REVISION GUIDE

How does something *not alive* take over a cell?

Viruses

A virus is a few genes in a protein coat, with no metabolism of its own, yet it can turn a cell into a factory for more viruses. Find out what all viruses share, how varied they are, how phage lambda's lytic and lysogenic cycles work, where viruses may have come from, and why influenza and HIV evolve so fast. Higher level only.

6 chapters

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-a2-3-viruses

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By the end you can

- [ ] List the features all viruses share: small fixed size, DNA or RNA, a protein capsid, no cytoplasm and few or no enzymes A2.3.1
- [ ] Describe the diversity of viruses, using phage lambda, coronaviruses and HIV A2.3.2
- [ ] Outline the phases of the lytic cycle of phage lambda, and what the virus takes from its host A2.3.3
- [ ] Outline the lysogenic cycle of phage lambda A2.3.4
- [ ] Discuss the evidence that viruses arose several times from other organisms A2.3.5
- [ ] Explain why some viruses evolve rapidly, with influenza and HIV, and the consequences for treatment A2.3.6

Tick each one when you can do it without the book.

01 Genes in a *box*

A2.3.1 HL STRUCTURAL FEATURES COMMON TO VIRUSES

Viruses are so varied that only a few features are shared by all of them. Each is small, and each kind has a fixed size: most are between 20 and 300 nanometres across, a tenth or less of a bacterium's length, and they do not grow. Each has genetic material made of one kind of nucleic acid, DNA or RNA. Each has a **capsid**, a coat of protein round its nucleic acid, built from many copies of a few protein units.

What viruses lack matters as much. There is no cytoplasm and there are no ribosomes, and a virus carries few enzymes or none. So a virus cannot release energy, make proteins or copy its own genes. For all of that it depends on a host cell: it is an **obligate parasite**, reproduced only by the cell it infects.

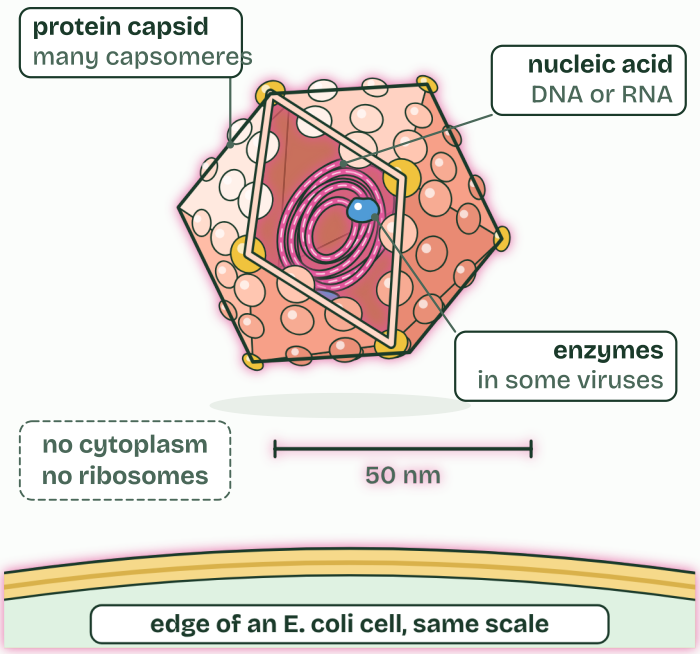
KEY POINTS

- Small and of fixed size.
- DNA or RNA as genes, inside a protein capsid.
- No cytoplasm, no ribosomes, few or no enzymes: copied only by a host cell.

KEY TERMS

capsid
The protein coat of a virus, built from many copies of a few kinds of protein, which protects its nucleic acid.

obligate parasite
A parasite that can only reproduce inside a host. Viruses are obligate intracellular parasites.



Nucleic acid One kind only, DNA or RNA, never both. It holds the genes for the capsid proteins and the few other proteins the virus needs.

Capsid A coat made of many copies of a few kinds of protein, fitted together as capsomeres. It protects the nucleic acid and, in many viruses, carries the proteins that attach to a host cell.

Enzymes A few, in some viruses only: for example reverse transcriptase in HIV. Most viruses carry none and use the host cell's.

Small, fixed size Most viruses are between 20 and 300 nanometres across, far smaller than a bacterium (about 2000 nm long). Each kind of virus is always about the same size.

WATCH OUT

Antibiotics do not work on viruses. They target bacterial structures and enzymes, such as cell walls and bacterial ribosomes, that a virus does not have.

PREDICT

Why can a virus not be grown in a dish of sterile nutrient broth, as bacteria can?

(A) The broth is too warm for a virus, whose proteins denature at the temperatures bacteria prefer

(B) It has no ribosomes or enzymes of its own, so it cannot use the nutrients without a host cell

(C) It is too small to take in nutrients, so it must be grown in a broth of smaller molecules instead

Decide before you look. Answer on page 18.

