River Valley High School
2025 JC1 H2 Biology

Lecture Topic 15: Organisation of Genomes – Prokaryotes

Name: ________________________ ( )   Class: 25J__   Date: ___________________

References

Title	Author
Biology (8th edition)	Campbell and Reece
Biology of Microorganisms (12th edition)	Madigan, Martinko, Dunlap, Clark
Biological Science 2 (3rd edition)	Green, Stout and Taylor
Molecular Biology of the Cell (5th edition)	Alberts, Johnson, Lewis, Raff, Roberts and Walter
Foundations in Microbiology (7th edition)	Talaro
Microbiology (4th edition)	Baker, Griffiths, Nicklin

Website

URL	Description
http://highered.mcgraw-hill.com/sites/0072556781/student_view0/chapter13/	Narrated animations on transformation, transduction and conjugation (by selecting the animation quiz)

H2 Biology Syllabus 9477 (2025) Candidates should be able to use the knowledge gained in the following section(s) in new situations or to solve related problems.	
Related Topics	**Content**
Organisation of Genomes – Viruses	Role of bacteriophage in bacterial transduction
Control of Gene Expression	Regulation of gene expression Molecular techniques in the study of gene expression

Learning Outcomes

1A. Organelles and Cellular Structures

d. Describe the structure of a typical bacterial cell (small and unicellular, peptidoglycan cell wall, circular DNA, 70S ribosomes and lack of membrane-bound organelles)

2B. Organelles and Cellular Structures

a. Describe the structure and organisation of prokaryotic genomes, (including DNA/RNA, single-/double-stranded, number of nucleotides, packing of DNA, linearity/circularity and presence/absence of introns).

d. Outline the mechanism of asexual reproduction by binary fission in a typical prokaryote and describe how transformation, transduction and conjugation (including the role of F plasmids but not Hfr) give rise to variation in prokaryotic genomes.

Lecture Outline

I. Bacterial Cell
- A. Bacterial cell structure
- B. Bacterial genome

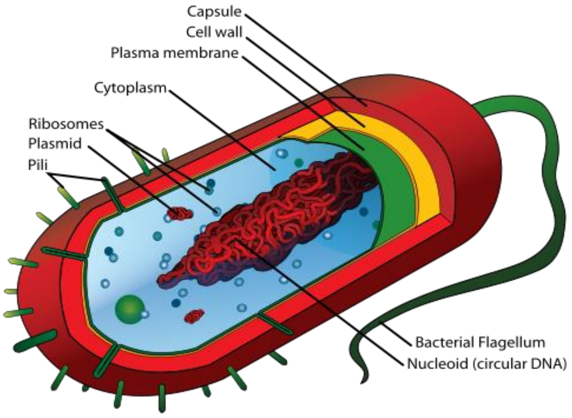
II. Bacterial Reproduction

III. Genetic Recombination in Bacteria
- A. Transformation
- B. Transduction
- C. Conjugation

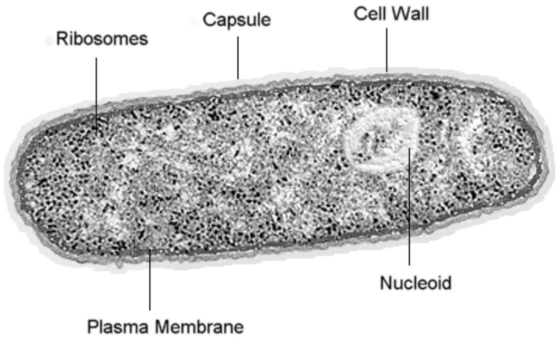
I. Bacterial Cell

Bacteria are the most diverse and widespread prokaryotes, colonising almost all habitats on Earth. They are unicellular and have diameters ranging from 0.5-5 µm, much smaller than many eukaryotic cells. Despite its small size, a bacterium is able to achieve its life functions all within a single cell.

A. Bacterial cell structure



Structure of a typical bacteria cell.



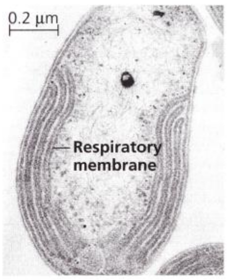
Electron micrograph of a bacteria cell.

