Bacteria (Prokaryotes) General

Bacteria → all are prokaryotes

prokaryote = "before nucleus"

smallest, simplest, oldest cells on earth
1-5µm (vs eucaryotes 10-100µ long)

if human hair were enlarged to size of tree trunk
→ bacterial cell would be size of cockroach

simple structure; not much internal structure

→no organelles – much **less efficient** design

yet extremely successful group:

→1st cells – survived for 2 Billion Years as only kinds of cells on earth

even after much more efficient cells appeared (eukaryotes) they remained successful and abundant

→ bacteria are the most common organism on the earth

dominate the biosphere in terms of numbers

(outnumber all eukaryotes combined)

eg. more bacterial cells in a handful of dirt than all people who have every lived

eg. 1 tsp rich soil contains 1 Billion bacterial cells; 40,000 species

eg. one **species** of bacteria (=*Prochlorococcus* sp.) outnumbers ALL other organisms in the open oceans

eg. as much as 70% of bacteria alive on earth live on and below the ocean floor

eg. the average office desk harbors 20,961 'germs'/sq in

→ ~400'x more than the average toilet seat

→In 'number of cells' bacteria dominate the cells found in many of their hosts:

eg. cows: rumen contains over 25 gallons with 10B bacteria/tsp

eg. humans: our bodies contain ~10x's more bacterial cells than human cells

→ ~3-6lbs of bacteria/ person

only about 10,000 'species' formally named;

most don't grow on artificial media; cant study them

a new way of analyzing species (=metagenomics) allows us to better estimate the number of species present

→current estimates are that we have described just 1% of bacterial species

Bacterial Structure

Microbial Communities

bacteria rarely occur in isolated colonies of a single species

while individual bacterial cells are too small to see without a microscope, bacteria are often found in **microbial communities** that are visible to the naked eye

→ large multicellular aggregations when nutrients are plentiful – then are easily visible

many species of microorganisms (bacteria, fungi, protozoa, algae)

tend to be embedded in **matrix** of water and organic molecules (glycoproteins and polysaccharides)

in some ways these microbial communities take on characteristics of multicellular organisms:

→establish new lines of **communication** to coordinate their actions

they can control activities of the group; they can "talk" to each other by secreting certain chemicals

→**behavior** of the group is different than of any individual species within group

eg. slime bacteria "hunt in packs"

swim together in huge swarms

→lots of **interactions** and **symbioses**

Advantages to individual species in Microbial Communities:

1. provide more stable environment
2. protect cells from UV and heat
3. minimize effects of rapid changes in environment

   eg dental plaque

4. may offer protection from predators
5. highly effective in trapping nutrients

   → most environments are nutrient scarce

   eg. "swarms" of myxobacteria in soil
   → communal feeding
   →can only kill and digest other bacteria if in swarms, otherwise can't produce enough digestive enzymes

6. source of new genes that can be traded as

needed

Kinds of microbial communities

some examples of different kinds of microbial communities:

Colonies
Bacterial Blooms
Biofilms & Microbial Mats
Stromatolites

1. Colonies

colonies of a single species of bacteria are almost never found in nature

but are common when grown on lab cultures

each colony may produce distinctive features such as color, smell, shape, etc. that can be used to help identify the species

a **'colony'** on agar plate is assumed to be a massive growth of a single species of bacterium

only a few (<0.1%) bacterial species can be grown on artificial media:

selective media
→ prevents the growth of certain bacteria while allowing others to grow

enrichment media
→ has special nutrients that enhance the growth of the desired bacteria

differential media
→ contains a specific nutrient and an indicator the show whether the species is able to use that nutrient

2. Bacterial Blooms

rapid reproduction of bacteria produces vast quantities of cells, primarily of a single species

occur when conditions are favorable and food is plentiful

often visible on ponds and lakes in spring

eg. blue-green bacterial blooms often occur in ponds, lakes or reservoirs in spring or summer

rapid growth and decomposition often removes oxygen from water resulting in massive fish kills

eg. cloudy or smoky white blooms are a common problem in new or unbalanced aquaria

3. Biofilms (or microbial mats)

multilayered sheets of bacteria growing on rocks, streambeds, soil crumbs etc

biofilms are also important in medicine

eg. plaque on teeth causes tooth decay

eg. infections that should respond well to antibiotics don't once biofilm is established

the more interconnected the bacteria are, the more resistant to treatment they become

eg. 65-80% of chronic infections in industrialized nations linger because of biofilm formation:

cystic fibrosis
gum disease
chronic inner ear, urinary tract and bone infections

eg. MRSA (methicillin-resistant *Staphylococcus aureus*

kills 90,000/yr in US

even more difficult to eradicate once a biofilm is established

4. Stromatolites

some of the oldest fossils of life on earth are bacterial communities called **stromatolites**

large rocky columns that take 1000's of years to grow

today bacteria still produce stromatolites that closely resemble the fossil ones

produced mainly by **blue-green bacteria**

(=cyanobacteria)

many species interacting
→like a miniature ecosystem of microorganisms

produced most of the O_2 in the earth's early atmosphere

5. Multicellular "Behavior" in Bacteria

some bacteria can come together to form "fruiting bodies" that produce spores for reproduction

sometimes simple mounds of cells

sometimes highly branching structures

in some cases there is a division of labor as in fungi, animals and plants

__**Microscopic Structure of Bacteria**__

most individual bacterial cells are way too small to be seen without a microscope

there are, however, a handful of species that are 100 of times larger than most bacteria

one species is even visible to the naked eye

all bacteria are **prokaryotes:**

no nucleus

small cells, simple structure

usually no organelles

– much **less efficient** design

1. Cell Wall

almost all bacteria have a **rigid cell wall** surrounding the cell membrane

bacterial cell walls have a unique structure and chemistry unlike the cell walls in any other kingdom

chemistry of cell wall varies from species to species

in most bacteria the cell wall is made of **bacterial starch** (= peptidoglycan)

the cell wall protects the bacteria

→ allows them to live in "extreme" environments

the rigid cell wall produces the three basic **shapes** of bacterial cells:

cocci (spheres)
rods (bacilli)
spirals (includes curves and corkscrew

shapes)

→ remove cell wall and all turn into spheres

under the microscope, bacteria are often found as individual cells = **unicellular**

but some species are typically found in distinctive colonies or groupings

eg. **filaments** or clumps of cells; **diplococci**, **staphylococci**, **streptobacilli**, etc