02 No two *alike*

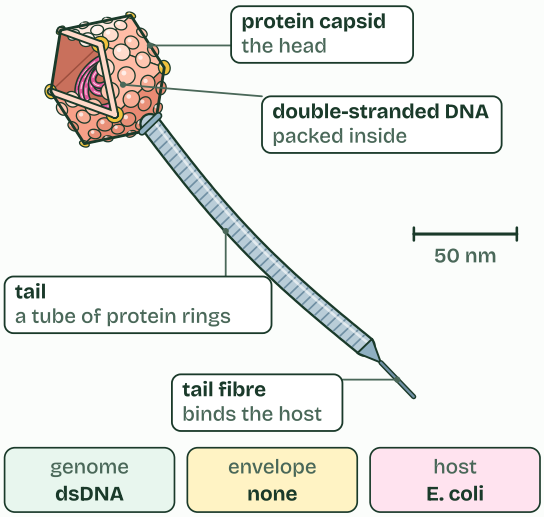
A2.3.2 HL DIVERSITY OF STRUCTURE IN VIRUSES

Beyond those few shared features, viruses differ in almost everything. Their genetic material may be DNA or RNA, and either may be single-stranded or double-stranded. Some have only a capsid; others are **enveloped**, wrapped in a layer of membrane taken from the last host cell as they left it, studded with the virus's own proteins. Shapes range from many-sided capsids to helical rods and heads with tails.

Three examples show the range. **Bacteriophage lambda** infects the bacterium *E. coli*: double-stranded DNA in a many-sided capsid, a long tail, and no envelope. **Coronaviruses**, including the one that causes COVID-19, have single-stranded RNA and an envelope bristling with spike proteins, which bind to receptors on the host's cells. **HIV** is enveloped too, with two copies of a single-stranded RNA genome in a cone-shaped capsid and the enzyme reverse transcriptase, which copies its RNA into DNA once it is inside a helper T cell.

KEY POINTS

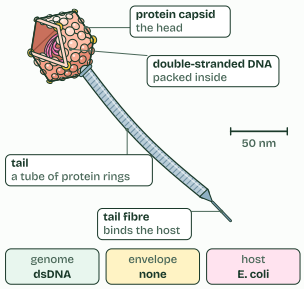
- DNA or RNA, single- or double-stranded.
- Enveloped (membrane from the host) or not.
- Lambda: dsDNA, tail, no envelope. Coronavirus: ssRNA, spikes, envelope. HIV: ssRNA, reverse transcriptase, envelope.



SWITCH IT

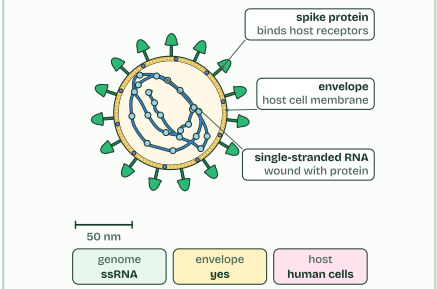
3 SETTINGS

1



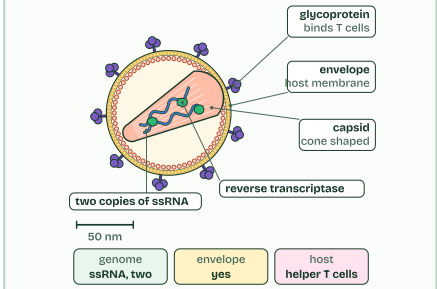
Phage lambda

2



Coronavirus

3



HIV

WATCH OUT

A virus's envelope is not its own membrane: it is a piece of the host cell's membrane, picked up as the virus buds out.

PREDICT

Soap breaks up lipid membranes. Which of the three viruses would soap affect least?

(A) HIV, because its capsid lies inside the envelope and so the capsid is shielded from the soap

(B) Phage lambda, because it has no envelope and its protein capsid has no lipid for soap to dissolve

(C) The coronavirus, because its spike proteins stick out beyond the envelope and keep the soap away

Decide before you look. Answer on page 18.

03 Take over, *burst out*

A2.3.3 HL LYTIC CYCLE OF A VIRUS

Phage lambda shows how a virus uses its host. It **attaches** by its tail to specific receptor proteins on the wall of an *E. coli* cell, then **injects** its DNA, leaving the empty capsid outside. Inside, the DNA joins its ends into a circle.

In the **lytic cycle**, the cell does all the work. The host's enzymes and nucleotides **copy** the phage DNA many times, using the host's ATP. The host's ribosomes read the phage genes and **make phage proteins**: capsid units, tails and the enzymes the phage needs. The parts **assemble** into new phages, each head packed with a copy of the DNA. Finally a phage enzyme breaks down the cell wall, the cell bursts, which is **lysis**, and about a hundred new phages are **released** to infect other cells. The whole cycle takes under an hour.