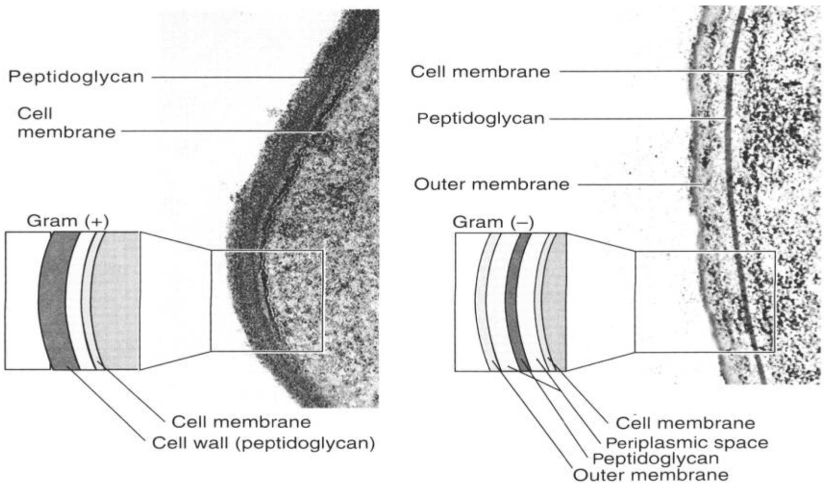
Internal Structures

	Structure	Function
1. Nucleoid	♦ Non-membrane-bound ♦ A region of cytoplasm where bacterial chromosome is found ♦ Appears lighter than surrounding cytoplasm in electron micrographs	♦ Contains one double stranded, circular DNA molecule ♦ Presence of large amount of RNA and RNA polymerase involved in transcription and translation
2. Plasmids	♦ Extra-chromosomal genome ♦ Small circular DNA molecule, not part of bacterial chromosome. ♦ Replicate independently from bacterial chromosome.	♦ Carry a few genes which code for proteins that are not required for survival. ♦ These proteins, when expressed, might result in characteristics that confer advantages in stressful environments (e.g. antibiotic resistance). *(KIV: Isolating, Cloning and Sequencing DNA)*
3. Ribosomes	♦ 70S *(unlike 80S in eukaryotes)* ♦ Give cytoplasm a granular appearance	♦ Required for polypeptide synthesis
4. Storage granules	♦ Small particles found in cytoplasm	♦ Stores nutrients and reserves (e.g. glycogen, lipids, ions)

Surface Structures

<table>
<tr><th></th><th>Structure</th><th>Function</th></tr>
<tr><td>1. Membrane

<u>1.1 Plasma membrane</u></td><td>• Phospholipid bilayer containing proteins</td><td>• <u>Selectively permeable barrier</u> that regulates the transport of material in and out of the bacterial cell
• <u>Proteins</u> involved in the transport of ions, nutrients and waste across the membrane
• <u>Energy transduction</u> as it contains enzymes involved in ATP synthesis (KIV: Energetics)</td></tr>
<tr><td><u>1.2 Mesosomes</u></td><td>• <u>Infoldings</u> of the plasma membrane


Electron micrograph showing mesosomes in bacterial cell</td><td>• <u>Increases surface area</u> for aerobic cellular respiration
• Aids in <u>separation of cells</u> into daughter cells during binary fission
• Participate in <u>cell wall synthesis</u></td></tr>
<tr><td rowspan="2"><u>1.3 Outer membrane</u></td><td>• <u>Gram-negative bacteria</u> have an additional outer membrane surrounding cell wall
• Similar to plasma membrane except that it contains specialized types of <u>lipopolysaccharides</u>[1] and <u>lipoproteins</u>
• Lipid portions of lipopolysaccharides are toxic.</td><td>• Helps to <u>protect</u> bacterium from the body's defence
• Confers <u>more resistance to antibiotics</u> because it impedes entry of drugs that damage the cell wall</td></tr>
<tr><td colspan="2">

Structure of cell walls and membranes of gram-positive (left) and gram-negative bacteria (right)</td></tr>
<tr><td>2. Cell wall</td><td>• Consists of <u>peptidoglycan</u> (sugars cross-linked by short polypeptide chains)</td><td>• Maintains <u>cell shape</u>
• Protects bacteria from osmotic lysis</td></tr>
<tr><td>3. Capsule/ Slime layer</td><td>• Thick jelly-like material surrounding surface of some bacterial cell wall
• Sticky layer of <u>polysaccharide</u> (sometimes protein)</td><td>• Helps in <u>adherence</u> to surfaces or other individuals in a colony
• <u>Protects</u> bacteria from environmental factors (e.g. dehydration , antibiotics, phagocytosis by white blood cells)</td></tr>
</table>

[1] Lipopolysaccharides are lipid molecules bound to polysaccharides

Appendages

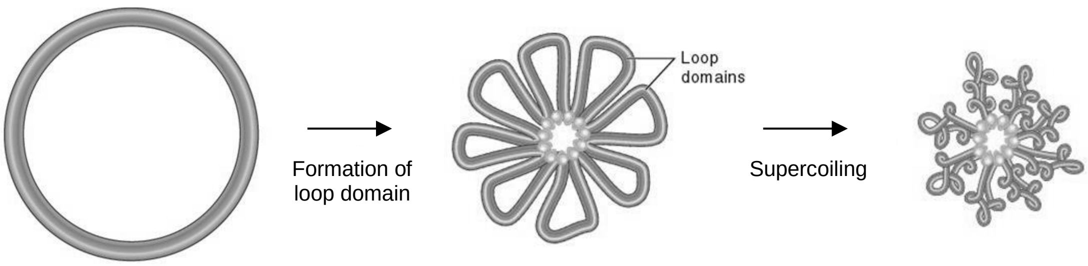
	Structure	Function
1. Flagella (Singular: flagellum)	• Hollow cylindrical thread made of proteins • Bacteria cells may possess none, one or multiple flagella	• For motility
2. Pili (Singular: pilus)	• Hollow hair-like structure made of protein pilin	• There are two types of pili: ○ **Fimbriae** (singular: Fimbria): Short attachment pili. Facilitates attachment to cells or surfaces ○ **Sex pili**: Long conjugation pili Facilitate transfer of genetic materials between two bacteria.

