# Unit- 3 Viral morphology and genomic structure

## 1. Introduction and general characteristics

Viruses are non-cellular, microscopic infectious agents that can only replicate inside a host cell, obligate intracellular parasites. Viruses cannot replicate itself outside the host cell. This is because viruses lack the required cellular machinery.

From a biological perspective, viruses cannot be classified either as living organism nor non-living. This is due to the fact that they possess certain defining characteristic features of living organisms and non-living entities. Viruses can also be crystallized, which no other living organisms can do. It is these factors that lead to viruses being classified in the grey area – between the living and non-living.

### ❖ General characteristics of Viruses

i. Obligate intracellular parasites of bacteria, protozoa, fungi, algae, actinomycetes, plants, and animals.
ii. Ultramicroscopic size, ranging from 20 nm up to 450 nm (diameter). Electron microscope is required to observe them.
iii. Not cellular in nature; structure is very compact and economical.
iv. Do not independently fulfill the characteristics of life.
v. Inactive macromolecules outside the host cell and active only inside host cells.
vi. Basic structure consists of protein shell (capsid) surrounding nucleic acid core.
vii. A virion consists of a nucleic acid core, an outer protein coating or capsid, and sometimes an outer envelope made of protein and phospholipid membranes derived from the host cell.
viii. All virions have a nucleic acid genome covered by a protective layer of proteins, called a capsid. The capsid is made up of protein subunits called capsomeres. Some viral capsids are simple polyhedral “spheres,” whereas others are quite complex in structure.

ix. Many viruses use some sort of glycoprotein to attach to their host cells via molecules on the cell called viral receptors.
x. Nucleic acid can be either DNA or RNA but not both.
xi. Nucleic acid can be double-stranded DNA, single-stranded DNA, single-stranded RNA, or double-stranded RNA.
xii. Molecules on virus surface impart high specificity for attachment to host cell.
xiii. Multiply by taking control of host cell's genetic material and regulating the synthesis and assembly of new viruses.
xiv. Absence of enzymes for most metabolic processes.
xv. Absence of machinery for synthesizing proteins.

## 2. Brief outline on discovery of viruses

1) **(1822–1895)** Louis Pasteur**:** - He was unable to find a causative agent for rabies and speculated about a pathogen too small to be detected using a microscope.
2) **(1884)** Charles Chamberland**:** - French microbiologist Charles Chamberland invented the Chamberland filter (or Pasteur-Chamberland filter) with pores small enough to remove all bacteria from a solution passed through it.
3) **(1892) Dmitri Ivanovsky: -** Russian biologist Dmitri Ivanovsky used this filter to study what is now known as the tobacco mosaic virus: crushed leaf extracts from infected tobacco plants remained infectious even after filtration to remove bacteria. Ivanovsky suggested the infection might be caused by a toxin produced by bacteria, but did not pursue the idea.
4) **(1898)** MartinusBeijerinck**:** **-** The Dutch microbiologist MartinusBeijerinck repeated the experiments and became convinced that the filtered solution contained a new form of infectious agent. He observed that the agent multiplied only in cells that were dividing, but as his experiments did not show that it was made of particles, he called it a *contagiumvivumfluidum* (soluble living germ) and re-introduced the word *virus*. Beijerinck maintained that viruses were liquid in nature.