KEY POINTS

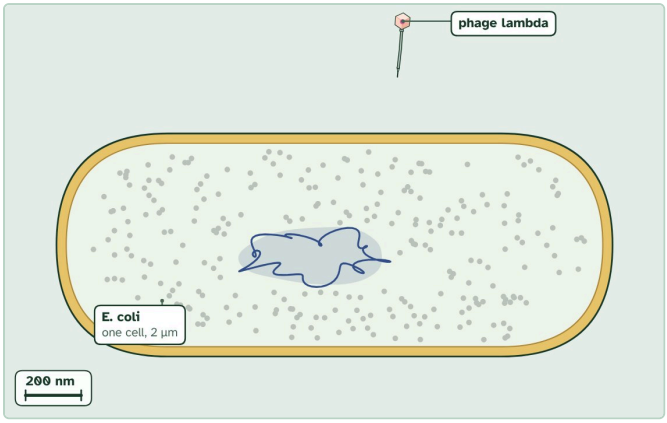
- Attach, inject, copy DNA, make proteins, assemble, lyse and release.
- The host supplies energy, nucleotides, amino acids, enzymes and ribosomes.
- The cell is destroyed; many new phages leave.

KEY TERMS

lytic cycle
The cycle in which a virus takes over a host cell to make many new viruses, then bursts the cell to release them.

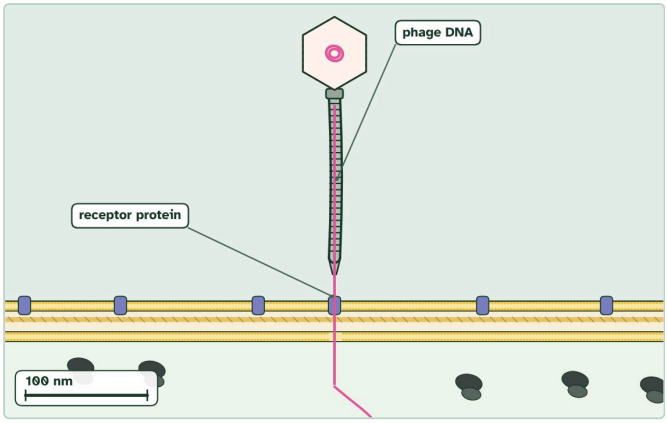
ANIMATION · PHAGE LAMBDA: LYTIC OR LYSOGENIC
8 MOMENTS

1 ATTACH



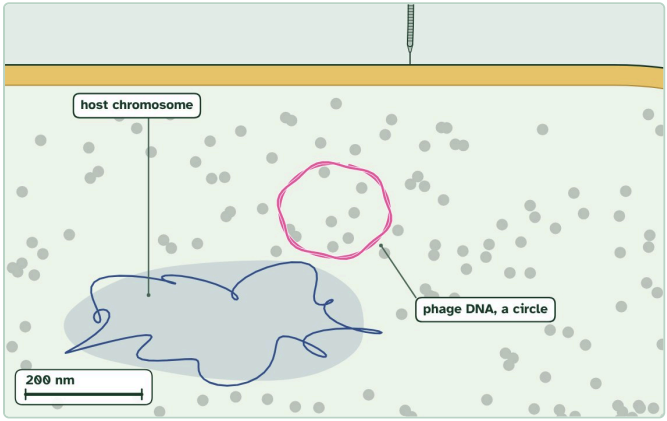
A **phage lambda** lands on an *E. coli* cell, and the fibre at its tail tip binds a receptor protein in the outer membrane: **attachment**.

2 INJECT



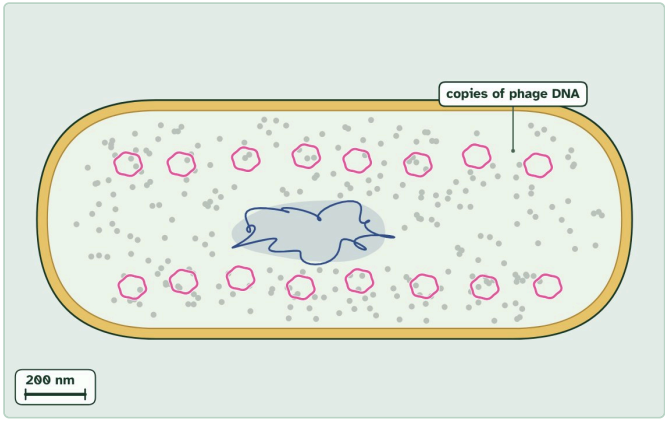
It **injects** its DNA down the hollow tail and through the cell envelope. The empty protein capsid stays outside.

3 CIRCLE



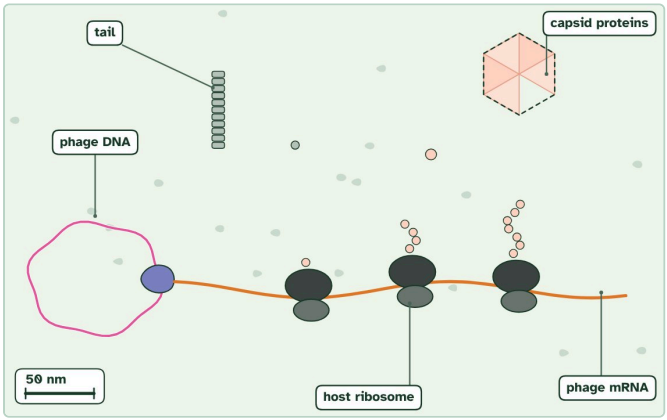
Inside, the DNA's two sticky ends pair up and it closes into a **circle**. Going deeper: the ends are the cos sites, and the host's DNA ligase seals them.

