

Nutrition and Growth of Bacteria (page 5)

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The Effect of Temperature on Growth

Microorganisms have been found growing in virtually all environments where there is liquid water, regardless of its temperature. In 1966, Professor Thomas D. Brock, then at Indiana University, made the amazing discovery in boiling hot springs of Yellowstone National Park that bacteria were not just surviving there, they were growing and flourishing. Brock's discovery of thermophilic bacteria, archaea and other "extremophiles" in Yellowstone is summarized for the general public in an article at this web site. See [Life at High Temperatures](#).

Subsequently, procaryotes have been detected growing around black smokers and hydrothermal vents in the deep sea at temperatures at least as high as 120 degrees. Microorganisms have been found growing at very low temperatures as well. In supercooled solutions of H₂O as low as -20 degrees, certain organisms can extract water for growth, and many forms of life flourish in the icy waters of the Antarctic, as well as household refrigerators, near 0 degrees.

A particular microorganism will exhibit a range of temperature over which it can grow, defined by three cardinal points in the same manner as pH (Figure 6, cf. Figure 4). Considering the total span of temperature where liquid water exists, the procaryotes may be subdivided into several subclasses on the basis of one or another of their cardinal points for growth. For example, organisms with an optimum temperature near 37 degrees (the body temperature of warm-blooded animals) are called **mesophiles**. Organisms with an optimum T between about 45 degrees and 70 degrees are **thermophiles**. Some Archaea with an optimum T of 80 degrees or higher and a maximum T as high as 115 degrees, are now referred to as **extreme thermophiles** or **hyperthermophiles**. The cold-loving organisms are **psychrophiles** defined by their ability to grow at 0 degrees. A variant of a psychrophile (which usually has an optimum T of 10-15 degrees) is a **psychrotroph**, which grows at 0 degrees but displays an optimum T in the mesophile range, nearer room temperature. Psychrotrophs are the scourge of food storage in refrigerators since they are invariably brought in from their mesophilic habitats and continue to grow in the refrigerated environment where they spoil the food. Of course, they grow slower at 2 degrees than at 25 degrees. Think how fast milk spoils on the counter top versus in the refrigerator.

Psychrophilic bacteria are adapted to their cool environment by having largely unsaturated fatty acids in their plasma membranes. Some psychrophiles, particularly those from the Antarctic have been found to contain polyunsaturated fatty acids, which generally do not occur in procaryotes. The degree of unsaturation of a fatty acid correlates with its solidification T or thermal transition stage (i.e., the temperature at which the lipid melts or solidifies); unsaturated fatty acids remain liquid at low T but are also denatured at moderate T; saturated fatty acids, as in the membranes of thermophilic bacteria, are stable at high temperatures, but they also solidify at relatively high T. Thus, saturated fatty acids (like butter) are solid at room temperature while unsaturated fatty acids (like safflower oil) remain liquid in the refrigerator. Whether fatty acids in a membrane are in a liquid or a solid phase affects the fluidity of the membrane, which directly affects its ability to function. Psychrophiles also have enzymes that continue to function, albeit at a reduced rate, at temperatures at or near 0 degrees. Usually, psychrophile proteins and/or membranes, which adapt them to low temperatures, do not function at the body temperatures of warm-blooded animals (37 degrees) so that they are unable to grow at even moderate temperatures.

Thermophiles are adapted to temperatures above 60 degrees in a variety of ways. Often thermophiles have a high G + C content in their DNA such that the melting point of the DNA (the temperature at which the strands of the double helix separate) is at least as high as the organism's maximum T for growth. But this is not always the case, and the correlation is far from perfect, so thermophile DNA must be stabilized in these cells by other means. The membrane fatty acids of thermophilic bacteria are highly saturated allowing their membranes to remain stable and functional at high temperatures. The membranes of hyperthermophiles, virtually all of which are Archaea, are not composed of fatty acids but of repeating subunits of the C5 compound, phytane, a branched, saturated, "isoprenoid" substance, which contributes heavily to the ability of these bacteria to live in superheated environments. The structural proteins (e.g. ribosomal proteins, transport proteins (permeases) and enzymes of thermophiles and hyperthermophiles are very heat stable compared with their mesophilic counterparts. The proteins are modified in a number of ways including dehydration and through slight changes in their primary structure, which accounts for their thermal stability.