B. Bacterial genome

Structure of bacterial genome

The genome of bacteria is considerably different from that of eukaryotes.

1. Bacteria cells are haploid, with only one set of chromosomes.
2. They lack membrane-bound nucleus. A bacterium's chromosome is located in the nucleoid.
3. Bacterial genome consists of one double-stranded, circular chromosome, whose structure includes fewer proteins than that found in linear chromosomes of eukaryotes.
4. A bacterium may have none, one or multiple smaller rings of extra-chromosomal DNA, known as plasmids. Plasmids carry only a few genes and its replication is independent of that for bacterial chromosome. Plasmids confer selective advantage and can be integrated into the chromosome.



Circular chromosome

DNA folded into chromosomal domains by association with proteins.

Supercoiled and looped DNA,

5. Bacterial chromosomes (~1100 µm in length) are compacted about 1000 fold to fit into the bacterial cell (1-2µm in diameter). This involves formation of loop domains, facilitated by DNA-binding proteins *(unlike histone proteins in eukaryotes)*; and subsequent supercoiling by DNA gyrase.

Organization of bacterial genome

Bacterial genome has compact genetic organization.

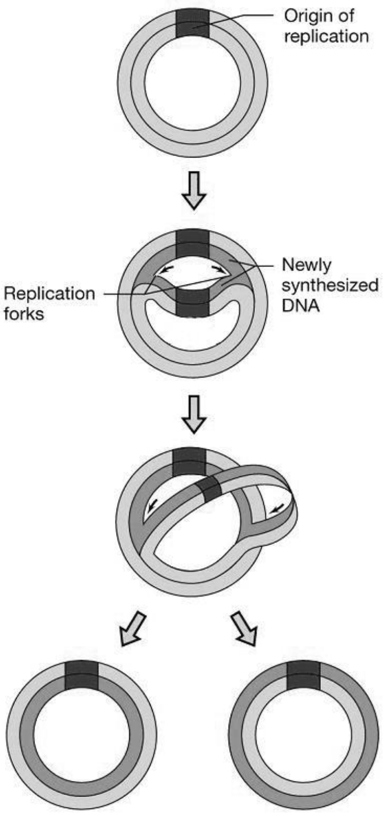
1. Size of bacterial genome is 0.5 – 10 Mb in length.
2. One origin of replication to initiate DNA replication.
3. 1500 - 7500 genes interspersed throughout the genome. Genes are often organized into operons.
4. Absence of introns. *(Recall: Organization and control of genome - Eukaryotes)*

II. Bacterial Reproduction

Three key features of bacteria biology contribute to its successful reproduction. 1. small size, 2. reproduction via binary fission and 3. short generation time.

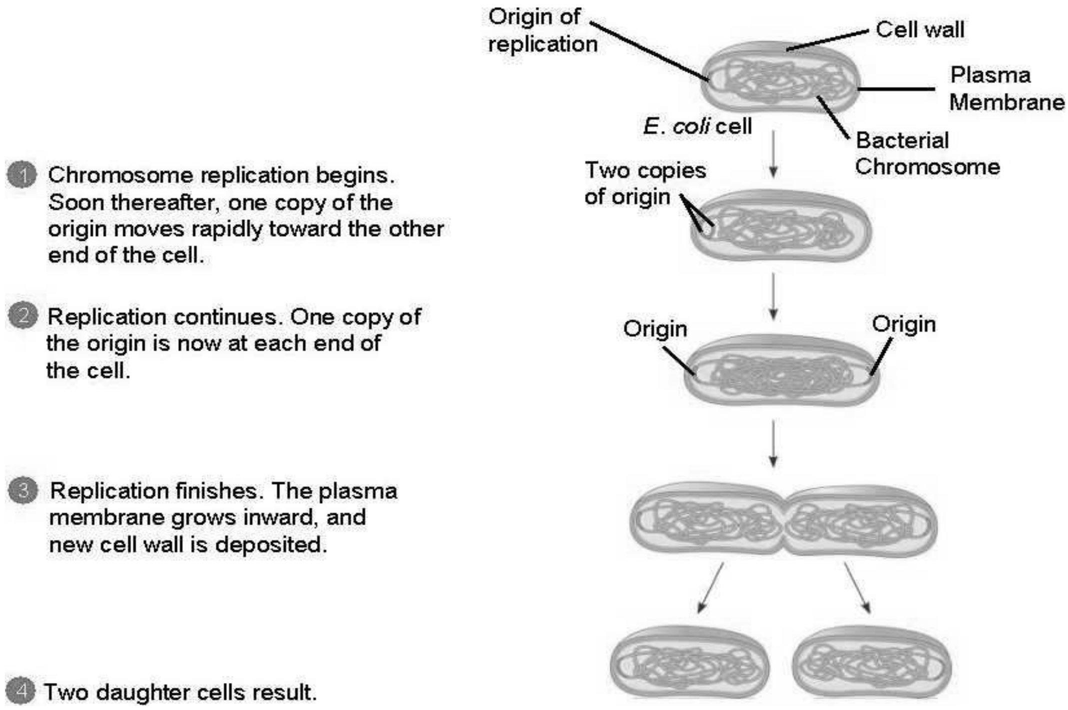
Under optimal conditions, *E. coli* can divide as often as every 20 minutes. However, bacterial reproduction can be limited by factors such as lack of nutrients, metabolic waste poisoning, competition and consumption by other organisms. In human intestine, *E. coli* typically divides every 12- 24 hours.