4 COPY DNA



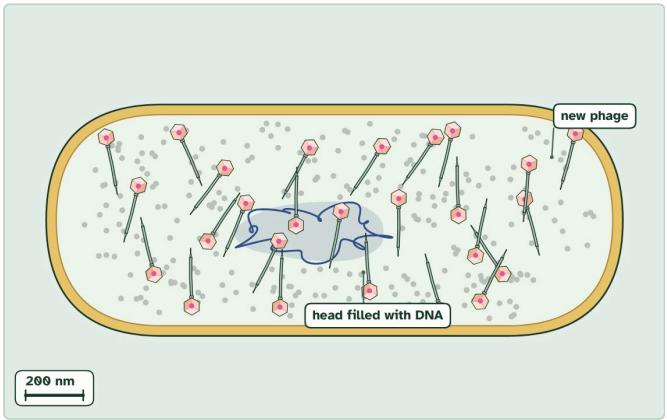
Lytic cycle. A virus has few enzymes of its own: the host's enzymes, nucleotides and ATP **copy the phage DNA** many times.

5 MAKE PROTEINS



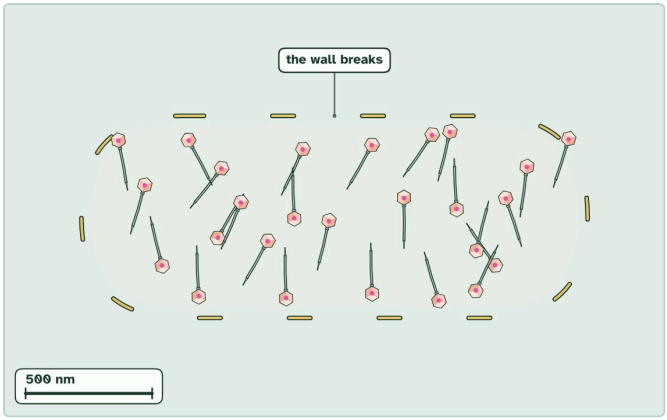
The host's RNA polymerase transcribes the phage genes, and the host's **ribosomes** translate them into **phage proteins**: capsid proteins and tail parts.

6 ASSEMBLE



The parts **assemble**: a copy of the DNA is packed into each new head, and a tail joins on.

7 LYSIS



Enzymes made from phage genes break down the cell wall from inside. The cell bursts: **lysis**.

8 RELEASED



About a hundred new phages are **released**, each able to infect another cell. The host cell is dead.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-a2-3-viruses#lytic

WATCH OUT

The phage does not "eat" the cell or "make" anything itself. Every step after injection is done by the host's own machinery, following the phage's genes.

PREDICT

A drug stops bacterial ribosomes working. What happens to phage lambda in a treated cell?

(A) It goes on as normal, because the phage carries ribosomes of its own inside its protein capsid

(B) No new phages are made, because the capsids, tails and enzymes are all made on the host's ribosomes

(C) The phage DNA cannot be injected into the cell, because the ribosomes act as the receptors for its tail

Decide before you look. Answer on page 18.

04 Lying *low*

A2.3.4 HL LYSOGENIC CYCLE OF A VIRUS

Phage lambda does not always kill its host at once. After its DNA has formed a circle, it can instead enter the **lysogenic cycle**. A phage enzyme inserts the circle into the host chromosome at a particular site. The inserted phage DNA is now a **prophage**. A repressor protein made from one of its genes keeps the genes for making phages switched off, so no capsids or tails are made and the cell lives on.

Every time the bacterium copies its chromosome and divides, the prophage is copied too, so a growing colony carries it in every cell. If the cell is stressed, for example when ultraviolet light damages its DNA, the repressor is destroyed. The prophage is cut out of the chromosome and the lytic cycle begins: copies, proteins, assembly and lysis. Lying low in many cells and switching on when the host is in trouble lets the phage spread whichever way conditions go.

KEY POINTS

- Phage DNA inserted into the host chromosome: a prophage.
- Copied with the chromosome at each division; no phages made.
- Stress such as UV switches it on: cut out, then lytic.

KEY TERMS

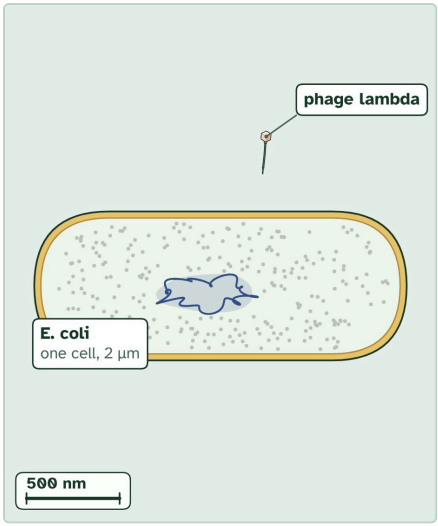
lysogenic cycle
The cycle in which a virus's DNA is inserted into the host chromosome and copied with it as the cell divides, without making new viruses, until it is switched into the lytic cycle.

prophage
Phage DNA inserted into a bacterial chromosome, where it is copied with the chromosome but its genes for making phages are switched off.