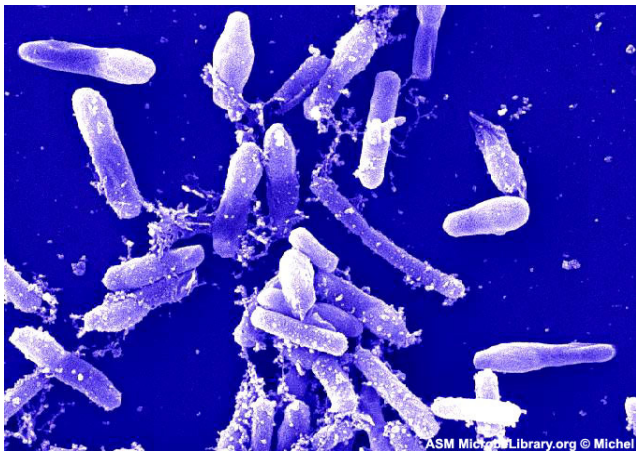


Figure 5. SEM of a thermophilic *Bacillus* species isolated from a compost pile at 55° C. © Frederick C. Michel. The Ohio State University -OARDC, Wooster, Ohio. Licensed for use by ASM Microbe Library <http://www.microbelibrary.org>. The rods are 3-5 microns in length and 0.5 to 1 micron in width with terminal endospores in a slightly-swollen sporangium.

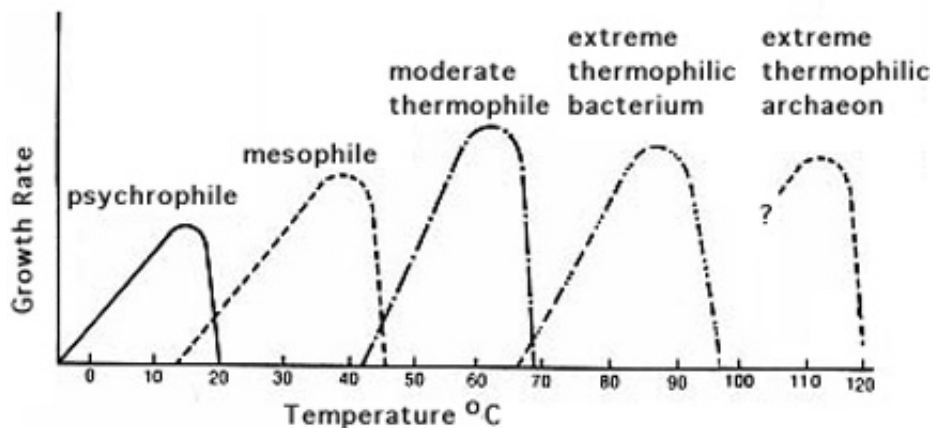


Figure 6 (below). Growth rate vs temperature for five environmental classes of procaryotes. Most procaryotes will grow over a temperature range of about 30 degrees. The curves exhibit three cardinal points: minimum, optimum and maximum temperatures for growth. There is a steady increase in growth rate between the minimum and optimum temperatures, but slightly past the optimum a critical thermolabile cellular event occurs, and the growth rates plunge rapidly as the maximum T is approached. As expected and as predicted by T.D. Brock, life on

earth, with regard to temperature, exists wherever water remains in a liquid state. Thus, psychrophiles grow in solution wherever water is supercooled below 0 degrees; and extreme thermophilic archaea (hyperthermophiles) have been identified growing near deep-sea thermal vents at temperatures up to 120 degrees. Theoretically, the bar can be pushed to even higher temperatures.

Table 9. Terms used to describe microorganisms in relation to temperature requirements for growth.

Group	Temperature for growth (degrees C)			Comments
	Minimum	Optimum	Maximum	
Psychrophile	Below 0	10-15	Below 20	Grow best at relatively low T
Psychrotroph	0	15-30	Above 25	Able to grow at low T but prefer moderate T
Mesophile	10-15	30-40	Below 45	Most bacteria esp. those living in association with warm-blooded animals
Thermophile*	45	50-85	Above 100 (boiling)	Among all thermophiles is wide variation in optimum and maximum T

* For "degrees" of thermophily see text and graphs above

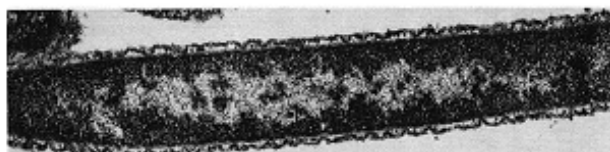
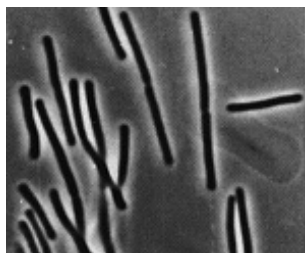


Figure 7. *Thermus aquaticus*, the thermophilic bacterium that is the source of taq polymerase. L wet mount; R electron micrograph. T.D. Brock. [Life at High Temperatures](#).

