Survival of organisms in extreme conditions

Organisms, known as extremophiles, survive in environments that other terrestrial life-forms find intolerable and in some cases lethal. They are evolved to survive in extreme hot niches, ice, and saline solutions, also adapting to survive in varying pH conditions; extremophiles are even found to grow in toxic waste, organic solvents, heavy metals, or in multiple habitats thought previously to be inhospitable for life. Within all the discovered extreme environmental condition, a variety of organisms have shown that they are able to not just tolerate these conditions, but they require these conditions for survival. If organisms can survive in these hostile environments on Earth it seems feasible that there could be life present in other areas of our solar system.

Extremophiles are classified according to the conditions in which they grow. These sections can be further divided into two broad categories: extremophilic organisms which need these hostile conditions to survive, and extremotolerant organisms which can withstand the extreme pressure of one or multiple conditions however, grow optimally at “ normal” and less hostile conditions. From all three domains of life, i. e. bacteria, archaea, and eukarya, extremophiles can be found. Most extremophiles are microorganisms with many of these being archaea, but protists, in the eukaryotes, have some extremophiles from the families: algae, fungi and protozoa. Archaea are the most common extremophilic domain, however are generally less versatile than bacteria and eukaryotes in at adapting to differing extreme environments. Although, some archaea are some of the most hyperthermophilic, acidophilic, alkaliphilic, and halophilic microorganisms known. The archaeal Methanopyrus kandleri strain 116 will tolerate and grow at temperatures up to 122°C (252 °F), while the genus Picrophilus (i. e. Picrophilus torridus) are some of the most acidophilic organism, growing at a pH as low as 0. 06. Bacteria like *cyanobacteria* , is best adapted to environments with multiple physicochemical parameters, by forming multi-layered microbial mats with other bacteria. They can survive in hypersaline conditions and alkaline lakes, which support high metal concentrations and low availability of water or xerophilic conditions, in a group of endolithic communities in stony desert regions. However, *c yanobacteria* is rarely found in an acidic environment at a pH lower than 6. Not only does this give insight into the origin of life on Earth, but opens up a new realm of possibilities for life elsewhere in the universe.

Thermophilic bacteria are common in soil and volcanic environments i. e. hot springs. Thermophiles are thought to be one of the original organisms to have survived on earth over 3 billion years ago, in an environment with much higher temperatures, this allows possibilities to assume that a life form could be found on another planet. The ability to proliferate at growth temperature optima well above 60°C is associated with extremely thermally stable macromolecules. As a consequence of growth at high temperature and unique macromolecular properties, thermophilic organisms can possess high metabolic rates, physically and chemically stable enzymes, and lower growth rate with a higher end product yield. Thermophilic reactions appear more stable, rapid and less expensive, and facilitate reactant activity and product recovery. Most thermophiles are anaerobes, this is due to oxygen being much less soluble at higher temperatures, therefore is not available to the organisms. Thermophiles and acidophiles have membranes that contain tetra-ether lipids, which form a rigid monolayer that is impermeable to many ions and protons. The ether type lipids are far stronger than the ester lipids found in mesophilic organisms, also the lipid layers consist of more branched and saturated fatty acids. This gives a stronger lipid complex, and is most prevalent in Archaean thermophiles. Thermophiles also stabilize their proteins, DNA, RNA and ATP, however there is no distinctive reason for how they stabilize. Though, most thermophilic organisms have more Cytosine and guanine bonds as the triple bond is a lot stronger than the Adenine Thymine bond. Thermophiles have developed unique ways of heat stabilizing their essential proteins. The protein surface energy and the hydration levels of the exposed non-polar groups are monitored and minimized by packing the hydrophobic regions into a dense core, of the protein, by the amino acids charge-charge interactions. An increased number of salt bridges and internal networks are present, stabilizing the internal structures and an elevated amount of synthesis of chaperone proteins. Chaperone proteins unfold and help to refold proteins that are not formed properly, this is important as during hot environment there is a higher chance of misfolded proteins. The methods thermophiles employ to survive on earth could be used to survive elsewhere in our solar system.

Psychrophilic organisms or psychrophiles grow best at low temperatures (freezing point of water or below) in areas such as deep sea and polar regions. The main problems for organisms in this environment is the exponential effect on the rate of biochemical reactions and the viscosity of internal and external environments, which changes significantly between 37µ’C and 0µ’C. (Feller & Gerday, 2003; Georlette et al, 2004; Russell, 2000).

