Dedicated to Mass Spectrometry

MS VISION TECH TIPPS SERIES
PART III — TEMPERATURE EFEFCTS ON ELECTRONIC

When operating a mass spectrometer - or any other type of electronic lab equipment - a typical requirements mentioned in the site preparation specs are the temperature stability as well as the absolute room temperature. These two things are independent from each other have different backgrounds.

Let's start with the first aspect, room temperature fluctuation. We will have a separate post on this and where to place instruments, but essentially the background is mass accuracy. The mass spectrometers vacuum part is built out of metal. Metals have the characteristics that they change their dimensions with changing temperature, usually the expand with increasing temperature. Depending on the actual metal these changes can vary from 0.5-23 ppm/K. If we look now at a typical MS system, changes in length are particularly critical in TOF systems for two reasons: they are used for accurate mass measurements and they measure the flight time, which is, among other factors, determined by the travel length of the ions. The current QTOF's all have in common that they use at least one reflector pass for a) extending the flight length and b) focussing reasons to increase the resolution of the system. By using a reflector, the effective flight length is doubled. So, let's assume we have an aluminium flight tube (like e.g. with the Bruker maxis or timsTOF), aluminium has an expansion coefficient of 23.1 ppm/K. Thus the length of the tube will change by 23 ppm per degree change in the room temperature. The effective flight path will however increase by 46 ppm (as it is twice the length). So you can immediately see that holding the temperature in the instrument room constant is critical for accurate mass determination. And even if you use special alloys such as Invar (which is an alloy made out of 65% iron and 35% nickel and has an expansion coefficient of around 1 ppm), the change is still 2 ppm/K. Other technologies like ion traps and quadrupoles are much less susceptible to changes by expansion and they are not used for accurate mass measurements. Therefore a change of a few ppm is usually not critical. Orbitraps are somewhere in the middle. While the dimensions of the Orbitrap are much smaller than a TOF flight tube, the relative change is identical and the system is also intended to deliver accurate masses. Thus it must be ensured that the temperature is constant for which a chiller can be used.

The second effect is a more long term effect. A change in the temperature in general affects the electronics as well. In chemistry the rule of thumb is that an increase in the temperature by 10 K doubles the reaction speed. In electronics the rule of thumb is that an increase by 10 K reduces the lifetime of electronics components by a factor of two.

While this is not completely accurate for various reasons, you can expect a number of effects when operating the system at elevated temperature. The rule for electronics is based on the same Arrhenius equation as for the chemical reactions. I will not go into the details, if you would like to get deeper into the topic I can recommend an article by R. Wilcoxon (https://www.electronics-cooling.com/2017/08/10c-increase-temperature-really-reduce-life-electronics-half/) as well the open access paper from A.A. Almubarak in Int. J. of Engineering Research and Application, Vol 7, Issue 5, p. 52-57 from 2017.

The Wilcoxon article describes that the activation energies relevant for the Arrhenius equation are typically in the range of 0.6-1 eV/K for various aging mechanisms in electronic components. Transformation of the Arrhenius equation gives you an acceleration factor, which is dependent on the difference between actual and intended use temperature. The acceleration factor is nowadays an establish approach for forced aging test according to various standards. With a temperature difference of 10 K and an activation energy of 0.8 eV/K you will then end up with an acceleration factor of ~2x in the range between 75 and 125°C. This brings us back to the rule of thumb that the increase by 10 K reduces lifetime by a factor of 2.

Wilcoxon also says that "in general, the Arrhenius model is likely appropriate for certain failure mechanisms including corrosion, electromigration and certain manufacturing defects, but is not suitable for other significant failure modes, such as the formation of conductive filaments, contact interface stress relaxation, and fatigue of package-to-board level interconnect." Thus not all failure modes will follow that rule. However, as we recently saw in a number of ThermoFisher's Orbitrap systems, e.g. corrosion is a significant issue producing ghost peaks and electronic background noise in older systems. Therefore an elevated temperature IS an issue.

In Almubarak's article it is stated that "Damage to an electronic component is the potential and direct effect of overheating... Note that most, if not all, of failures in electrical and electronic components, are commonly associated with overheating and subsequent burning... The susceptibility [of] an electronic assembly or electronic device to fail increases exponentially with temperature."

We have seen in our service work several cases in recent times where overheating was likely the issue for the breakdown. E.g. a failed ventilator which caused failure of a backpane on a Sciex 5500 instrument, likely a too close distance between LC and MS at the venting slits causing overheating issues on a Sciex source control module on a 6500, etc. These failures are costly (usually several 1000€) and will be promoted by elevated room temperature.

In order to avoid excessive strain on the electronic components in your precious systems we therefore recommend a couple of simple measures:

a) Stick to the manufacturers guidelines for the room temperature. Usually this will be in the range between 20 and 25°C. In areas like India, the Arabic peninsula, Southern China, etc. this might be critical but it is not only for the wellbeing of your operators but also to protect your investments.

b) Keep the temperature constant for maintaining stable calibration (we will have a separate article about this).

c) Make sure venting slits and ventilators are not blocked, have sufficient space to walls or neighbouring instruments.

d) Frequently check ventilators for operation. Also check the systems inside for dust and remove it if necessary. Check air filters for proper flow and potential blockage.

Temperature fluctuations or elevated temperatures do not necessarily need to cause a fatal breakdown. Sometimes changes are more subtle and produce failures over a longer time. One thing we observed quite frequently is failures on high voltage power supplies because of broken capacitors. On older systems these can be repaired for a few €. However, on modern multilayer boards the individual components cannot be easily exchanged by soldering. A highly qualified subcontractor is required for this so that usually it leads to a complete exchange of these components. The following table gives you a rough overview on how various more frequent electronic components are affected and how this may influence your measurement results:

Component	Temperature effect	Effect on MS instrument
Ceramic capacitors	Changes in dielectric constant and capacitance, reduced insulation resistance with high temp.	Changes in measurement results
Electrolytic capacitors	Increased electrolyte leakage; shortened life, large change in capacitance, increased series resistance with low temp.	Changes in measurement results
Tantalum capacitors	Electrolyte leakage; change in capacitance insulation resistance; series resistance	Changes in measurement results
Transistors	Increased leakage current; changes in gain; increases in opens and shorts	Electronic instability
Connectors	Flash over, dielectric damage	Potential electronics damage, instability, ghost peaks
Crystals	Drift;	Decreased mass accuracy
Switches	Oxidation of contacts	Instability, ghost signals
Thermistors	Increased shorts and opens	Electronic instability, inability for compensation of changing temperature