2. Capsule

some bacteria produce a **capsule**

= a gelatinous, sticky layer that allows bacteria to

→attach to substrates

→glues "colonies" together

→also increases pathogenic bacteria's resistance to host's defenses

3. Pili

some bacteria have pili used for **attachment**

and for **bacterial conjugation** in which genes are exchanged between two different bacterial

cells

(a type of primitive sexual reproduction)

some bacteria can also use their pili as legs for **walking** on solid surfaces

pili can also conduct electricity allowing communication within the community

4. Bacterial Flagellum

about half of all bacterial species are **motile**

can move up to 50µm/sec [~100x's body length/sec]

can move by:
flagella
slime trail
helical filaments (spirochaetes)

most use one or more **flagella**

flagellum is whip-like rod that rotates like propeller to move bacteria along

bacterial flagellum is the only rotary motor known in the living world

can spin at 6,000 rpm

allows bacteria to move ~10x's their length/second ability to move and orient produces simple behaviors = "**taxes**"

→movements toward or away from stimuli

eg. such as light, food, oxygen, gravity, etc.

eg. + & - chemotaxes

have specific receptor molecules on cell surface to detect chemicals

5. Magnetic Particles

some bacteria contain rows of magnetic particles that acts as a single, long magnet

allows them to orient toward the earth's magnetic field

allows them to travel in straight lines to find "surface" of water, specific light level, food, etc

reduces the effects of Brownian motion

7. Endospores (bacterial spores)

some bacteria can form endospores to survive adverse conditions

very resistant to destruction

→withstand desiccation and harsh conditions

<u>not</u> for reproduction

8. Cytoskeleton

like eukaryote cells the cytoskeleton is a series of interconnected protein fibers within the cell

in bacteria it anchors structures such as flagella, and magnetic particles and in some, helps to maintain shape

9. Vacuoles

a few bacteria have internal sacs that contain enzymes for specific jobs or that store various chemicals

10. Chromosomes & Genes

all living cells contain chromosomes

genome = all the genetic material that a cell contains

bacterial genome contains about 3000 genes

(humans contain ~21,000 genes)

bacterial genes are contained on two kinds of DNA:

a. **chromosome**

b. **plasmids**

a. chromosomes

DNA is in form of one large **circular chromosome**

not enclosed in membrane of nucleus

not associated with proteins (histones)

the chromosome itself is also of a much simpler structure than those in eucaryotic cells

b. plasmids

also one or few small circular pieces of DNA = **plasmids**

often contain genes for environmental tolerances and antibiotic resistances

Bacterial Physiology

<u>Bacterial Growth</u>

new bacterial cells can only grow slightly in size

when we say bacteria "grow" we usually mean they are reproducing, ie. increasing in numbers

bacterial growth = bacterial reproduction

one of the reasons bacteria are so successful is that most reproduce very rapidly

most bacterial reproduction is by **asexual fission**

asexual reproduction is much **faster** than sexual reproduction

the **Life Cycle** of bacteria is measured as the time between when the cell is first formed and when it divides by fission

time between divisions = **generation time**

generation time is typically about 20 o 30 minutes

Staph aureus	30 min
M. tuberculosis	18 hrs
T. pallidum	33 hrs
E coli	20 min

eg. E. coli: one cell at 8:00 am, no limiting factors:
→ 36 hrs later → 1 foot over surface of earth

some newly discovered bacteria found in the deepest, most barren parts of the ocean have the longest bacterial life cycles known

→ 100's of 1000's of years before each division

slowest metabolism of any known life form

Bacterial Metabolism

prokaryotes have a very simple structure but show an almost unlimited variety of metabolic pathways

bacteria show more **metabolic diversity** than all other kingdoms combined

→every kind of **food** eaten by any other form of life can be eaten by some species of bacteria

→some **nutrients** can only be used by bacteria and not by any other form of life

→bacteria can do **photosynthesis** dozens of different ways versus plants or algae which have only one type of photosynthesis

→ bacteria can produce energy (**respiration**) in 100's of different ways versus only 1 way for plants and animals

Bacterial Nutrition

all life requires **food** for survival, in most organisms food must provide 2 main resources:

A. **building blocks (nutrients)**

simple **elements & molecules** to construct larger organic molecules & cell parts

B. an **energy source**

energy powers all metabolism and everything the cell "does"

A. Building Blocks

As does all life bacteria require sources of Carbon, Hydrogen, Oxygen and Nitrogen, Phosphorus, etc as well as several other elements

as a rule bacteria require fewer and often simpler **essential nutrients** than higher life forms

eg. humans require about a dozen essential organic molecules; vitamins, some amino acids and some fatty acids

many bacteria can make ALL the organic molecules they need from simple atoms and inorganic molecules; they require NO essential organic molecules

also, bacteria, as a group, rely on an extremely diverse group of nutrients compared to us

bacteria can use 1000's of different kinds of nutrients:

→virtually every natural and human made chemical can be eaten by at least some bacterial species

including minerals in rock, acids, hydrogen sulfide, sulphur, etc

some bacteria can even break down pesticides, herbicides, petroleum, asphalt, DDT, concrete, computer chips, paints, even plastic and glass

eg. the plastic we throw in the oceans harbors 1000's of species of bacteria forming a uniquely identifiable **plastisphere**

eg. Carbon

of the **essential nutrients** carbon is often the most critical

carbon is needed for building any kind of organic molecule

eg. humans get carbon atoms from eating organic molecules

eg. plants get all the C they need from CO_2

→ but bacteria can get carbon from a wide variety of sources:

eg. organic carbon: methane, alcohols, sugars, starches, proteins, fats, petroleum, plastics, etc

eg inorganic carbon: CO_2, calcium carbonate, bicarbonate, etc

eg. Nitrogen

nitrogen is essential for making proteins and nucleic acids

most living organisms are fairly limited in the sources of nitrogen that they can use:

eg. animals get all their N from eating proteins

eg. plants need no organic foods, they get N from small inorganic nitrogen chemicals in the soil such as ammonia

bacteria can eat many forms of nitrogen both organic and inorganic

eg. a few bacteria can **fix** nitrogen gas from the air

bacteria are the only organisms that can do this

N_2 gas makes up 80% of atm but is completely unusable by all other life forms

eg. Phosphorus

most organisms including us get most of our phosphorus from organic molecules such as nucleic acids and lipids, and a few inorganic phosphates

plants get all their phosphorus from inorganic phosphates in the soil

again, bacteria can extract phosphorus from virtually any phosphorus containing compound, organic or inorganic

because bacteria can "eat" almost anything, they are very effective **decomposers** and recyclers