ANIMATION · PHAGE LAMBDA: THE LYSOGENIC CYCLE

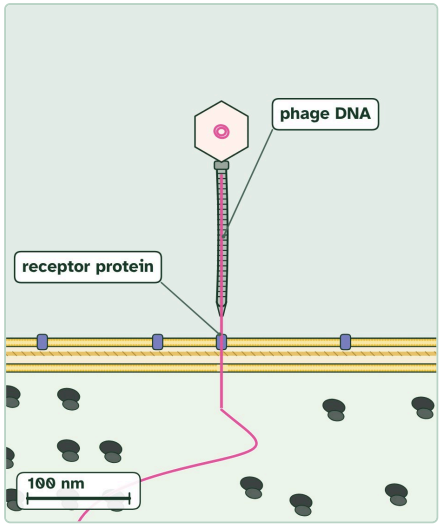
8 MOMENTS

1 ATTACH



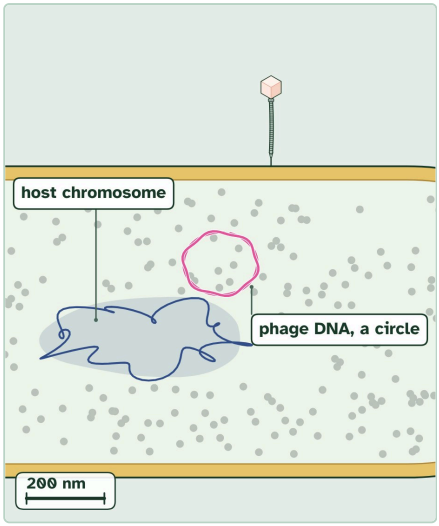
A **phage lambda** lands on an *E. coli* cell, and the fibre at its tail tip binds a receptor protein in the outer membrane: **attachment**.

2 INJECT



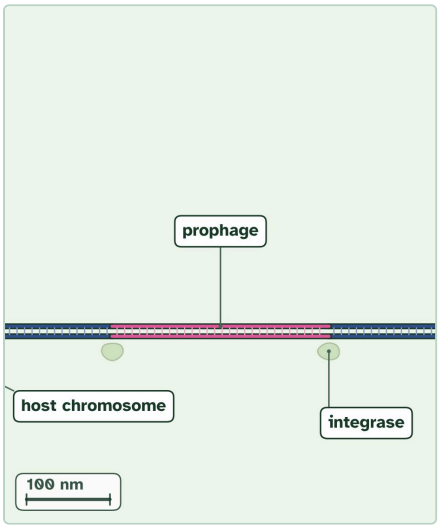
It **injects** its DNA down the hollow tail and through the cell envelope. The empty protein capsid stays outside.

3 CIRCLE



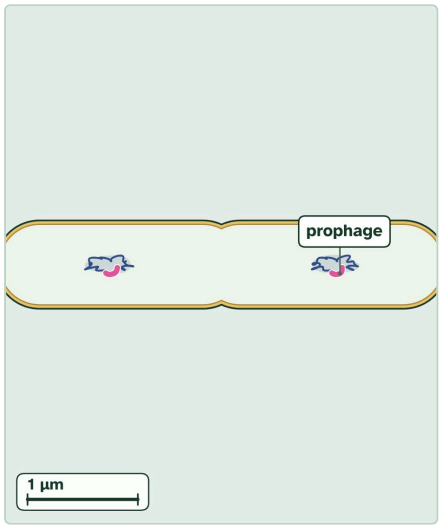
Inside, the DNA's two sticky ends pair up and it closes into a **circle**. Going deeper: the ends are the cos sites, and the host's DNA ligase seals them.

4 INTEGRATE



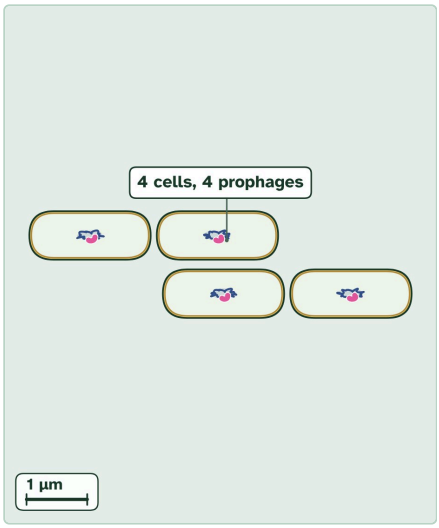
Lysogenic cycle. A phage enzyme, **integrase**, cuts the host chromosome at one particular site and joins the phage DNA in. Now it is a **prophage**.