5) **(1904-1971)** Wendell Stanley**: -** He proved viruses are particulate.
6) Friedrich Loeffler **and Paul Frosch: -** passed the first animal virus through a similar filter: aphthovirus, the agent of foot-and-mouth disease.
7) Frederick Twort discovered a group of viruses that infect bacteria, now called bacteriophages (or commonly *phages*).
8) Félix d'Herelle**: -** French-Canadian microbiologist described viruses that, when added to bacteria on an agar plate, would produce areas of dead bacteria.
9) **(1913) Steinhardt, C. Israeli, and R. A. Lambert: -** grown vaccinia virus in fragments of guinea pig corneal tissue.
10) **(1928) H. B. Maitland and M. C. Maitland**: - They grew vaccinia virus in suspensions of minced hens' kidneys.
11) **(1931)** Ernest William Goodpasture **and** Alice Miles Woodruff**: -** They grew influenza and several other viruses in fertilised chicken eggs.
12) **(1931)** Ernst Ruska **and** Max Knoll**.** The first images of viruses were obtained upon the invention of electron microscopy in 1931 by the German engineers Ernst Ruska and Max Knoll.
13) **(1935)** Wendell Meredith Stanley**: -**He examined the tobacco mosaic virus and found it was mostly made of protein. The tobacco mosaic virus was the first to be crystallised and its structure could therefore be elucidated in detail.
14) **(1941) Bernal and Fankuchen: -** The first X-ray diffraction pictures of the crystallised virus were obtained.
15) **(1949)** John Franklin Enders**,** Thomas Weller**, and** Frederick Robbins**: -** They grew polio virus in cultured human embryo cells, the first virus to be grown without using solid animal tissue or eggs. This work enabled Jonas Salk to make an effective polio vaccine.
16) **(1955)** Rosalind Franklin**: -** He discovered the full structure of the virus on the basis of X-ray diffraction pictures.
17) **(1955)** Heinz Fraenkel-Conrat **and** Robley Williams**: -** They showed that purified tobacco mosaic virus RNA and its protein coat can assemble by themselves to form functional viruses, suggesting that this simple mechanism was probably the means through which viruses were created within their host cells.

18) **The second half of the 20th century** was the golden age of virus discovery and most of the over 2,000 recognised species of animal, plant, and bacterial viruses were discovered during these years.
19) **(1957)**equine arterivirus and the cause of Bovine virus diarrhoea (a pestivirus) were discovered.
20) **(1963)** Baruch Blumberg**: -** Hediscovered Hepatitis B virus.
21) **(1965- 1970)** Howard Martin Temin **and** David Baltimore**: -** They described the first retrovirus. Reverse transcriptase, the enzyme that retroviruses use to make DNA copies of their RNA.
22) **(1983)** Luc Montagnier**'s team: -** At the Pasteur Institute in France; first isolated the retrovirus now called HIV.
23) **(1989)** Michael Houghton**'s team: -** They discovered Hepatitis C virus.

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❖ Virus, Virions, Viroids, Virusoids and prions.

Viruses and Virions difference

| Sr. No. | Virus | Virion |
|---|---|---|
| 1 | Viruse is microscopic structures consisting of a segment of nucleic acid (either DNA or RNA) surrounded by a protein coat that can replicate only inside a host cell. | It is a complete virus particle that consists of an RNA or DNA core with a protein coat sometimes with external envelope.It has nucleic acid as well as protein layers. |
| 2 | Viruse is nucleoproteins. | It has nucleoproteins as well as extra protein layers.It is also encapsulated by an external protein shell called a capsid. |
| 3 | A virus is the nucleoprotein particle. | Virion is the active, infectious form of the virus. |

| | | |
|---|---|---|
| 4 | A virus consists of a genetic material covered by a protein capsid, and it does not display any metabolic activity. | Virion is the vector stage of a virus that allows the transmission of the virus from an infected host cell to another host cell. |
| 5 | The virus is the extracellular phase. | The virion is the intracellular phase of the virus. |
| 6 | The shape ranges of viruses are – helical, icosahedral, prolate, envelope, and complex. | Avirion is usually spheroidal or rod-shaped. |
| 7 | Virus is a type of nucleoprotein. | Avirion refers to the entire article, which is contagious. |

## Viroids

- Viroids are small single-stranded, circular RNAs that are infectious pathogens. Unlike viruses, they have no protein coating. All known viroids are inhabitants of angiosperms (flowering plants), and most cause diseases to plants.
- Viroids are infectious agents composed exclusively of a single piece of circular single stranded RNA which has some double-stranded regions.
- Viroids are infectious pathogens that affect only plants, therefore are also called as the plant pathogens. Structurally, viroids are smaller than viruses and possess circular strands of ribonucleic acids (RNA’s) with no protein coating. These entities hijack the cellular machinery present in plant cells to replicate new copies of itself. It primarily affects all forms of higher plants.
- Viroids differ from the virus in structure and form. These consist of solely short strands of circular and single-stranded RNA without the protein coats.
- Viroids are catalytic RNA's (ribozymes) that cleave RNA to produce fragments containing a 5'-hydroxyl and a 2', 3'-cyclic phosphate.

- The first recognized viroid, the pathogenic agent of the potato spindle tuber disease, was discovered, initially molecularly characterized, and named by Theodor Otto Diener, plant pathologist at the U.S Department of Agriculture's Research Center in Beltsville, Maryland, in 1971.