→bacteria are of major importance in the world's **biogeochemical cycles**

eg. nitrogen cycle, carbon cycle, etc

bacteria can even decompose (=eat) "nonbiodegradable" compounds

eg. rough estimates for time to degrade:

leather	2,000 yrs
plastic	1,000's of yrs
humus	35,000 yrs
glass	1, 000,000's of yrs
lignite	1 million yrs
amber	25 million yrs
chitin	500 million yrs

→ but each is eventually broken down

Bacterial Energy Sources

all life uses energy in the form of **chemical bonds**

chemical bonds in all molecules are "stored energy"

when you break those bonds
→ energy is released

eg. chemical bonds in gasoline are broken down to provide energy for movement

ALL life gets its energy from breaking the chemical bonds in sugars and other **organic molecules**

producing energy this way = **respiration**

these sugars and other energy storing molecules can come from two sources:

→most organisms (eg. animals and fungi) must **eat** organic molecules (eg. sugars, starches, proteins,etc) and then break them down to extract energy

= Heterotrophs

eg. animals (including humans) eat mainly large complex organic molecules

then break them down to extract nutrients and to produce energy

most bacteria are **heterotrophs**

they can eat a wide variety **organic molecules** to break down for energy

eg. plants and animals generally break down sugars for respiration

eg. bacteria can break down sugars as well as almost any other organic molecules such as proteins, fats, oils, starches, etc.

→some organisms (algae, plants, blue-green bacteria) can *make their own sugars* and organic molecules from small inorganic molecules using some other outside energy source

= Autotrophs

eg. plants need only simple inorganic nutrients

they then use energy from sunlight to convert these into organic sugars and other large molecules

they can then break these sugars down to release energy for all their needs

some bacteria are **autotrophs** and use some other source of energy to build their own organic molecules for respiration

eg. energy from sunlight

like plants and algae do

eg blue green bacteria

eg. energy from inorganic compounds

no plant or animal can extract energy from small inorganic compounds

certain bacteria can oxidizes inorganic compounds for energy

eg. H_2S; NH_3; Fe^{++}, S_2 H_2, H_2SO_4, etc

eg. some deep ocean autotrophs (thermal vents) extract energy from the oxidation of hydrogen sulfide to sulfate

Bacterial Respiration

ALL life gets its energy from breaking the chemical bonds in sugars and other **organic molecues**

=respiration

most life, including plants & animals, break down sugars using oxygen gas

→ **aerobic respiration**

completely breaks sugars down to CO_2 & H_2O
much more efficient
much more complicated set of reactions

but many bacteria can partially break down sugars into smaller organic compounds without using oxygen gas

→ **anaerobic respiration**

much simpler process
only partially breaks down the sugars, etc
much less efficient

one example of anaerobic respiration is **fermentation**

many bacteria are **fermenters**
→ extract energy from sugars by converting them to other organic compounds

eg. sugars →
- carbon dioxide
- acetone
- alcohols
- vitamins
- lactic acid
- acetic acid
- citric acid

many of these fermentation products have become commercially important products

Growth Rate

in nature, bacteria rarely grow as richly as in lab cultures

bacteria are **opportunistic**

→when conditions or nutrients are right they reproduce quickly

→when conditions are unfavorable or food runs out metabolism slows or ceases

the rate of bacterial growth is often affected mostly by the essential nutrients in shortest supply

when essential nutrients are abundant get rapid reproduction (growth)

→ often form **blooms**

as essential nutrients are depleated growth slows or stops altogether

living bacteria have been found living in 8.7 Million year old sediment below the floor of the ocean

nutrients are so scarce that they grow extremely slowly

they grow so slowly that they rarly even divide for probably 100,000' of years

Environmental Factors

because bacteria are relatively simple and very adaptable they can survive, and even thrive, under many conditions that we would consider quite harsh

eg. ideal conditions for humans:
nice balmy temperatures
not too hot, not too dry,
plenty of food and drink,
not overcrowded, etc.

bacteria, as a group, have the **widest tolerances** for temp, pH, salt, etc than any other kingdom of organisms

their rates of growth and reproduction are greatly affected by various environmental factors:

temperature preferences
pH tolerance
salt concentrations
oxygen requirements
light (for photosynthetic bacteria)

each species has its own preferences and **tolerance limits** for these factors

Extremophiles

organismsm that prefer the "extremes" of these conditions needed for life are called **extremophiles**

eg. (our "normal" = 98º F) microbes that thrive in temperatures 122ºF (>50ºC) =**thermophiles**

hot springs, ocean thermal vents

eg. (our normal pH~7) microbes that thrive in pH <5 = **acidophiles**

acid lakes and bogs, mine tailing drainage

eg. (our normal ~0-3%) microbes that thrive in salt concentrations ~10-20% =**halophiles** (sea=3% salt)

great salt lake, dead sea, desalination ponds

Oxygen Requirements

bacteria have various requirements for **oxygen** gas depending on their kind of respiration

obligate aerobes (strict aerobes)

→ die without oxygen gas

obligate anaerobes (strict anaerobes)

→ die in the presence of oxygen gas

facultative anaerobes

→ can use oxygen when available, and do anaerobic metabolism when its not

Bioluminescence

some deep water marine bacteria are bioluminescent glowing “food” attracts bacterial feeders as a means of dispersal for the bacteria

<u>Exposure to Radiation</u>

Deemed “**the world’s toughest bacterium**”

Deincoccus radiodurans was discovered in 1956 in a can of meat that had spoiled despite being sterilized by radiation

found that it can withstand and actually grow during exposure to 3 million rads of radiation (=1000’s x’s lethal human exposure)

exposure to such strong radiation breaks its genome into pieces but the bacterium is able to quickly repair itself

it can also withstand extreme heat, cold and high acidity

we still have no idea of its natural habitat

Bacterial Dormancy & Spores

scientists have found living bacteria inside 30,000 year old salt crystals from Death Valley.

they fed on algae entombed in a tiny droplet of hypersaline water within the crystal

bacteria trapped in ice crystals for over 500,000 years, over a mile below the surface are able to survive & metabolize in a film of liquid water that allows diffusion of nutrients but no reproduction, just waiting for the ice to melt

even when nutrients are in short supply bacteria don’t necessarily die

→ they can enter a **dormant state** in which metabolism ceases for up to 1000’s of years, until favorable conditions return

→ some can form resistant bacterial **spores**

Spores are extremely resistant to destruction

eg. *B anthracis* → 50-70 yrs

eg. from deep ocean sediments → 5800 yrs

eg. spores extracted from salt crystals in 250 M year old deposits

→**Bacterial Cells can be essentially immortal**

Bacterial Mutations & Evolution

evolution is based on variations caused by **sexual reproduction** and **mutations**

→ nature then **selects** the cells with the most useful combination of traits

How did bacteria, which reproduce primarily asexually evolve and diversify so quickly?