5 DIVIDE



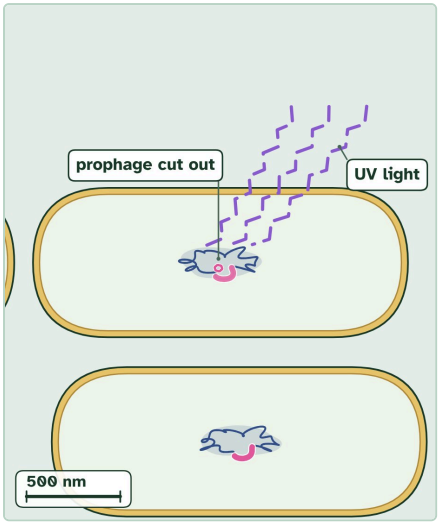
The prophage's genes for making phages are switched off. When the cell **divides**, the prophage is copied along with the chromosome.

6 DAUGHTER CELLS



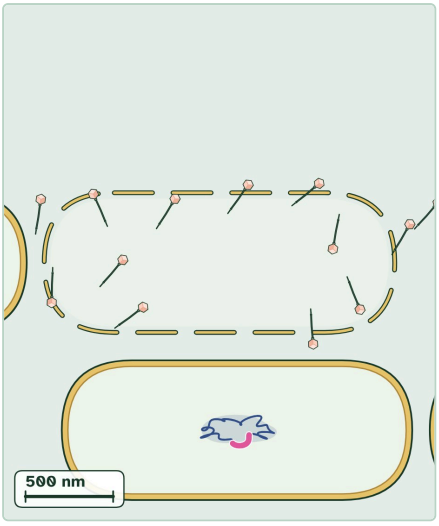
So **every daughter cell** carries the prophage. No phages are made, and the cells live on.

7 INDUCTION



Stress, such as **UV light** damaging the DNA, switches the prophage on, and it is **cut out** of the chromosome. Going deeper: the damage sets off the cell's SOS response, which inactivates the repressor that kept the prophage silent.

8 LYTIC CYCLE



That cell enters the **lytic cycle**: the phage DNA is copied, new phages are made, and the cell bursts.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-a2-3-viruses#lysogenic

WATCH OUT

In the lysogenic cycle the phage is not dormant outside the cell. Its DNA is inside every daughter cell, part of the chromosome.

PREDICT

A culture of bacteria carrying the lambda prophage is exposed to UV light. What would be seen in the next hour?

(A) The bacteria divide faster than before, because the UV light switches the prophage's genes for division on

(B) Many of the bacteria burst and new phages appear, as the prophages are cut out and enter the lytic cycle

(C) No change at all, because a prophage inside the chromosome is protected from the UV by the cell wall

Decide before you look. Answer on page 18.

05 Many *beginnings*

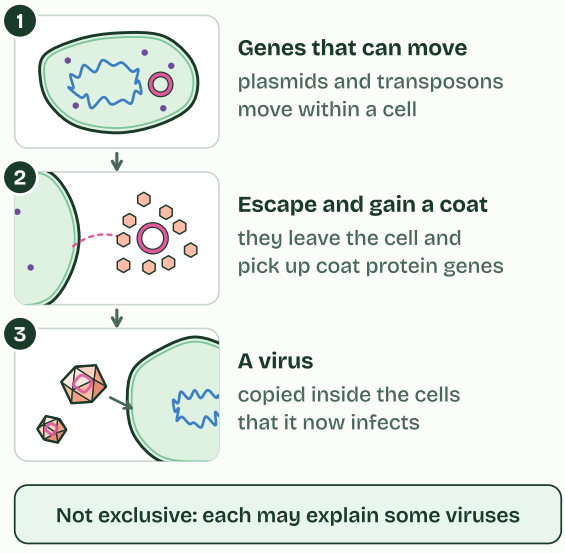
A2.3.5 HL EVIDENCE FOR SEVERAL ORIGINS OF VIRUSES FROM OTHER ORGANISMS

Viruses leave no fossils, so their origins are worked out from what they are like today. The most striking thing is how different they are from each other: DNA or RNA, one strand or two, enveloped or not, many shapes, and many with genes found in no other virus. If all viruses came from one ancestor we would expect more in common. This diversity suggests viruses arose several times.

Three hypotheses, which are not exclusive, suggest how. Genes that could already move about within a cell may have **escaped** and gained a protein coat. Small cells living as parasites inside other cells may have **lost** part after part that the host supplied, until only genes and a coat were left. Or virus-like replicators may have existed **before cells** and gone on as their parasites. What viruses share, a capsid, few genes, no metabolism, may then be convergent evolution: the same extreme form of parasitism shaping unrelated starting points the same way. They do share the genetic code with living organisms, which fits viruses having come from cells that already used it.

