Specific Requirements for Life

all life evolved on earth and as such are subjected to similar range of conditions

these conditions have molded species along similar patterns

The main REQUIREMENTS (needs) for life to exist:

1. **Liquid Water**
2. **Temperature Range between 0º – 100º C**
3. **Salt /Water Concentration ~3.3%**
4. **Nutrient & Energy Sources**
5. **Free Oxygen O_2 for Energy Production**
6. **Pressure Range Near 1 atm**
7. **Elimination of Metabolic Wastes**
8. **pH Range near Neutral**
9. **Gravity**

In general, simpler organisms can tolerate wider ranges of conditions

eg. Bacteria vs vertebrates

Kingdoms with the simplest organisms are more likely to have species that can tolerate "extreme" conditions

these conditions have molded species along similar patterns

1. Liquid Water

all life is made mostly of water

eg. humans 60-70 %

eg. jellyfish up to 95%

one of the reasons for this is life is basically a series of chemical reactions

=metabolism

and you cant have chemical reactions unless the chemicals are dissolved in something

→no water no metabolism

eg. seeds, cysts, etc

eg. some animals can enter anabiotic state tardigrades, nematodes

also, when water freezes it expands and ice crystals can damage the cell

in habitats where water is scarce life have found ways to use water more efficiently

eg. some desert animals have very efficient kidneys or never need to drink

or store it

eg. succulents, cacti

frozen water is the same as no water at all

eg. tundra, boreal forests

2. Temperature Range

	freezing	body temp	boiling
ºF	32º	98.6º	212º
ºC	0º	37º	100º

in universe, temperatures can vary over millions of degrees

lowest temperature recorded in biosphere is –88.3ºC (antarctica)

highest temp = 350ºC (hydrothermal vents)

in most of biosphere temp ranges over ~100º

the vast majority of life occurs between 20º & 40º C (="normal")

most higher organisms have colonized only the warmer bits

eg. survivable limits for most plants = ± 60° C

simpler organisms (eg. bacteria) usually have wider tolerance ranges for temperature and other environmental factors

→less complex structure, can mutate and adapt more quickly temperature is most important because life requires **liquid water**

pure water is liquid from 0º to 100º C (32ºF – 121ºF)

→metabolism (chemical reactions) requires that the chemicals be dissolved in some kind of liquid

→some large, complex organic molecules (proteins and DNA) are also very sensitive to temperature changes

upper temperature limits

few places in biosphere go much above 45º C (~100-120ºF)

what is ave temp of hot shower??

hot springs (45-50º C) have existed for millions of years

why haven't animals or plants adapted to them?

→At 50º (~ 120ºF) proteins are generally denatured

→Cell membranes begin to break down and get leaky above 50º

→DNA melts between 65-75º (73º = 150-160ºF)

some bacteria can survive 70º C

(=thermophiles)

eg. current record holder is an archaebacterium,*Pyrolobus fumarii*, from hydrothermal vents that can survive and prosper under pressure at 112º - dormant at room temp

some microbiologists predict that the true upper limit for bacteria is 160º; temp at which ATP decomposes

48º is considered upper limit of **animal** life

eg. a few animals can survive up to 50º C (fish that live in hot springs),

But provided water was normally liquid, there is no reason why life should not persist and evolve on hotter worlds

→but life would be truly fast; consuming masses of nutrients and ridding lg amts of wastes

<u>lower temperature limits</u>

4/5th's of the inhabitable portions of the planet never gets above 5º C (~40ºF)

most of deep sea is 2º (~34ºF)

again the main consideration is that water remain liquid there are a few brackish pools in Anarctica where water remains fluid at –5º;

lower temp limit for bacterial activity seems to be –12º (~10ºF), if water remains liquid

eg. some bacteria have been kept in lab cultures of water glycerol mixture to –20º C

some seaweeds (Protists) survive and grow locked in solid antarctic ice of winter ice shield

→ insulated, actually warmer than at surface

over 1000 lichen and simple plant species live in the anarctic where ave summer temp = -29º C and average winter temp = -61ºC

→ survive mostly on sun exposed rocks where temperatures can actually reach up to 10 degrees

freezing kills animals because cells become disrupted.