→ but have many ways to alter their genetic makeup

1. due to rapid life cycles, **natural mutations** are another main source of genetic variations

one of the main sources of genetic variations over generations is random natural mutations

all life mutates and passes some of these mutations on to the next generation

we (humans) accumulate about 60 mutations per generation (20 yrs) that we pass on to our children

bacteria mutate 100 x’s faster than humans and reproduce every 15 or 20 minutes

→ populations of *E. coli* can accumulate about

10 million mutations **per day**

2. bacteria do perform a simple kind of “sexual reproduction” called **conjugation**

   2 different strains use **pili** to exchange some genes (not all)

3. viruses that infect bacteria sometimes add new genes to the bacteria but don’t kill the bacteria

4. bacteria can **trade genes** easily with other species of bacteria, even with eukaryotes

   their DNA is loose inside cells → easy access to genes

   they often have spare strands of DNA (extra genes)

5. bacteria can even absorb DNA from the environment

   when bacterial cells die the DNA is released some of it can be taken up by surrounding cells

   this environmental DNA can even be ancient DNA from now extinct species

<u>Bacterial ‘Species’</u>

a **species** is defined as a group (population) of organisms that naturally interbreed with each other

the typical distinction between different **species** does not apply to bacteria

bacteria "create a huge planetary gene pool that gives rise to temporarily classifiable bacterial 'types' or 'strains' which radically and quickly change, keeping up with the environmental conditions"
-Margulis and Sagan, 1995

we are now also beginning to find bacterial genes in plants and animals, being passed on to offspring and contributing to evolution of species

So, Why are Bacteria So Successful?

even though:

bacteria are the smallest, most primitive cells on earth

simple structure; not much internal structure
→no organelles

much **less efficient** at metabolism

yet:

bacteria dominate the biosphere in terms of numbers;

play vital role in the recycling of nutrients

virtually all other forms of life are dependent on bacteria directly or indirectly for their survival

→ bacteria are generally not dependent on any other life form for their survival

Why?

1. bacteria have a relatively simple, relatively uncomplicated structure

→much less efficient but very adaptable

2. bacteria have tremendous **physiological diversity**

→ bacteria can metabolize 1000's of different kinds of nutrients

→ can use many food and energy sources as available; and change as needed

3. bacteria, as a group, have the **widest tolerances** for temp, pH, salt, etc than any other kingdom of organisms

→many species can survive, and even thrive, under many conditions that we would consider quite harsh

4. they have a **rapid reproductive rate** to quickly take advantage of optimal conditions when they occur

→asexual reproduction is much **faster** than sexual reproduction

5. when nutrients are in short supply or conditions are unfavorable they don't necessarily die

→ they can enter a **dormant state**

→ some can form bacterial **spores**

they can remain dormant or 1000's even millions of years

always there and ready to take advantage of favorable conditions

6. can freely and rapidly mutate, absorb genes from their surroundings and exchange genes with viruses and other bacteria to adapt to new foods, conditions or become more resistant to harsh conditions

Ecological Roles of Bacteria

1. Biogeochemical Cycles

bacteria are essential for cycling nutrients

virtually ANY naturally occurring organic chemical and many synthetic organic chemicals can be broken down ("eaten") by at least some bacteria

including: paper, paints, leather, textiles, computer chips, metals, petroleum, concrete, plastics, DDT, etc

→if they weren't here, we wouldn't be either

the world would fill up with dead animals and plants

we would run out of nutrients

2. Primary Producers

bacteria are base of food chain in some ecosystems

eg. ***Prochlorococcus*** (the world's most abundant marine organism) and other marine phytoplankton carry out about half of the world's photosynthesis

eg. blue green bacteria in aquatic ecosystems

eg. hydrothermal vents

eg. methane seeps

3. Oxygen Production

BG bacteria were the only autotrophs for billions of years and created our oxygen containing atmosphere

and even today make most of the O_2 in our atmosphere

4. Numerous Symbioses

symbiotic bacteria are common in all kingdoms of life, including bacteria symbiotic with other bacteria

almost all animals have bacterial symbionts

a. cellulose digesting bacteria

some species of bacteria, some protists, and most fungi are able to produce the proper enzymes to digest cellulose in plants

virtually no animal species can produce cellulose digesting enzymes

animals that are strict herbivores rely on cellulose digesting microorganisms to extract nutrients from plant materials

eg. termites

100's of species of cellulose digesting bacteria and protist that digest the bits of wood eaten by the termites

a diet restricted to wood only (not softer green parts of plants) is very low in nitrogen and termites also have nitrogen fixing bacteria that converte N_2 into useable nutrients for the termites

eg. ruminate mammals (such as cows)

a portion of their stomachs are modified into fermentation chambers

they have several 100 species of cellulose digesting bacteria, 40-50 species of cellulose digesting protists, and some fungal species (billions of cells/ml; 1/5th tsp) that ferment the plant material to release nutrients for the cow to absorb

b. Root Nodules; a symbiosis between bacteria and plants

nitrogen is an important nutrient for all forms of life and one of the most hard to get essential nutrients for plants

even though the air contains 80% N_2, no higher organisms can use it therefore nitrogen is usually in short supply for most organisms

nitrogen fixing bacteria and some cyanobacteria are able to converte the N_2 from the air into useable nitrogen compounds for other organisms

Some plant roots have a symbiotic relationship with these nitrogen fixing bacteria

→ mainly legumes (beans, peas, bluebonnets)

→ also some bryophytes, water fern, some cycads

plants secrete chemicals into soil to attract bacteria

Rhizobium or some cyanobacteria (mainly *Anabaena* or *Nostoc*) responds by secreting chemicals that trigger plant to enclose the bacterial cells

nitrogen can only be "fixed" in low O_2 conditions so the plant creates a "growth chamber": a swelling on root called **root nodules**

each nodule contains millions of bacteria

bacteria convert nitrogen gas (N_2) into useable nitrogen 'fertilizer' for the plant

eg *Rhizobium*: $N_2 \rightarrow NH_3$

up to 30% of the plants sugars made by photosynthesis are given to the bacterial symbionts in exchange for the NH_3 they produce

bacteria get nice place to live and free carbs

plant gets hard to get nitrogen fertilizer in the form of ammonia

other symbioses with N-fixing bacteria:

diatoms
fungi of certain lichens
shipworms
termites

c. Petroleum Fly Larvae

the adult fly lives around petroleum seeps (eg. La Brea tar pits) feeding on insects that get stuck in the goo

its larvae actually live in the oil and survive by eating the bacteria that thrive in the oil and are symbiotic in their guts.