In an attempt to overcome the effects on the cytoplasmic membrane, i. e. permeability and hence transportation across the membrane, there is a higher lipid concentration in the membranes containing more unsaturated, polyunsaturated, methyl-branched fatty acids, and shorter acyl-chain length. The lipid head group within the membrane is also thought to be larger. All of these adaptations increase the fluidity of the membrane and in turn survival at lower temperatures (Chintalapati et al, 2004). Another adaptation for lower temperatures is the ribosomal extract, RNA polymerase, having a larger elongation factor and the presence of peptidyl-prolyl cis-trans isomerase which have shown to retain activity near 0°C in multiple differing psychrophilic microorganisms, like Moritella profunda, Another enzyme catalyses cis-trans prolyl isomerisation, and its high activity and overexpression at low temperatures might be important for overcoming the impaired folding protein rates. Likewise, nucleic-acid-binding proteins like Escherichia coli’s CspA-related proteins and RNA helicases, which are important in the transcription and translation of DNA and RNA secondary structures, are also overexpressed (Berger et al, 1996; Lim et al, 2000). The relationship between the flexibility of the membrane and the increase in activity is meant to create quite an unstable organism however, only in mesophilic environments. In a comparison of thermodynamic parameters between psychrophilic enzymes and their mesophilic homologues, at low temperature there is a decrease in activation enthalpy, meaning a decrease in the number of enthalpy-driven reactions that have to be broken in catalysis. Organisms in this habitat are also considered to be oligotrophic as they live with lower nutrient content. Psychrophiles could use all of these adaptations in similar environments except Earth.

Acidophiles and alkaliphiles are optimally adapted to acidic or alkaline pH values, acidophiles live in a higher concentration of Hydrogen ions as, Alkaliphilic organism live in a higher concentration of hydroxide ions. Acidophiles partially deflect the flow of protons into the cell by reversing the membrane potential with a reduced pore size in the membrane channels. By having a highly impermeable cell membrane organism can restrict the influx of protons, with their chemiosmostic gradient and by actively exporting protons out of the cell maintaining a habitable internal pH. In comparison to mesophiles, acidophiles have a higher proportion of secondary transporters which reduce the energy demands associated with moving protons, solutes and nutrients across the membrane. Acidophiles contain more DNA with a high proportion of protein repair mechanisms which repair at a lower pH, in *B. acidocaldarius* there is a higher level of cytoplasmic buffering found. In most acid environments there is a high metal content which these organisms use in their favour to stabilize their intercellular enzymes. In alkaliphilic organisms, such as *Bacillus pseudofirmus* and *B. halodurans,* oxidative phosphorylation occur to support non-fermentative growth and proton-coupled ATP synthases occurs, using proton-motive force (PMF) but mostly from the sodium-ion gradient. A major adaption of the alkaliphiles for surviving in their environments is within the diversity of their enzymes. Mesophilic organisms produce enzymes with similar activity however, do not have the same enzymatic capacity to cope with the increase pH. An internal pH is maintained by the active and passive regulation mechanisms across the membrane, actively removing the hydroxide ions. The addition of cytoplasmic pools of polyamines and low membrane permeability, with sodium ion channels actively regulates these levels. Alkaliphillic bacteria also compensate for the high levels by having a high membrane potential or coupling Na^+ expulsion through the ETC. All of these processes used could be utilized by interplanetary organism.

Throughout our solar system there are many environments where some of these extremophiles could use their adaptations to survive. The main necessity for life would be the presence of even a minimal supply of water. In our solar system there are environments thought to be able to support life. Titan, one of Saturn’s moons, has sustainable atmosphere composed primarily of nitrogen, similar to earths. There are many ammonia and methane lakes on titan that theoretically could combine, in an electrically charged environment, to make an organic habitat. Thermophiles that also contain sulfureted properties could survive there as they survive in similar conditions in the deep ocean hot springs. Enceladus, another of Saturn’s moons has an abundant supply of water vapour geysers and Europa, one of Jupiter’s moons, both are thought to be entirely covered in ice. Psychrophiles and Alkaliphilic or Acidophilic organism could adapt to live in this environment. Enceladus is considered an active water world with oceans with Europa thought to have subglacial water systems under the ice layer. Models of Enceladus predict the oceans to be a solution of $Na\text{-}Cl\text{-}CO_3$ with a pH of 11 to 12. This is a similar environment to Lake Shala in the Rift Valley Lakes, with a high alkaline pH and due to it being the deepest lakes on earth, a cold temperature at its lowest depth. Europa has a highly acidic water system and due to the total coverage of ice on the surface of the moon, any organism able to survive there must also be anaerobic.

Overall, on earth we have many extreme environments which are considered lethal to most organism but are home to extremophiles, such as thermophiles, psychrophiles, acidophiles and alkaliphiles. From the way many of these organism adapt to survive on earth it is feasible that organism with similar adaptations could be present or could survive elsewhere in our solar system, in similar environments.