Binary fission, meaning 'division in half', is a method of asexual reproduction by which bacteria reproduce.



Replication of bacterial circular DNA

1. The process of cell division is initiated at a specific region of the bacterial chromosome, known as origin of replication. DNA replication begins at this point and moves in both directions.
2. The double-stranded DNA separates to form a replication bubble. Both strands of DNA act as templates for the synthesis of new daughter strands. Similar to DNA replication in eukaryotes, each of the two replication forks has a leading and a lagging strand.
3. As replication continues, two origins of replication results, with one moving to the opposite end of the cell.
4. Enzymes like helicase, topoisomerase, primase, DNA polymerase and DNA ligase are also involved in the DNA synthesis.
5. At the **same time**, the bacteria cell elongates and eventually grows to twice its size upon completion of DNA replication.
6. Following this, the plasma membrane grows inwards, forming mesosomes. This facilitates the formation of a new cell wall, and the division of cell into two daughter cells, each with a complete set of genome.



Bacterial cell division by binary fission.

III. Genetic Recombination in Bacteria

Unlike in eukaryotes where meiosis and fertilization give rise to genetic variation in offspring, bacteria undergo binary fission, where daughter cells are genetically identical to the parent cell. Genetic diversity in bacteria can be attributed to mutations and genetic recombination.

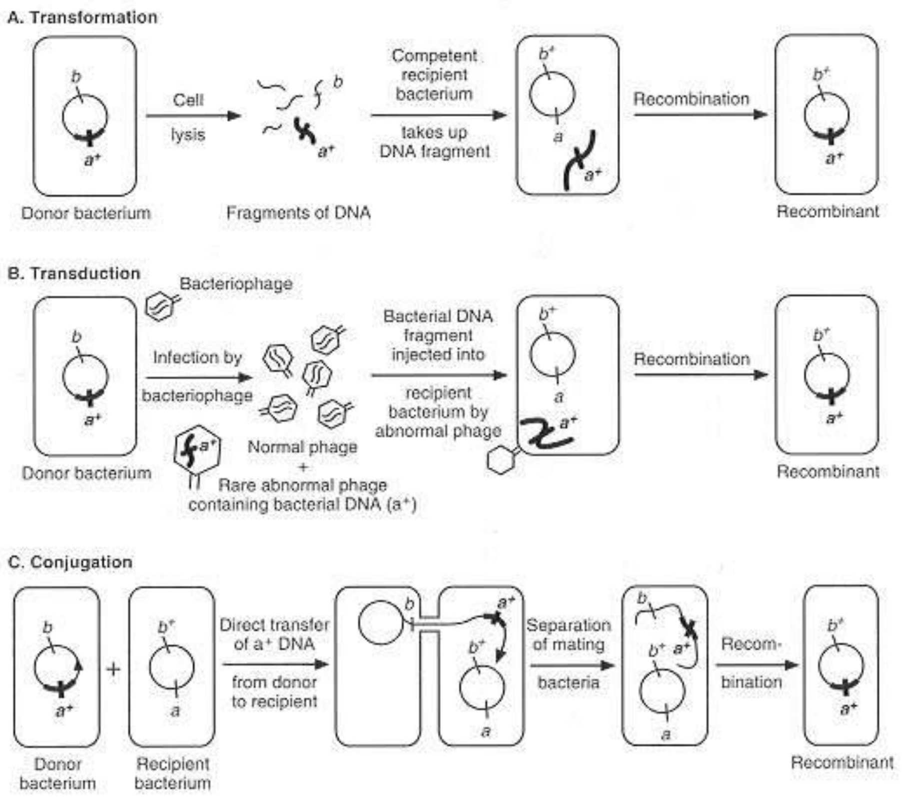
Processes facilitating genetic recombination/ horizontal gene transfer in bacteria include:
Transformation: acquisition of DNA from the environment.
Transduction: acquisition of bacterial DNA via a bacteriophage intermediate
Conjugation: acquisition of DNA directly from another bacterium.

Genetic recombination

Genetic recombination in transformation and transduction and sometimes conjugation will involve the exchange of nucleotide sequences between homologous strands of DNA.