d. Human bacterial symbionts; the "normal flora" or "microbiome"

"you are born 100% human, but die 90% microbial"

-even this adage has been recently disproven:

bacteria colonize our gut in the womb where they begin to shape our immune system and susceptability to diseases

3 lbs of bacteria (10x's the number of human cells; 400 microbial genes for each human gene)

→ mainly in gut

eg. dental plaque on human teeth contains 100 or more bacterial species; many of which are found no where else in nature

eg. some places on the skin contain up to 300 different species

→ the "richest" areas: belly button, buttocks & gluteal crease

→ only a few species were found: greasy spot behind ear, side of nose, toe webs and sternum

which species you have on your skin determine whether you get acne or not

some are **mutualistic** (both benefit)

eg. **skin bacteria** play a vital role in preventing unchecked inflammation triggered by injury and bacterial pathogens

widespread use of antibacterial hand gels may exacerbate such skin inflammation

eg. gut bacteria

→help break down hard to digest fibers and starches

→make essential vitamins

→protect us from pathogens

→provide additional nutrients from food eaten

→remove plant toxins and some carcinogens

→remove chemicals like H_2 gas that are toxic to "good" gut bacteria

→activate our immune systems to better resist infections

gut bacteria change and adapt as foods change

→ those better able to metabolize dominant food tend to increase

eg. baby:milk→solid food→vegetables

we are beginning to see that our symbiotic microorganisms play an essential role in our survival, adaptation and evolution

our microbiome is also strongly correlated with our genetic makeup

→ may be as distinctive as our fingerprints; mostly correlated with genes that control our immune system

a new (2011) study shows that the abundance of certain bacteria in your feces correlates with your age, gender, body mass index, and nationality

obesity, diabetes, Crohn's disease, colitis, autism may be the result of an imbalanced microbial ecosystem in our guts

some forms of severe malnutrition have been linked to a particulary group of intestinal bacteria

intestinal bacteria have also been linked to celiac disease & inflammatory bowel syndrome

some are **commensals** (don't benefit or harm us)

but many of these are "**opportunists**"

→ can sometimes cause problems

d. some bacteria (bdellovibrios) are parasitic inside other bacteria

e. some algae & protozoa have a mutualistic relationship with bacteria

eg. bacteria inside protist inside termite

f. some fungi have a symbiosis with blue green bacteria

eg. one form of lichens

5. Unique Bacterial Ecosystems:

A. Deep Ocean Hydrothermal Vents

discovered in 70's at deep ocean ridges

hot mineral rich waters flowing out of cracks in the crust,

especially rich in H_2S (hydrogen sulfide)

whole community of organisms,
many are unique species;
include large worms and clams, crabs, shrimp, fish, and dense clouds of bacteria

bacteria live inside the tissues of some of these animals;

the animals absorb H_2S from the hot waters,

use **hemoglobin** to carry this H_2S to the bacteria deep in their tissues

the bacteria use the energy in H_2S to make sugars which the animals absorb

therefore it's an entire ecosystem that is not based on solar energy for autotrophic production

B. Hydrocarbon Seeps

methane (natural gas) leaks from sediment in Gulf of Mexico

creates methane pools on seafloor

mussels at hydrocarbon (methane) seeps have symbiotic bacteria in their gills

these bacteria oxidize methane to get energy and food

bacteria live in vacuoles of gill cells

clam gets organic molecules made from the methane and secreted by the bacteria

Direct Human Impacts of Bacteria

1. Crop Production

one of the most limiting nutrients especially for plants is **nitrogen**

but there is lots of nitrogen in the air
→ 80% N_2

some bacteria can **fix** this nitrogen gas
→ only organisms that can do this

some of these bacteria form symbiotic **root**

nodules with plant roots and allow these plants to grow in poorer soil

these require much less fertilizer to grow
→ much cheaper

blue green bacteria are used in China to fertilize rice paddies

2. Food Products

fermenting bacteria are used to make a wide

variety of **foods**:

bread, bakery products, yogurt, cheeses, , etc, etc, etc,

many of the smells and flavors of these food products is due to the bacterial used

most of these products use a culture of 6 - 8 different bacterial species; often with several fungal species as well

A. Cheeses

Often produced by the actions of groups of microorganisms including bacteria and fungi

the characteristic textures and flavors of different cheeses result from; the kind of milk used (cow, goat, sheep, etc); whether the cheese is ripened (cured) or unripened and what mixture of microorganisms are used

The first step in making most cheeses is to prepare a **curd** by adding lactic acid bacteria and rennin or bacterial enzymes to milk.

The bacteria sour the milk and enzymes coagulate the milk protein, casein, to produce a **soft 'curd'** to make cheese and a **liquid 'whey'** which is a waste product.

The amount of whey removed determines the hardness of the cheese. eg. soft cheeses the whey is simply drained away. Harder cheeses are heated and pressurized to remove additional whey from the mixture.

After this separation, most cheeses are ripened with inoculations of various species of bacteria and/or fungi.

B. Other milk based products

eg. Yogurt

The lactose in the milk is fermented by microorganisms to produce lactic acid. The flavor is a result of the sugar and the 2-3% lacatic acid generated by this fermentation.

eg. Butter

Butter is produced by inoculating cream or milk with microorganisms and allowing it to. The characteristic aroma and taste of butter result from the fermentation process.

eg. Buttermilk

eg. Sour Cream

C. Sourdough Bread

Wheat flour is fermented using *S. exiguus* and *Lactobacillus sanfrancisco* to produce the tart, acidy flavor

D. Oriental Sauces

eg. Soy Sauce, Memmi

Soy sauce is produced by the fermentation of roasted soy beans and wheat using a mixture of various bacteria and fungal species including:

E. Vinegar

Vinegar is a fermented food traditionally made by the spontaneous souring of wine. Industrial Vinegar production begins by inoculating the fruit juice with yeasts which ferment it to an alcohol content of 10-20%. Then the juice in inoculated with the bacterium, *Acetobacter aceti*, which convert the alcohol to acetic acid.

F. Cured vegetables

eg. Sauerkraut

Sauerkraut is produced by the natural fermentation of layers of shredded cabbage alternating with layers of salt. The salt inhibits undesirable bacteria and draws out the juices of the cabbage. In two to three months fermentation by microorganisms produce acids and esters with the desired aromas and flavor.

eg. Pickles

Pickles are made by fermenting cucumbers in a mixture of bacteria normally found growing on them.

eg. Green Olives

eg. Kimchi

Made from shredded cabbage fermented with lactic acid bacteria

G. Cured Meats

eg. Cured (Fermented) Beef or Pork Sausages

eg. Pepperoni, Salami, Thuringer, Polsa

These are generally produced by adding seasoning agents to the ground meats, stuffing the meat into casings and incubating them with a bacterial culture at warm temperatures. Mixed acids produced from the fermentation give the sausage its unique flavor and aroma.