→Ice crystals break cell membranes

→Freezing removes water, raises salt concentrations to lethal levels

Isolated cells (blood, semen) a few cells can survive

all alcohols are antifreezes; glycerol is an alcohol (= cryoprotectants)

eg. numerous arthropods survive freezing in tundra by generating antifreezes in and around their cells, often glycerol

eg. human, after 7 hrs exposure to sub zero temp (-1ºC) body temp below 25ºC, revived; such survivors are often drunk

some complex life forms form resistant structures

active life vs **resistant structures**

eg some insects can survive –50º C (-58º F)

eg. dehydrated, seeds, cysts

eg. some lichens (algae, fungi) have been kept viable in lab at temperatures *near* absolute 0 (-273.15ºC)

3. Salt /Water Concentration ~3.3%

most cells are the approximate salt content of ocean water = 3.3% salt (or 33ppt)

→ salinity fairly constant 33-35 ppt, similar proportions of salts

too little salts causes imbalance in ions within a cell and it can no longer function properly

too much salt denatures proteins and causes dehydration

eg humans water intoxication, dehydration

microorganisms (bacteria and some protists) can withstand wide fluctuations in salt concentrations; eg 0.3% to 33% salt

more complex organisms tolerate narrower range of variation.

most higher plants grow in rich soil with relatively little salt.

a few higher plants can withstand salt concentrations equal to salt water

eg. salt marshes, seawater, salt deserts

eg. marine vs freshwaters adaptations

organisms that live in very salty water need ways to get rid of excess salt

organisms that live in freshwaters need to have ways to hold onto salt

4. Nutrient & Energy Sources

all life is essentially a collection of elements and molecules that react and interact with each other

any chemical that an organism "needs" is a **nutrient**

these chemicals can be in the form of:

a. individual elements:

eg. iron, copper, zinc,

b. small **inorganic** molecules:

eg. water, oxygen gas, sodium chloride, hydrogen sulfide, ammonia,

c. larger **organic** molecules:

eg. sugars, starches, proteins, fats, etc

these nutrients are needed for 2 major reasons:

→ as a "**building block**" to construct larger organic molecules

→ or as an **energy source**

<u>Building Blocks</u>

about 25 elements are universally required for life

=**essential nutrients**

of all elements required for life the bulk of living matter consists of only 4 elements:

H,C,O,N → comprise 95% of human body

H, C, N, O, Na, Mg, P, S, Cl, K, Ca
→ comprise >99% of all biomass

some organisms get all of their "building blocks" from individual elements or simple inorganic molecules

other organisms get some nutrients from simple molecules but also require organic molecules

eg. vitamins, AA's

humans require 45-50 specific individual nutrients

Energy Source

most life gets energy by breaking organic molecules down into simpler inorganic molecules:

organics ⟶ CO_2 + H_20

⇩

ENERGY

some organisms (eg. us) must eat organic molecules and then break them down for energy

→ **heterotrophs**

other organisms (eg. plants & algae) use simple inorganic molecules and energy from sunlight to make organics

$$CO_2 + H_20 \xrightarrow{\text{sunlight}} \text{organics}$$

then these organics can be broken down as need to produce energy

→ **autotrophs**

<u>Nutrient Availability in ecosystems</u>

some nutrients are easier to get in some environments than in others

eg. mountain gorillas chew and swallow rotting wood, sometimes till their gums bleed

for decades reason was unknown

recently discovered sodium gets more concentrated as wood rots, sodium is in short supply in terrestrial ecosystems

5. free oxygen O_2 for energy production
(most, not all)

except for some bacteria, O_2 is needed by organisms to make energy

= aerobic respiraton

O_2 is a gas

→ in large multicellular organisms need separate system to take it in

eg. plants: small pores create passageways
= stomata

eg. animals: respiratory system, gills, lungs, etc

6. Pressure Range Near 1 atm

air pressure at sea level = 1 atm (=1.013 bar)
→about 14 lbs per square inch

pressure is equivalent to weight of air:

eg. a room 12x15x9 ft holds about 170 lbs of air

changes due to weather are only a few % of this
yet winds have lots of force

main effect of pressure is on atmospheric gasses
esp air breathers

→ too little pressure → not enough O_2

→ too much pressure → gas bubbles in blood, Nitrogen narcosis

<u>lower limit:</u>

lowest atm humans can survive is about 1/5th of an atmosphere

→would become starved for oxygen if pressure were much lower

few animals are able to live above 22,000 ft elevation

eg. wild sheep struggle at 17,000'
eg. small black attid spiders on Mt Everest
eg. small wingless grasshopper → 18,000'
eg. a few bees, moths and butterflies → 21,000'

some bacteria can survive in “vacuum packed” foods

upper limit:

hydrostatic pressure increases about 1 atm for every 10 meters in depth

2/3rd ’s of biosphere (3/4th ‘s of oceans) are subjected to pressures 100’s of x’s greater

at bottom of ocean trenches pressure is equiv of 1100 atm (15,400 lbs/in^2)

most bacteria are more or less indifferent to 300 fold increases in pressure

but some deep sea bacteria may need the high pressures to grow

(obligate barophiles; still questionable; live in intestinal tracts of deep sea animals)

some squid, worms and deep living fish and shellfish die when brought to sea level pressures

deep sea: cant have gas sacs or will get “bends”

fish with swim bladder cannot survive such depths

→deep sea fish and benthic fish lack swim bladders

deep diving mammals can collapse their lungs

7. Elimination of Wastes

metabolism produces things you need
but also produces waste products

→ must avoid a build up of toxins

sometimes waste products are recycled:

eg. plants → **secondary products**
antiherbivory
structural support

eg. animals → **bile** used for digestion
→ CO_2 for acid base balance

eg. sharks → **urea**
in blood for salt & water balance

over evolutionary history some former waste products became important resources for new life forms

eg. photosynthesis in some bacteria, algae and plants → **oxygen gas**

originally a horrible pollutant

later used in much more efficient energy production

eg. excess **calcium carbonate** produced by early animals became an important resource in the form of protective shells and skeletons

→ Cambrian Explosion

8. pH Range near Neutral

pH = - log $[H^+]$ {acidity - 7 - alkalinity}

fluid inside most living cells is about 7.7

like salts, too much or too little acidity can affect large organic molecules

eg. denatures proteins

eg. humans body fluids pH=7.4
<7.0 and >7.8 → death

however most soil bacteria can withstand environment of pH = 5 – 8

extreme microorganisms can live in pH of 1 to 13

more complex organisms are more restricted in pH tolerance

animals can rarely grow in environments above pH of 10.5

acid rain in northern lakes kills fish and aquatic fauna; kills trees in N forests

9. Size Limitations

How big can living organisms become?
depends on a variety of factors; some of the most important are:

a. surface/volume ratio
b. effects of gravity
c. metabolic rate

a. Surface to Volume Ratio

materials must be able to easily enter and leave a living organism

→gas exchange
→nutrients
→waste disposal

single celled organisms are usually very small and these processes can diffuse in and out easily

as an organism gets larger there is proportionally less surface area

→the **volume** or mass of the organism is limited by the **surface area** available for this exchange

a few cells can become fairly large

eg. some slime molds

but they are very thin and without much volume

as organisms get larger they are divided into smaller **compartments** (cells, organs, etc)in order to centralize and specialize certain functions within the larger organism

the compartmentalization keeps chemicals and processes concentrated

→prevents dilution of resources and activities

→increases efficiencies

also each compartment has an adequate surface area for exchange of materials

b. Effects of Gravity

life evolved in gravity:

→plants use gravity for orientation of roots

→some animals use gravity for development of skeletal, muscular & cardiovascular systems

eg. NASA microgravity research

the force of **gravity** confers limitations to the size an organism can grow because increasing **weight** means more support is needed

→weight is more critical on land than in water

→buoyancy reduces need for support

→weight is more critical for a mobile animal than for a nonmobile plant or fungus

→weight is more critical in flying animal than in land animal

eg. largest animal on earth is blue whale

but new data suggests an ichthyosaur species was much larger

eg. largest animals on land are dinosaurs and some extinct mammals

eg. largest land animal alive today is an elephant

c. metabolic rate

greater metabolic rates place greater demands on the size of a multicellular organism

→those with the lowest metabolic rates can grow larger

eg. fungi, protists and plants are the largest organisms we know of

animals have a considerably greater metabolism and are therefore relatively small

eg. only ~100 animals species are larger than humans

eg. elephant

requires lots of food: 300-600lbs/day

feeds 16 of every 24 hours

also requires 30-50 gallons of water per day

10. allometric relationships

during development
greater size greater complexity, need more
systems, division of labor, etc

body size affects **metabolic rate** in homeotherms:
→smaller animals have greater metabolism than larger animals/unit mass

therefore, increasing size results in greater efficiency per unit weight

surface to volume ratio:
→why do larger organisms consist of more than one cell

larger organisms require **distribution systems**

eg. vascular plants
planarian – digestive tract, excretory system
insect-tracheal system
circulatory systems