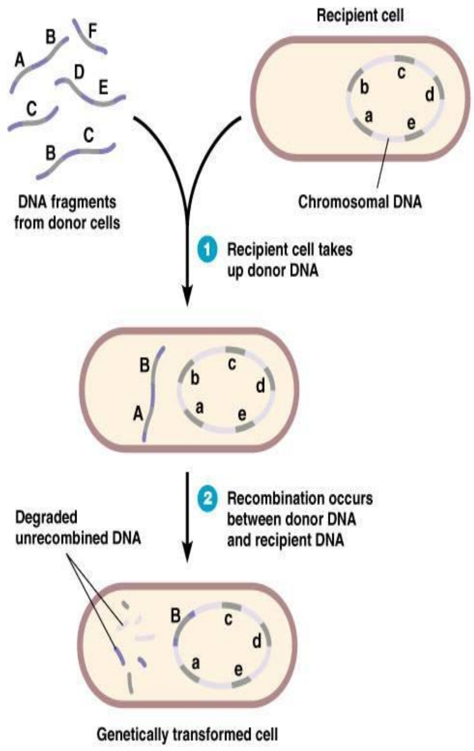
Advantages:

The new combinations of DNA resulting from genetic recombination gives rise to genetic variations in offspring, enabling populations to adapt to environmental changes.



Diagrams illustrating genetic recombination occurring in transformation, transduction and conjugation

A. Transformation



Acquisition of DNA from environment via transformation.

In transformation, the genome of a bacterium cell is altered by the uptake and incorporation of foreign DNA acquired from the environment. This incorporation results in the formation of recombinant DNA. These new proteins/ RNA might have an effect on the cell's metabolism and/or structure.

The process of transformation

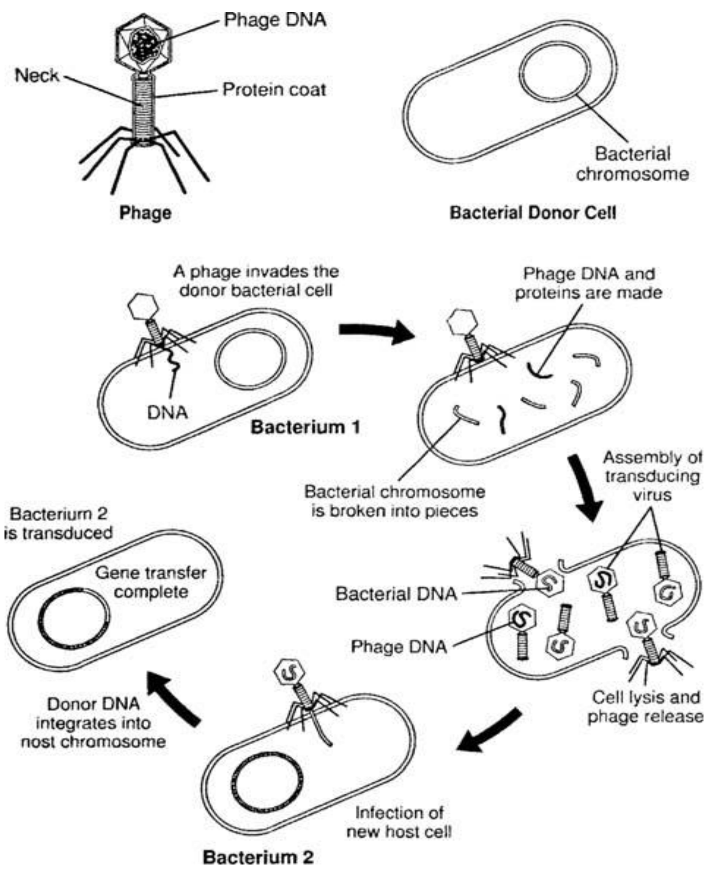
1. Foreign DNA of closely related species (e.g. DNA from dead, lysed cells) can be recognised by cell-surface proteins of bacterium. This facilitates transport of DNA into the cell.
2. Upon entry into the cell, the foreign allele is incorporated into the cell chromosome by homologous DNA exchange. *(e.g. Allele B from donor undergoes homologous exchange with allele b of recipient DNA)*
3. The cell is now a **recombinant**. Its chromosome contains DNA derived from two cells.
4. The cell will express the newly incorporated gene and pass it on to offspring during binary fission.

B. Transduction

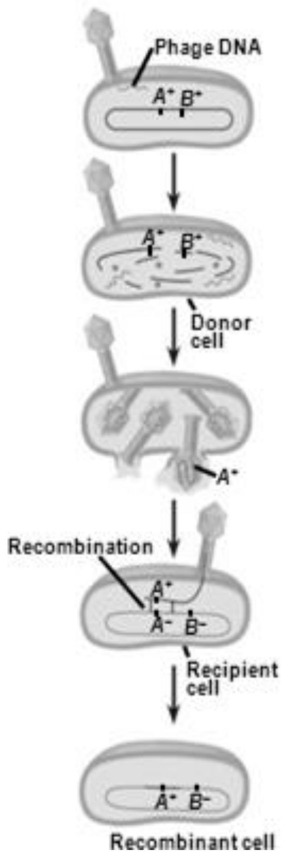
In transduction, genes are transferred from one genome to another. In transduction, bacteriophages carry bacterial genes from one host to another during the phage reproductive cycle. The transferred DNA may recombine with the genome of the new host cell.