3. Beverages

A. Acidophilus Milk

Lactobacillus acidophilus is added to milk to produce an acidity of 2-3% lactic acid.

B. Coffee

After coffee beans are picked they are soaked in water containing natural cultures to loosen the berry skins before roasting. Some fermentation occurs which is believed to produce some of the unique flavors of various varieties of coffee.

C. Cocoa

Microbial fermentation is used to help remove the cocoa beans from the pulp covering them in the pod. The products of this fermentation contribute to the flavor of the cocoa.

4. Bacteria as food

the only bacteria cultured today as a protein supplement is ***Spirulina***, a bluegreen bacterium common in freshwater lakes and ponds as "pond scum"

some claim many unsubstantiated benefits
but no solid evidence for most claims

eg. cure AIDS, Alzheimer's, herpes, etc
also: energize body, enhance digestion, focus mind, keep pets healthy, etc

→complaints about nausea and diarrhea are common

there is some interest in using bacteria directly as food product

bacteria are high in protein

Meat and fish contains ~20% protein
bacterial cells contain ~50% protein

and can be easily grown in large quantities to produce protein much quicker than cattle or other animals:

eg. estimated yield of protein produced per day by:

1000 lb steer	→ 1 lb
1000 lbs soybeans	→ 100 lbs
1000 lbs bacteria	→ 100 trillion lbs

and bacterial protein would also be >10x's cheaper than cattle or fish protein

5. Industrial Microbiology:

a. current production:

uses large cultures of bacteria and other microorganisms to produce various industrial chemicals such as amino acids, citric acid, enzymes, pharmaceuticals, etc

eg. amylase (Bacillus subtilis) → textiles, food and drink production

eg. proteases (*Bacillus*) → clarify beer, tenderize meat, used in toothpaste to reduce plaque; some used in laundry detergents to help clean

eg. rennet (several species) → prepares curd for cheese making

eg. leather tanning

eg. linen processing; uses *Clostridium* species

eg. millions of pounds of specific amino acids and vitamins are extracted from bacterial culture

b. future production:

eg. sticky slime secreted by bacteria contains a natural adhesive that may be less expensive but just as strong as a wood adhesive for making plywood and particleboard

eg. genetically engineered bacteria are increasing the variety of industrial products we can produce from bacteria

6. Pharmaceutical Products

a. many natural bacterial products are harvested for pharmaceutical purposes:

eg. antibiotics. antibiotics were first discovered in fungi (eg. Penicillin); today many antibiotics are also extracted from "fungus-like" bacteria.

Amphomycin from *Streptomyces canus*

Bacitracin from *Bacillus subtilis*

Erythromycin from *Streptomyces erythreus*

Nystatin from *Streptomyces noursei*

eg. botox. botulism toxin, one of the deadliest bacterial toxins is injected into muscles of face and head to eliminate wrinkles

also is used to treat migraines

new (2010) research has found that facial expressions trigger and intensify appropriate feelings

paralysis produced by botox injections may alter emotional reactions associated with proper facial expression and may even weaken brain circuits that coordinate some emotions

eg. streptokinase (*Streptococcus*) → dissolves clots, reduced heart attacks

b. Genetic Engineering

genes for human proteins have been inserted into bacteria and cultures of these bacteria now produce commercial quantities of:

human insulin
human growth hormone
human somatostatin
human interferon

7. Microbial damage to foods and other products

because bacteria are such good decomposers they cause billions of dollars in crop and materials losses each year

eg. $50 B/yr stored foods are lost due to bacteria

eg. paper, paints, textiles, leather, metal, etc are destroyed or weakened

8. Microbial Corrosion

metal corrosion causes $100's of Billions of dollars in damage to pipelines, bridges, storage tanks etc in the US each year

almost all metal corrosion is caused at least partly by bacteria

many bacteria produce hydrogen sulfide and various acids that corrode metals and other products

eg. the "rusticles" on the sunken titanic are largely due to bacterial activity

long term exposer may also cause bacterial corrosion on many other materials such as plastics, concrete

9. Mining of Minerals

some bacteria are associated with gold and other mineral deposits

can be used to extract and concentrate metals from low grade ores and slag

eg. gold

some bacteria can extract gold from solution and convert it into gold particles that can be extracted

researchers have now developed a genetically modified bacterium that emits light when gold is detected. Can use light meter to detect the signal

eg. Maganese Nodules

fist sized, deep sea mineral deposits formed by bacteria

1st discovered on Challenger expedition of 1874

contain high concentrations of Fe, Mn, Cu, Ni, Co

esp abundant on red clay sediments of NE Pacific

US Bureau of Mines estimates the richest deposits exceed 16 Billion metric tons (17.6 B tons)

→ 20x's all known land reserves of some of these minerals

→ >2000 years worth at current useage

→estimate that 16 Million tons accumulate each year

("grow" ~ 1-10mm/million yrs)

small scale trials have collected some → still not economically feasible

eg. 2006 some bacteria are being used to recover **palladium** from spent catalytic converters

10. Bioremediation

because of their ability to metabolize such a wide variety of chemicals bacteria are being tested and used to help decontaminate hazardous waste sites

soil bacteria can sometimes transform highly toxic chemicals into harmless compounds

eg. contaminated soil around munitions factories are laced with species that can metabolize nitroglycerine and other explosives

eg. soil bacteria that can transform benzene benzene into harmless chemicals

eg. a community of bacteria that break down components of petroleum are sprinkled on oil spills to reduce the damage they might cause on beaches

eg. some bacteria can decompose creosote, trichloroethylene and 245-T (agent orange)

as our knowledge increases we will be able to drastically cut the costs of cleanup of contaminated sites

11. Renewable Energy Production

a. Methane Production

Some bacteria (archaea) are used for **energy** (methane) production

a typical dairy cow produces 200-600 l of methane/day; 50-150 kg/yr

if burnt, a cows annual methane emissions would yield about as much energy as 200 liters of gasoline

gut bacteria produce 2B tons of methane/yr affect global carbon cycle

methane collected from garbage and dung used as renewable energy source

b. Biofuels

existing biofuels are produced from waste cooking fats or hydrocarbon producing plants

they cannot be processed by refineries

genetically engineered bacteria can now be made to convert waste sugar to feedstock for refineries

would dramatically reduces cost of alternative energy production

c. Fuel Cells

biologists have recently (2006) powered a small fuel cell by feeding bacteria chocolate factory wastes (diluted caramel and nougat wastes)

the bacteria broke down the waste sugars to produce hydrogen

the hydrogen was used to power a fuel cell

could provide a waste for normally landfilled wastes

another microbe (*Rhodoferax ferrireducens*) is

able to extract enough energy from sugars that the process has been used to make a small fuel cell that can power hand calculators

12. Toxic Blooms

some cyanobacteria can cause toxic fish kills in fw ponds, lakes and reservoirs

especially in spring and fall

13. Bacterial Diseases

a. Food Poisoning

It is estimated that between 24 and 81 million cases of food borne diarrhea disease occur each year in the United States,

costing between $5 billion and $17 billion in medical care and lost productivity.

