A2.3 Viruses

Unity and diversity—Cells

Additional higher level: 2 hours

Guiding questions

• How can viruses exist with so few genes?

• In what ways do viruses vary?

Additional higher level

Note: There is no SL content in A2.3

A2.3.1—Structural features common to viruses
Relatively few features are shared by all viruses: small, fixed size; nucleic acid (DNA or RNA) as genetic material; a capsid made of protein; no cytoplasm; and few or no enzymes.

• **Viruses** are **subcellular (non-living) infectious agents** that are **obligate intracellular parasites**
• Viruses rely on a **host cell** for energy supply, nutrition, protein synthesis and other life functions
• Viruses are diverse in structure but share many features:
  • **Small size** to allow for entry into hosts
  • **Fixed size** as they do not grow or divide like cells
  • **Nucleic acid (DNA or RNA)** as genetic material with very few genes that dictate replication & infection mechanisms
  • **Protein capsid** that protects, transports, and delivers viral genome to host cell
  • **Enzymes** (few or none) that can aid in entry and replication of some viruses
  • **No cytoplasm** because they do not carry out metabolic reactions like cells

A2.3.2—Diversity of structure in viruses
Students should understand that viruses are highly diverse in their shape and structure. Genetic material may be RNA or DNA, which can be either single- or double-stranded. Some viruses are enveloped in host cell membrane and others are not enveloped. Virus examples include bacteriophage lambda, coronaviruses and HIV.

• Viruses are highly diverse in shape & structure because they are highly adapted to exploit life functions in specific hosts
  • **Genetic material**: may be RNA or DNA, which can be either single- or double-stranded
  • **Membrane**: viruses can be **enveloped** by the host cell membrane (usually acquired when the virus exits the host cell, surrounding the capsid) or **non-enveloped**
  • **Protein capsid**: variable shapes like **helical**, **spherical**, or **icosahedral**
• **Bacteriophage lambda (λ)** is **non-enveloped** with **single-stranded DNA** that infects ***E. coli***
• **Coronaviruses** are **enveloped** with **single-stranded RNA** that infect humans & animals (**zoonotic**)
• **HIV** is an **enveloped retrovirus** that uses **reverse transcriptase** to incorporate the 2 copies of its **single-stranded RNA** into **T-helper lymphocytes** (host cell)

A2.3.3—Lytic cycle of a virus

Students should appreciate that viruses rely on a host cell for energy supply, nutrition, protein synthesis and other life functions. Use bacteriophage lambda as an example of the phases in a lytic cycle.

- **Bacteriophages** (**phages**) are viruses that infect bacteria & exploit their life functions via a **lysogenic** or **lytic replication cycle** (depending on the virus & environmental stimuli)
- **Lytic cycle** (**A**ll **P**enguins **D**ance **B**efore **M**aking **L**unch):
  1. **Attachment**: phage attaches itself onto the surface of the host cell to inject its genetic material
  2. **Penetration**: linear phage DNA is injected into host cell cytoplasm by penetrating cell membrane
  3. **DNA circularization**: linear phage DNA circulates into a loop
  4. **Biosynthesis**: phage DNA and proteins are synthesized by host cell machinery
  5. **Maturation (assembly)**: viral components are assembled into complete phages in the host cell
  6. **Lysis**: cell membrane or wall undergoes **lysis (rupture)** to release phages

A.2.3.4—Lysogenic cycle of a virus

Use bacteriophage lambda as an example.

- **Lysogenic cycle**:
  1. **Attachment**: phage attaches itself onto the surface of the host cell to inject its genetic material
  2. **Penetration**: linear phage DNA is injected into host cell cytoplasm by penetrating cell membrane
  3. **Integration**: phage DNA is integrated into the host cell circular chromosome to form a **prophage**
  4. **Cell division**: the **lysogen** (host cell with prophage) grows and divides normally
- The prophage spreads passively with the lysogen until stressful stimuli experienced by the host cell trigger the lytic cycle, which separates the phage DNA from the host chromosome
- Example: **bacteriophage lambda (λ)** uses its protein tail to bind a maltose outer membrane integral protein channel in *E. coli* in both lysogenic & lytic cycles

A2.3.5—Evidence for several origins of viruses from other organisms

The diversity of viruses suggests several possible origins. Viruses share an extreme form of obligate parasitism as a mode of existence, so the structural features that they have in common could be regarded as convergent evolution. The genetic code is shared between viruses and living organisms.

- The diversity of viruses suggests several possible origins, so the structural features that they have in common could be regarded as convergent evolution (i.e. have not evolved via common ancestry)
- There are several equally valid hypotheses for the evolution of viruses:
  - **Progressive (escape) hypothesis**: DNA or RNA material in cells ‘escaped’ & gained the ability to enter and eventually exploit other cells
  - **Regressive hypothesis**: viruses were once (possibly complex or free-living) cells that lost genetic information over time as they adopted a parasitic approach to replication
  - **Virus-First hypothesis**: viruses existed before all cells on earth and eventually evolved more complex and organized functions, leading to cell formation

A2.3.6—Rapid evolution in viruses
Include reasons for very rapid rates of evolution in some viruses. Use two examples of rapid evolution: evolution of influenza viruses and of HIV. Consider the consequences for treating diseases caused by rapidly evolving viruses.

- There are several reasons for the very rapid rates of evolution in some viruses:
  - **High mutation rates** due to the absence of proofreading or repair mechanisms
    - For example, HIV has high mutation rates as reverse transcriptase cannot proofread or repair
  - **Recombination** can occur between two different viruses that infect the same host cell
    - For example, influenza viruses can undergo recombination & evolve different glycoproteins, allowing them to attach to different host cell receptors
  - **Large viral population sizes** produced by the host cell **strengthen selection**
  - **Short infectious life cycles** increase transmission, which exposes the virus to new environments & **strengthens selection**
- Treatment of viruses must take into consideration the diversity of viral form & function:
  - Viral vaccines need to be constantly updated as viral strains evolve resistance
  - Early treatment is important before the genetic diversity of the virus increases
  - Isolation of infected patients to reduce transmission

Linking questions

• What mechanisms contribute to convergent evolution?

• To what extent is the natural history of life characterized by increasing complexity or simplicity?

Review questions

- Suggest **one** advantage of the lysogenic cycle over the lytic cycle. [1]
- Explain how viruses can exist with very few genes. [2]
- Explain why viruses are not considered living organisms. [2]
- Explain why viruses are considered obligate parasites. [2]
- Explain the challenges of treating diseases caused by rapidly evolving viruses. [3]
- Outline the diversity of viral structures using **three** examples. [3]
- Explain why the diversity of viruses supports the idea of multiple origins. [3]
- Explain why some viruses have rapid rates of evolution. [4]
- Discuss the evidence for the evolution of viruses. [4]
- Outline the features that all viruses share. [6]
- Explain why viruses evolve despite not being considered alive. [6]
- Compare and contrast the modes of replication in bacteriophages. [7]
- Describe the lysogenic and lytic cycles of bacteriophages. [8]

References

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