Process of Generalised transduction

1. Phage infects host bacterial cell and hydrolyses bacterial chromosome into small pieces of DNA (i.e. lytic cycle).
2. Phage DNA and proteins are made to facilitate phage assembly. A small random fragment of host bacterial DNA may be **accidentally packaged** into a phage capsid. This bacteria cell is referred to as the donor cell.
3. Phage carrying the donor bacterial DNA may not be able to reproduce due to lack of phage DNA. However, the phage may still be able to infect another host cell.
4. This transducing phage attaches to another recipient bacterial cell and injects the fragment of donor bacterial DNA.
5. Some of the donor bacterial DNA may replace the recipient cell's chromosome at homologous regions via homologous DNA exchange. As a result, the recipient cell chromosome becomes a combination of DNA derived from two cells. This recombinant recipient cell would then express the newly incorporated gene.



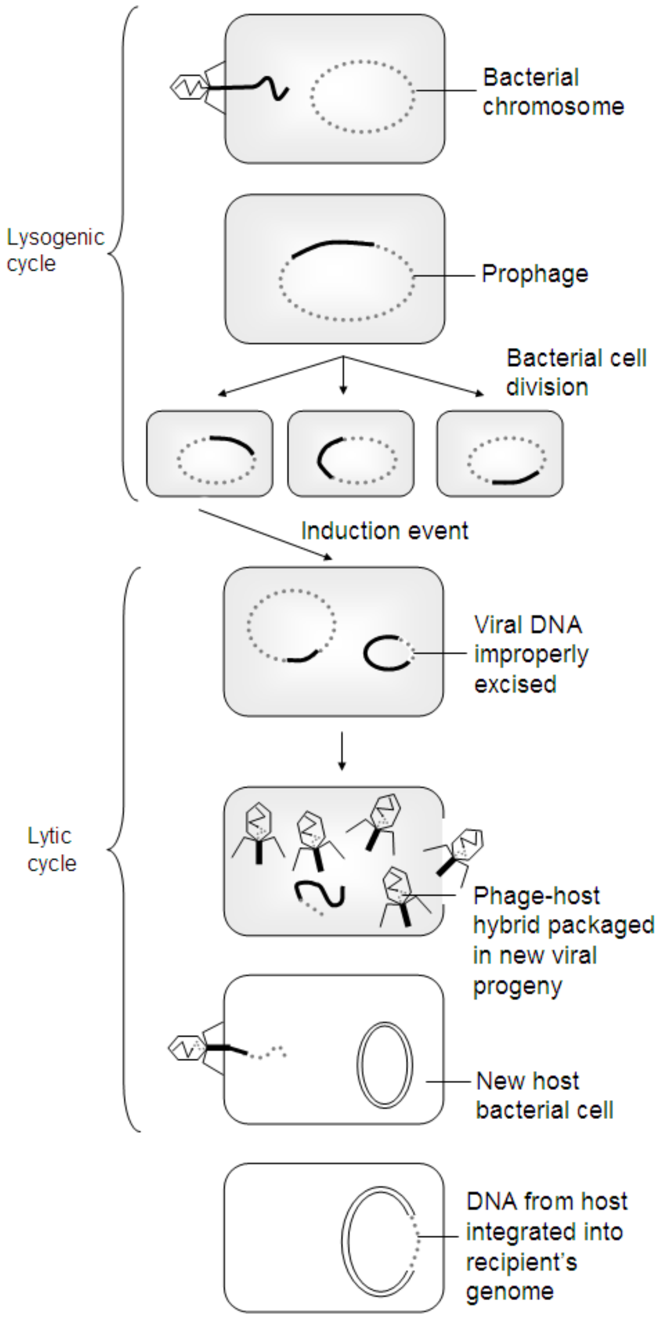
Transfer of bacterial genome via generalised transduction.



Genetic recombination occurring during transduction.