More than 90 percent of the cases of food poisoning each year are caused by *Staphylococcus aureus, Salmonella, Clostridium perfringens, Campylobacter, Listeria monocytogenes, Vibrio parahaemolyticus, Bacillus cereus,* and Entero-pathogenic *Escherichia coli*.

These bacteria are commonly found on many raw foods. Normally a large number of food-poisoning bacteria must be present to cause illness.

Poor personal hygiene, improper cleaning of storage and preparation areas and unclean utensils cause contamination of raw and cooked foods.

eg. *Staphylococcus aureus*

When *S. aureus* is allowed to grow in foods, it can produce a toxin that causes illness.

Although cooking destroys the bacteria, the toxin produced is heat stable and may not be destroyed.

Staphylococcal food poisoning occurs most often in foods that require hand preparation, such as potato salad, ham salad and sandwich spreads.

eg. *Salmonella*

The gastrointestinal tracts of animals and man are common sources of *Salmonella*.

High protein foods such as meat, poultry, fish and eggs are most commonly associated with *Salmonella*.

The major causes of salmonellosis are contamination of cooked foods and insufficient cooking. contamination of cooked foods occurs from contact with surfaces or utensils that were not properly washed after use with raw products.

eg. *Clostridium botulinum*

Botulism accounts for fewer than one of every 400 cases of food poisoning in the U.S. it occurs mostly in home-canned foods.

Cl. botulinum can exist as a heat-resistant spore, and can grow and produce a neurotoxin in under processed, home-canned foods.

An affected food *may* show signs of spoilage such as a bulging can or an off-odor.

The botulinum toxin is destroyed by boiling the food for 10 minutes.

b. Bacterial Pathogens

[some examples of bacterial diseases]

Tuberculosis (*Mycobacterium tuberculosis)*
Gonorrhoea *(Neisseria gonorrhea)*
Anthrax (*Bacillus anthracis*)
Syphilis (*Treponema pallidum*)
Borellia → relapsing fever, lyme disease
Leptospira → leptospirosis from urine of dogs, cats, pigs
Helicobacter → ulcers
Legionella → legionnaires disease
Bordetella → whooping cough
Salmonella → typhoid fever
Shigella → bacillary dysentery
Yersinia → plague
Vibrio → cholera
Clostridium: botulism, gas gangrene, tetanus
Staphylococcus aureus
Streptococcus pneumonia

Some Examples of Bacterial Diseases:

eg. Tuberculosis (*Mycobacterium tuberculosis)*

is an ancient disease

→ skeletons and mummies from 4500 BC show signs of the disease

has been called the worlds most neglected epidemic

→kills more people worldwide than any other infectious disease

about 1/3rd of the world's population is infected, with 8-10 million new cases each year

about 2 million people die each year from the disease

one of most easily combated diseases if caught early

very difficult to get rid of in advanced cases

slow growing pathogen – respiratory disease

infection in lungs causes formation of 'tubercles'

90% of infected people remain infected for life but never develop symptoms of the disease = **asymptomatic** (subclinical)

good example of a balanced host/parasite relationship
→ hosts are usually not aware of pathogen and it is usually eliminated by the immune system

if body's defenses fail → disease results

most commonly acquired by inhaling

has long incubation period

the infection causes formation of tubercles in lungs as bacteria multiply inside

of body's defenses are overwhelmed may produce symptoms:
weight loss
coughing bloody cough
fatigue
weakness
anorexia
low grade fever

may become a chronic infection

major concerns today:

1. two new strains have appeared:
   →a fast growing form
   grows 1000x's faster
   much more easily spread → don't need extended contact (just standing in line with infected can get it)

   →a completely antibiotic resistant form

first appeared in 2006, now confirmed in 27 countries (2007)

2. increased poverty and urbanization

   → rates in cities higher than in rural areas is a disease of the urban poor, homeless, AIDS victims

3. increase in HIV patients

   more susceptible to infection

eg. Anthrax (*Bacillus anthracis*)

common soil organism
→ grows slowly in soil

produces spores that can persist for years

up to 60 years

is a **zoonosis** – animal disease that people can catch

a fatal disease of livestock; eg. sheep, cattle, goats, horses

people catch it from animals, not usually from other people

soil is a reservoir → spores can persist

in humans is mainly and occupational disease: farmers, vets, textile and fur workers, etc

ID is very low: 1-3 spores

enters through cuts and abrasions on skin or spores can be inhaled

cutaneous anthrax

if spores enter skin through abrasions or cuts:

begins as a skin infection of pustules

develops into a necrotic ulcer

bacilli release toxins that cause local swelling

if untreated may spread through lymphatic system to blood to cause septicemia

if so will cause shock and death within a few days

is relatively easily treated and removed

5-50% mortality if untreated

pulmonary anthrax

is the most dangerous form; much higher mortality rate

→ can be fatal within hours

need pretty high exposure to spores to actually get the disease

produces flu like symptoms

gets into blood much more quickly → systemic toxemia

eg. Syphilis (*Treponema pallidum*)

humans are only natural hosts

STD→ survives only a few minutes to hours in body secretions; up to 36 hrs in stored blood

first recognized in 1500's:

thought it may have been a disease picked up by Native Americans and spread to Europeans,

new evidence doubts this, it was in Europe before contact with Americas

very common in US until 40's and discovery of penicillin

on increase again today

esp among prostitutes and drug users

disease is slow and progressive with long periods of latency

easily treated in early stages, difficult to treat in advanced stages

progresses through three major stages:

1st – (9-90d after infection)

after sexual contact, the bacteria enters through breaks in skin

produce open sores in genital area (cancres)

they persist for several weeks, then heal

2nd – (3 wks – 6 mo after 1st stage heals)

several months later the bacteria have spread throughout the body,

secondary lesions appear on skin surface: trunk, arms, legs, genitalia, palms, soles

highly infectious at this stage

causes fever, headaches, sore throat, rash, etc.

