to shift heat away from things that get hot, but you could spread that heat throughout the colder parts of your ship before it's eventually lost to space.

So, our future star-trekking spacecraft are likely to have heat pipes running from their reactor core all around the ship. Pipes near the core will have fluids with high boiling points and as the heat slowly spreads throughout the ship, pipes towards the outer hull will have fluids with lower boiling points. The Goldilocks principle will apply throughout – keeping things not too hot and not too cold. It will be cool, because it won't be *too* cool.

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