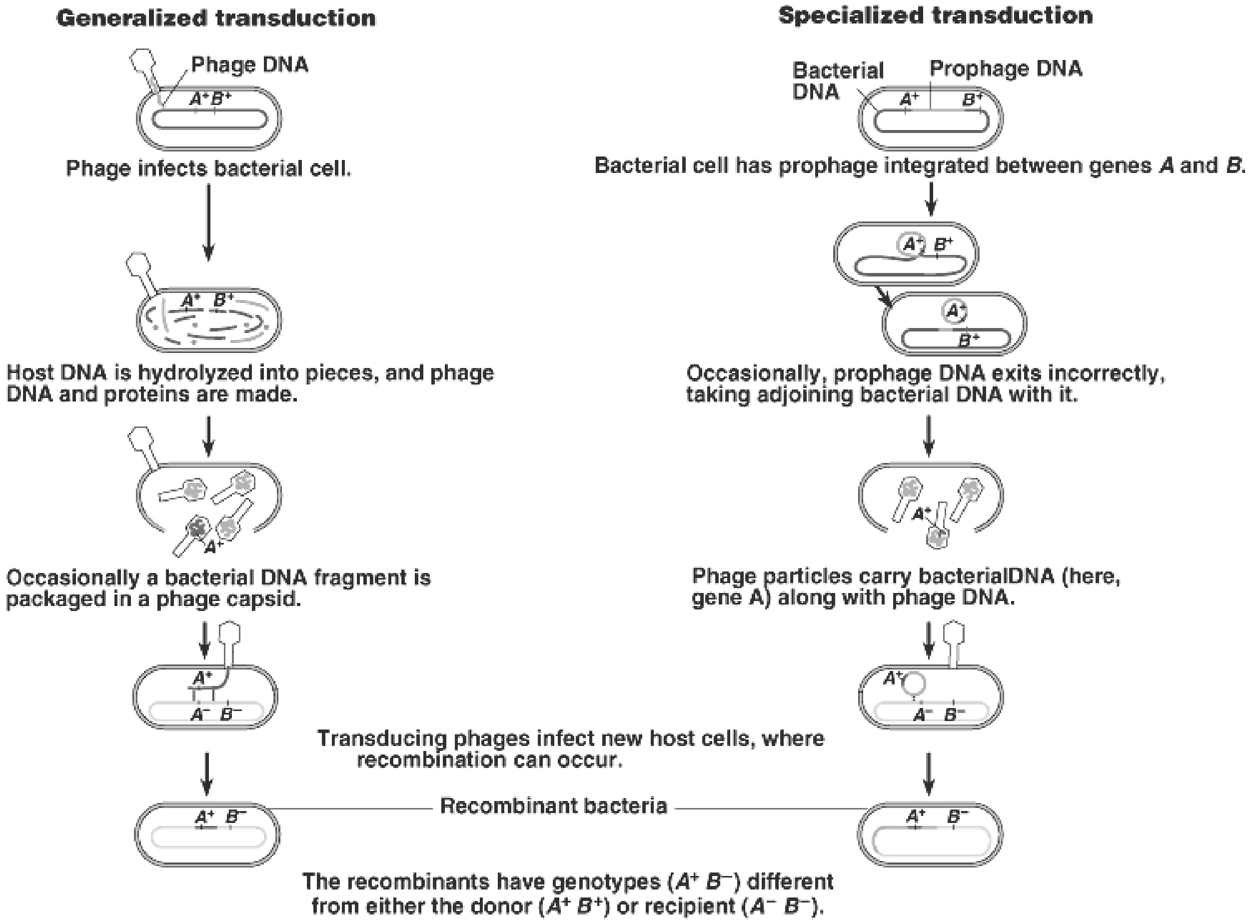
Process of Specialised Transduction

- Occurs in temperate phages (able to integrate their genome into that of bacteria to form prophages) when they exit lysogenic cycle.



Transfer of bacterial DNA via specialised transduction.

1. λ phage attaches to host bacterial cell and injects viral genome into host cell.
2. Phage DNA integrates into bacterial chromosome, to become a prophage. The bacterium reproduces normally, replicating the viral genome and transmitting it to daughter cells (i.e. lysogenic cycle).
3. Spontaneous induction: Phage genes activated and lytic cycle is induced.
4. Viral DNA may be **improperly excised** to include some of the adjacent bacterial DNA.
5. The phage-host hybrid DNA is packaged into new phage progeny.
6. λ phage (virus carrying bacterial DNA) infects a new host cell (recipient) and the donor bacterial genes are injected along with the viral genome.
7. Genetic recombination via homologous DNA exchange may occur between homologous regions of donor and recipient DNA.
8. Or there could be integration of the phage and bacterial DNA into the recipient genome, as phage enters the lysogenic cycle.



Comparison of the process of generalised transduction and specialised transduction.

Summary of Transduction

Phages occasionally carry bacterial genes from one cell to another. In generalised transduction (left), random pieces of the host chromosome are packaged within a phage capsid. In specialised transduction (right), a prophage exits the chromosome and carries with it, adjacent bacterial genes. In both types of transduction, the transferred DNA may recombine with the genome of the recipient bacterial cell.

C. Conjugation

Conjugation involves the transfer of genetic materials between two cells, usually the same species. It is unidirectional (from donor to recipient) and involves direct cell-to-cell contact through the formation of a temporary mating bridge/ sex pilus.

The ability to form sex pili for the process of conjugation is due to the presence of a piece of DNA called the F factor (F for fertility). The F factor consists of approximately 25 genes, most of which are responsible for the production of sex pili (singular: pilus). F factor that exists as an extra-chromosomal plasmid called F plasmid.