symptoms disappear in a few weeks

3rd – (3-30 yrs after primary infection)

latent period lasts up to 20 years, about 30% of patients untreated will show severe pathology

noncommunicable unless secondary lesions appear again

causes soft lesions in skin, bone, blood vessels, liver, CNS

wide range of symptoms depending on tissue showing lesions:
rupture of blood vessels
heart damage
blindness
derangement
convulsions
brain damage

eg. Gonorrhea (*Neisseria gonorrhoeae*)

highly infectious **sexually transmitted disease**

known from ancient times

→ described in 3500 bc Egyptian papyrus

→ 3rd century BC, Hippocrates described its mode of transmission:

"excesses of the pleasure of venus"
ie. "**venereal disease**"

strictly human pathogen

several hundred thousand (600,000) cases reported in US each year

>60% cases are 15 – 24 yrs old

→ but millions may be infected and not know

requires direct body contact

→does not survive more than 1-2 hours outside body

Infectious Dose: ~100-1000 bacteria

in males

usually infects urethra = acute urethritis

→causing yellowish discharge

if untreated may lead to arthritis, endocarditis or meningitis

but many are asymptomatic

in females

urinary and reproductive systems may both get infected

often mild or asymptomatic in early stages

→ most common cause of spread of the disease

produces bloody vaginal discharge in ~1/2 cases

if untreated, may ascend to cause pelvic inflammatory disease

scar tissue produced may cause sterility

infants born to infected moms may become infected
→results in blindness

silver nitrate, or now antibiotics applied to child's eyes immediately after birth

14. Bacterial pathogens have also been implicated in contributing to some psychological diseases such as obsessive compulsive disorder (*Streptococcus* sp.)

15. Sewage Treatment

eg. activated sludge

16. Bacteria for Biological Control

eg. *Bacillus thurigiensis* → a pathogen of Lepidoptera only

as bacterial cells make spores it also makes a diamond shaped protein crystals

sprayed on leaves these crystals dissolves in caterpillar stomach juices

on dissolving it causes paralysis and death to caterpillar

eg. *Bacillus popilliae* → kills Japanese beetle larvae

17. Forensics

researchers have recently reported (2010) that the 1400 or so different kinds of bacteria on our fingers can leave a unique "microbeprint" on surfaces such as computer keyboards and mice

samples up to 2 weeks old could be linked to a specific user

18. Future Applications:

a. pharmaceuticals

bacteria living in extreme environments are being screened for useful chemicals

eg. The "Berkeley Pit" in Butte, Mont., is the nation's largest environmental-disaster site, with 40 billion gallons of highly toxic copper-mine waste. Researchers have found more than 160 types of "extremophiles" in the pit and have demonstrated that some are effective against lung and ovarian cancers.

the botulism toxin extracted from *Clostridium* species is the **Botox** used in "beauty" treatments

b. gut flora

our bacterial symbionts exist as a complex interacting community with specific characteristics

we're finding that each person has a unique set of microorganisms on their skin and in their guts

eg. The bacteria found on a keyboard can identify the user as well as fingerprints

→ intestinal flora seem to have a dramatic effect on several "autoimmune" diseases

promising research has shown fecal transplants have cured symptoms of Parkinsons, diabetes and obesity

→ gut bacteria affect our mood and behavior

the bacteria telegraph chemicals to the brain via vagus nerve that can have a direct effect on behavior

may be direct connection to gut flora and psychiatric disorders such as depression, autism and schizophrenia

→ use of antibiotics can cause dramatic and long term changes in our gut flora and increase risk of some chronic diseases such as IBS

with each use of antibiotics the gut flora usually return to previous numbers and diversity

but occasionally, changes remain permanent

in the future:

eg. might be able to test for changes in kinds and numbers of species as an early indication of certain diseases

eg. doctors may prescribe bacterial supplements to improve physical health

eg. fecal transplants: restores bowel flora to a healthy state

eg. 100% cure rate for *C. difficile* infections, a deadly disease common in patients on antibiotic therapy

c. using bacteria for data storage

scientists are looking for a more permanent way to store information

all existing ways from paper to discs and zip drives can be easily lost or destroyed

a big concern is loss due to a catastrophic nuclear war

(2003) scientists successfully encoded the song "it's a small world" into artificial DNA strands. These strands were then encoded into the DNA of a living bacterium such as E. coli

the encoded song was protected from loss, viral infection and high doses of radiation 1000 x's lethal level for humans

the scientists then successfully retrieved the song after hundreds of bacterial generation

19. Threat of Biological Warfare

biological weapons include:

a. viruses

eg. Ebola, hanta, Equine Encephalitis, yellow fever

b. bacteria

eg. cholera, plague, anthrax, typhoid,

c. biological (plant or animal) toxins

eg. botulism, aflatoxin

d. genetically altered organisms

biological warfare is a global threat where a single individual could change the balance of power

History of Biological Weapons

6th century BC: Assyrians poisoned enemy wells with ergot (fungal toxin)

1346: Tartars hurled plague victims into city under seige

1763: French and Indian wars: British gave Indians blankets from smallpox hospital

1937-45:

Japanese experimented with biological warfare:

killed >3000 Chinese, Koreans, and Russians and Americans in these experiments

also dropped "biological bombs" on China

Nazi Germans tried to develop biological weapons but the only known actual use was pollution of a reservoir in Bohemia with sewage in May 1945

after WWII US captured leaders of Japans Biological Warfare Division and never prosecuted them, instead protected them to work for US

1949-69: in US; millions were exposed to bacteria in >230 cities:
attempted to measure dispersal patterns, etc. by dropping "nonpathogenic" species including *B. subtilis*
made no attempt to monitor health of "subjects"

1984: Oregon, followers of Bhagwan Shree Rajneesh seeded salad bars in the area with *Salmonella*
→ sickened 571 people

early '90's: Aum Shrinrikyo, a Japanese cult launched at least

9 germ attacks in Tokyo
→ action was meant to kill millions
but there were no known injuries or deaths

1991: Gulf War: Iraq had deployed but not used missiles carrying anthrax, botulism and aflatoxin

2001: Anthrax was mailed to several people and businesses in east coast → several deaths

1975 Biological weapons convention

produced 1st worldwide treaty; prohibited development, production and stockpiling and use of biological arms

Anthrax as a Biowarfare Agent

preferred biowarfare agent since it lasts long and can be relatively easily dispersed

50% of people who inhale 8000-10,000 spores will die

most research as biowarfare agent centers around making the spores lighter and more easily spread in air