Table 10a. Minimum, maximum and optimum temperature for growth of certain bacteria and archaea.

Bacterium	Temperature for growth (degrees C)		
	Minimum	Optimum	Maximum
<i>Listeria monocytogenes</i>	1	30-37	45
<i>Vibrio marinus</i>	4	15	30
<i>Pseudomonas maltophilia</i>	4	35	41
<i>Thiobacillus novellus</i>	5	25-30	42
<i>Staphylococcus aureus</i>	10	30-37	45
<i>Escherichia coli</i>	10	37	45
<i>Clostridium kluyveri</i>	19	35	37

<i>Streptococcus pyogenes</i>	20	37	40
<i>Streptococcus pneumoniae</i>	25	37	42
<i>Bacillus flavothermus</i>	30	60	72
<i>Thermus aquaticus</i>	40	70-72	79
<i>Methanococcus jannaschii</i>	60	85	90
<i>Sulfolobus acidocaldarius</i>	70	75-85	90
<i>Pyrobacterium Brockii</i>	80	102-105	115

Table 10b. Optimum growth temperature of some procaryotes.

Genus and species	Optimal growth temp (degrees C)
<i>Vibrio cholerae</i>	18-37
<i>Photobacterium phosphoreum</i>	20
<i>Rhizobium leguminosarum</i>	20
<i>Streptomyces griseus</i>	25
<i>Rhodobacter sphaeroides</i>	25-30
<i>Pseudomonas fluorescens</i>	25-30
<i>Erwinia amylovora</i>	27-30
<i>Staphylococcus aureus</i>	30-37
<i>Escherichia coli</i>	37
<i>Mycobacterium tuberculosis</i>	37
<i>Pseudomonas aeruginosa</i>	37
<i>Streptococcus pyogenes</i>	37
<i>Treponema pallidum</i>	37
<i>Thermoplasma acidophilum</i>	59
<i>Thermus aquaticus</i>	70
<i>Bacillus caldolyticus</i>	72
<i>Pyrococcus furiosus</i>	100

Table 10c. Hyperthermophilic Archaea.

Genus	Temperature for growth (degrees C)			Optimum pH
	Minimum	Optimum	Maximum	
<i>Sulfolobus</i>	55	75-85	87	2-3
<i>Desulfurococcus</i>	60	85	93	6
<i>Methanothermus</i>	60	83	88	6-7
<i>Pyrodictium</i>	82	105	113	6
<i>Methanopyrus</i>	85	100	110	7

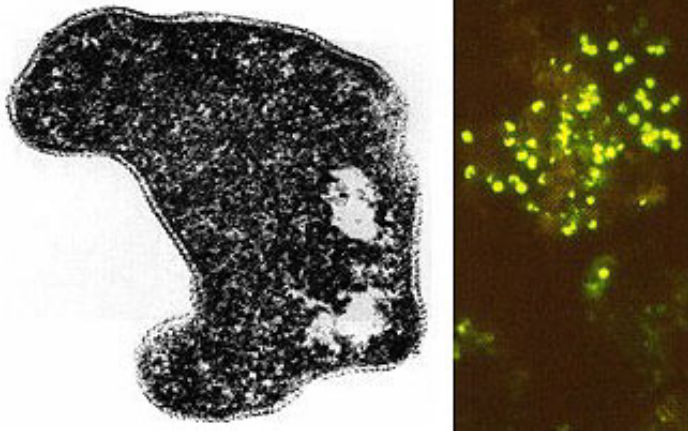


Figure 8. *Sulfolobus acidocaldarius* is an extreme thermophile and an acidophile found in geothermally-heated acid springs, mud pots and surface soils with temperatures from 60 to 95 degrees C, and a pH of 1 to 5. Left: Electron micrograph of a thin section (85,000X). Under the electron microscope the organism appears as irregular spheres which are often lobed. Right: Fluorescent photomicrograph of cells attached to a sulfur crystal. Fimbrial-like appendages have been observed on the cells attached to solid surfaces such as sulfur crystals. T.D. Brock. [Life at High Temperatures](#).

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