Bacteria cells with **F plasmids** are termed F^+ cells, while those without are termed F^- cells. During conjugation, F^+ cells function as donors, initiating contact with a F^- cells, also known as recipients. In addition, the F^+ condition is transferable: a F^+ cell can convert a F^- cell to F^+ by transferring a copy of the F plasmid. Other plasmids like R plasmid (plasmid carrying antibiotic resistance genes) also have genes that encode for sex pili to enable plasmid transfer from one bacterial cell to another via conjugation.

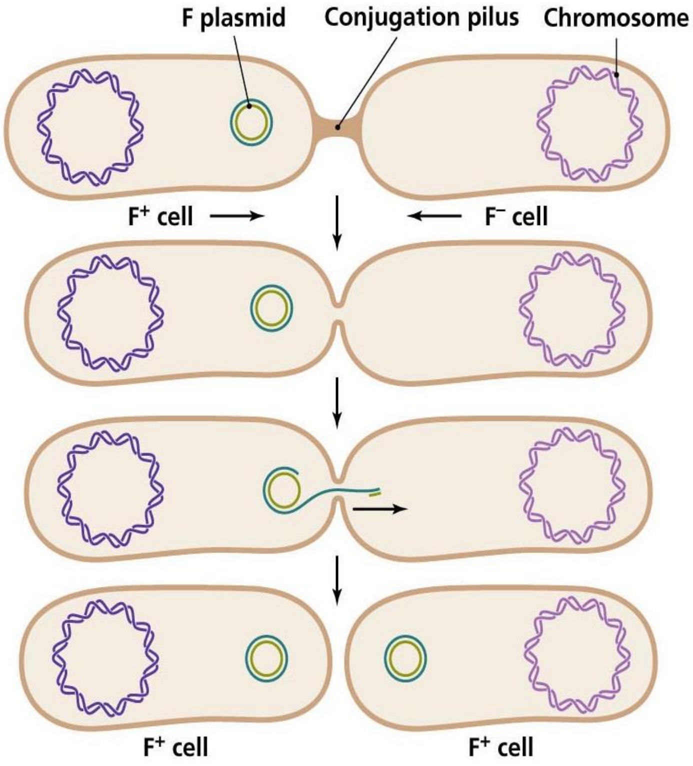
Process of conjugation

1. **F^+ donor cell** uses sex pilus to attach to the **F^- recipient cell**. After contacting the recipient cell, the sex pilus retracts, pulling the two cells together. A temporary mating bridge is formed between the two cells.

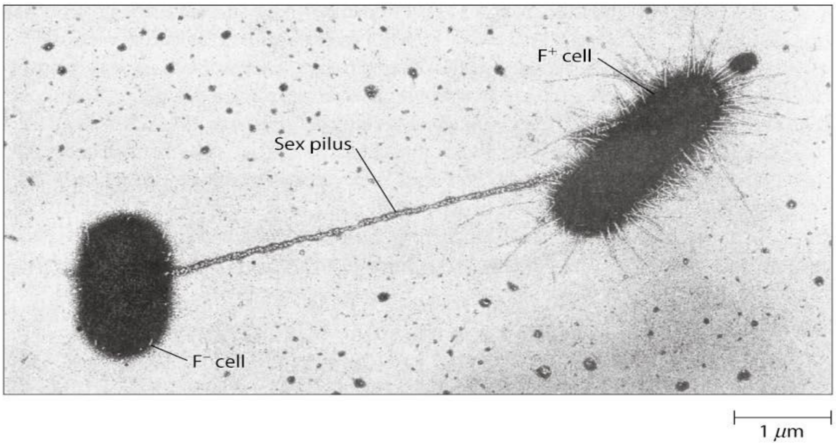
2. The double stranded donor F plasmid breaks at a specific point, allowing for one strand to move from donor to the recipient cell via the mating bridge.

3. As the transfer of the single strand F plasmid continues, DNA replication begins. Both strands of the donor F plasmid act as templates, each synthesizing a daughter strand via complementary base pairing.

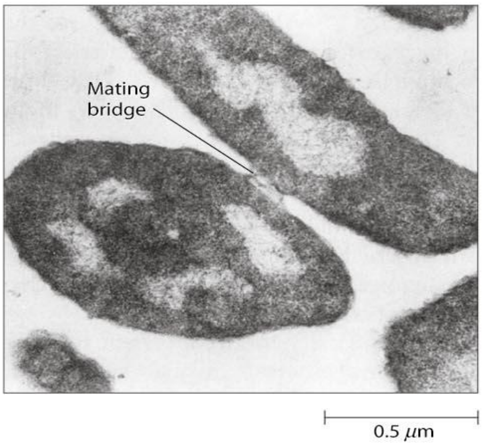
4. Upon completion of transfer and replication, the plasmid in the recipient cell circularizes. The resultant is a complete F plasmid in each cell. The recipient cell, having acquired a F plasmid, is now a F^+ cell.



Transfer of F plasmid via conjugation.



Electron micrograph showing bacteria undergoing conjugation. The F⁺ cell extends sex pili, one of which is attached to the F⁻ cell.



Electron micrograph showing mating bridge between two bacterial cells undergoing conjugation.