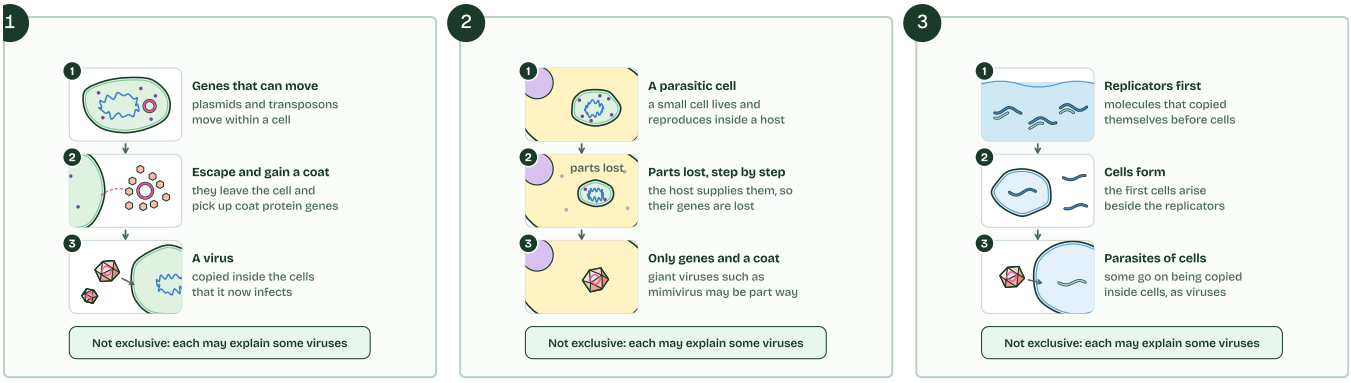
KEY POINTS

- Great diversity among viruses suggests several origins.
- Escaped genes, reduced parasitic cells, or virus-like replicators before cells.
- Shared features may be convergent evolution; the genetic code is shared with life.



SWITCH IT

3 SETTINGS



Escaped genes | **Reduced cells** | **Virus first**

WATCH OUT

Sharing features does not always mean sharing an ancestor. Wings in birds and bats look alike for the same job, not because of a common winged ancestor; viral capsids may be the same.

PREDICT

Why does the shared genetic code support viruses having come from cells?

(A) It shows that all viruses came from one single ancestor, which lived before the very first cell

(B) A virus's genes must be read by its host's ribosomes, using the code the host lineage already had

(C) It shows that viruses evolved their own code first, and the earliest cells took the code from them

Decide before you look. Answer on page 18.

06 A moving *target*

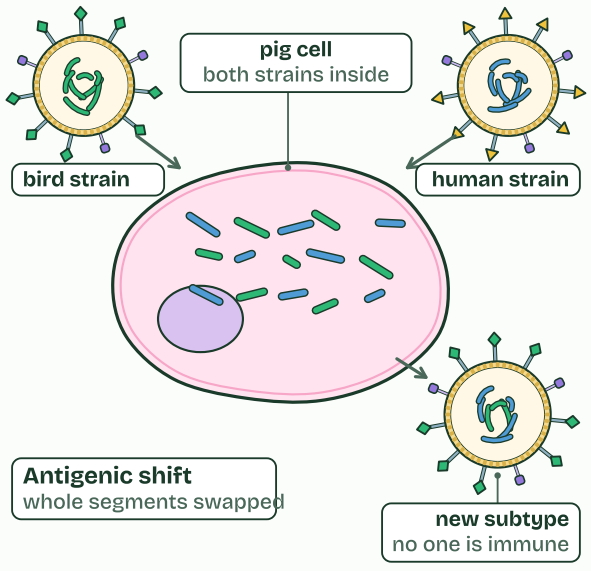
A2.3.6 HL RAPID EVOLUTION IN VIRUSES

Some viruses evolve faster than anything else in biology. Three things combine. Many have RNA genomes copied by enzymes that do not proofread, so mutations are frequent. They reproduce very fast, a new generation in hours, with huge numbers in each host. And the immune system and drugs select hard for any variant that escapes them, so natural selection acts on all that variation at once.

Influenza changes in two ways. Small mutations in the genes for its surface proteins accumulate year by year, **antigenic drift**, so antibodies from last year's infection or vaccine fit less well; that is why the flu vaccine is remade every year. Its genome is in eight separate RNA segments, and if two strains infect one cell, such as a bird strain and a human strain in a pig, they can swap whole segments, **antigenic shift**, making a new subtype that nobody is immune to and that can cause a pandemic. **HIV** mutates so fast that many variants arise in a single patient. A drug used alone soon selects a resistant variant, so HIV is treated with a combination of three or more drugs at once, and no vaccine has yet worked.

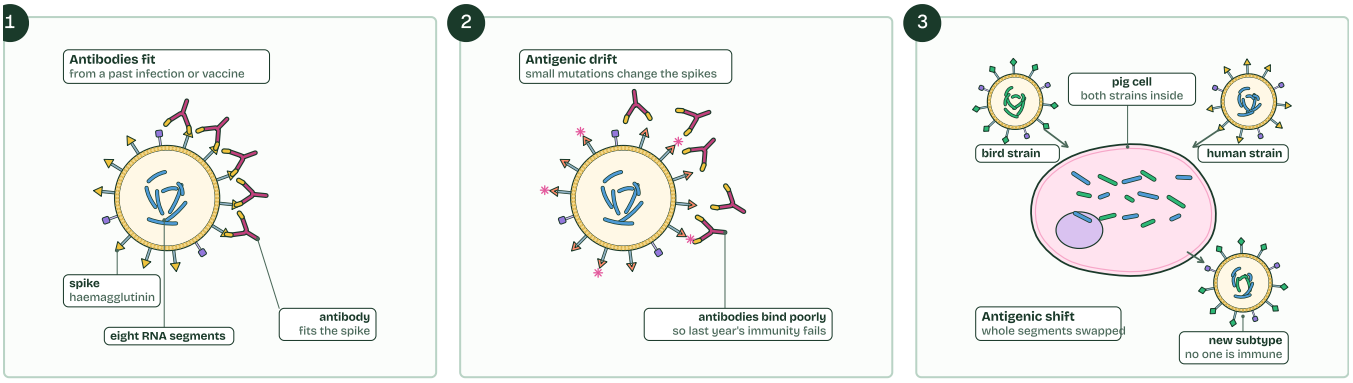
KEY POINTS

- Fast: frequent mutation (RNA copying without proofreading), short generations, huge numbers, strong selection.
- Influenza: drift (new vaccine each year) and shift (pandemics).
- HIV: resistance to single drugs, so combination therapy; no vaccine.



STEP BY STEP

3 STEPS



Antibodies from a past infection or vaccine fit the spikes of the virus.

Antigenic drift: small mutations change the spikes, and the antibodies bind poorly.

Antigenic shift: two strains infecting one cell swap whole RNA segments, making a new subtype.

WATCH OUT

The virus does not "decide" to change to escape a drug. Mutations arise at random; the drug kills the variants it can, leaving the resistant ones to multiply.

PREDICT

Why does a combination of three anti-HIV drugs work better than one drug used on its own?

(A) The three drugs react with each other and form a single far stronger drug once they are inside the body

(B) A variant would need resistance to all three at once, which is far less likely to arise by chance mutation

(C) Three drugs stop the virus mutating, so the variants that resist any one drug are never able to form

Decide before you look. Answer on page 18.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

capsid 01
The protein coat of a virus, built from many copies of a few kinds of protein, which protects its nucleic acid.

lysogenic cycle 04
The cycle in which a virus's DNA is inserted into the host chromosome and copied with it as the cell divides, without making new viruses, until it is switched into the lytic cycle.

lytic cycle 03
The cycle in which a virus takes over a host cell to make many new viruses, then bursts the cell to release them.

obligate parasite 01
A parasite that can only reproduce inside a host. Viruses are obligate intracellular parasites.

prophage 04
Phage DNA inserted into a bacterial chromosome, where it is copied with the chromosome but its genes for making phages are switched off.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on A2.3 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?topics=A2.3&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 Why can a virus not be grown in a dish of sterile nutrient broth, as bacteria can?

B **It has no ribosomes or enzymes of its own, so it cannot use the nutrients without a host cell**

A virus has no metabolism: nothing to take up nutrients, release energy or make proteins. It must be grown in living cells, such as bacteria for phages or cultured animal cells or eggs for viruses of animals.

02 Soap breaks up lipid membranes. Which of the three viruses would soap affect least?

B **Phage lambda, because it has no envelope and its protein capsid has no lipid for soap to dissolve**

Soap destroys a lipid envelope, and an enveloped virus without it can no longer bind to cells. That is why handwashing works so well against coronaviruses. A virus with only a protein capsid, such as lambda, is far less affected.

03 A drug stops bacterial ribosomes working. What happens to phage lambda in a treated cell?

B **No new phages are made, because the capsids, tails and enzymes are all made on the host's ribosomes**

A virus has no ribosomes, so every phage protein is made by the host's. Stop them and no capsids or tails are made. The DNA can still get in, because injection uses receptors on the wall.

04 A culture of bacteria carrying the lambda prophage is exposed to UV light. What would be seen in the next hour?

B **Many of the bacteria burst and new phages appear, as the prophages are cut out and enter the lytic cycle**

UV damage leads to the repressor being broken down. In cell after cell the prophage is cut out, the lytic genes are switched on, phages are made, and the cells lyse. The culture clears as the cells burst.

05 Why does the shared genetic code support viruses having come from cells?

B **A virus's genes must be read by its host's ribosomes, using the code the host lineage already had**

A virus's genes are translated by the host's ribosomes, so they must use the host's code. A virus with a different code could not reproduce. That fits viruses arising from, or alongside, cells that already used the universal code; it does not show a single origin.

06 Why does a combination of three anti-HIV drugs work better than one drug used on its own?

B **A variant would need resistance to all three at once, which is far less likely to arise by chance mutation**

Variants resistant to any one drug arise often, but needing three separate resistance mutations in one virus is very unlikely, so selection has nothing to work with. The drugs do not stop mutation.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.