The plants that are infected by viroids are responsible for the crop failures and also causes loss of millions of dollars in the agricultural revenue every year. Some of the plants that are affected by these pathogens are potatoes, tomatoes, cucumbers, chrysanthemums, coconut palms, avocados, etc.

Viroids are the plant parasites like transcriptional machinery of the cell organelles such as the nucleus or the chloroplast since they are known to be non-coding. These replicate by the process of RNA–RNA transcription. They mainly infect the epidermis of the hosts after causing mechanical damage to the cell wall of the plant.

## Characteristic Features of Viroids

- Viroids contain only RNA.
- These are known to be smaller in size and infect only the plants.
- The human pathogen hepatitis D virus is a subviral agent similar in structure to a viroid.
- These are among the smallest known agents causing infectious disease.
- Viroids are the species of nucleic acid with relatively low molecular weight and a unique structure.
- They reproduce within the host cell which they affect in and cause variations in them causing death.
- Viroids are mainly classified into two families namely Pospiviroidae- nuclear viroids and Avsunviroidae- chloroplasticviroids.
- Viroids are said to move in an intracellular manner, cell to cell through the plasmodesmata, and a long-distance through the phloem.

## Replication of viroids

The viroid's replication mechanism uses RNA polymerase II, a host cell enzyme normally associated with synthesis of messenger RNA from DNA, which instead catalyzes "rolling circle" synthesis of new RNA using the viroid's RNA as a template.

Upon infection, viroids replicate in the nucleus (Pospiviroidae) or chloroplasts (Avsunviroidae) of plant cells in three steps through an RNA-based mechanism. They require RNA polymerase II, a host cell enzyme normally associated with synthesis of messenger RNA from DNA, which instead catalyzes "rolling circle" synthesis of new RNA using the viroid as template.

## Ribozymes

Viroids are often ribozymes, having catalytic properties that allow self-cleavage and ligation of unit-size genomes from larger replication intermediates.

Ribozymes (ribonucleic acid enzymes) are RNA molecules that have the ability to catalyze specific biochemical reactions, including RNA splicing in gene expression, similar to the action of protein enzymes. The 1982 discovery of ribozymes demonstrated that RNA can be both genetic material (like DNA) and a biological catalyst (like protein enzymes), and contributed to the RNA world hypothesis, which suggests that RNA may have been important in the evolution of prebiotic self-replicating systems.

## Viroid Diseases

Some of the diseases that are caused by the infection of viroids in plants are citrus exocortis, cucumber pale fruit, chrysanthemum stunt. These infectious diseases are spread by the propagation of seeds in plants by cutting, tubers, etc and also by mishandling the contaminated implements. Hepatitis- D is caused in humans by viroid like particles.

The symptoms that are caused by the infection of viroid in plants include stunting of growth, stem necrosis, deformation of the leaves and fruits, and at last causing the death of the plant.

Most of the viroids are said to infect the plants, including coconut and the apple trees. The (PSTV) potato spindle tuber viroid causes significant crop damage to the potato yields causing the tubers to elongate and then crack. The other common type of viroid infection symptoms includes stunting and leaf epinasty.

## Classification of viroids

### Family Avsunviroidae

Genus Avsunviroid; type species: Avocado sunblotch viroid

Genus Pelamoviroid; type species: Peach latent mosaic viroid

Genus Elaviroid; type species: Eggplant latent viroid

### Family Pospiviroidae

Genus Pospiviroid; type species: Potato spindle tuber viroid

Genus Hostuviroid; type species: Hop stunt viroid

Genus Cocadviroid; type species: Coconut cadang-cadang viroid

Genus Apscaviroid; type species: Apple scar skin viroid

Genus Coleviroid; type species: Coleus blumei viroid 1

## ❖ Prions

### What are Prions?

The term Prion means proteinaceous infectious particles. Prions are the infectious agents responsible for several neurodegenerative diseases in mammals, like, CreutzfeldtJakob disease. This happens due to the abnormal folding of the proteins in the brain.

It refers to the hypothesis that the infectious agents causing the diseases contain only proteins. It explained why the infectious agents are resistant to ultraviolet radiations. They can break down the nucleic acids, but are receptive to substances that denature proteins.

### **Structure of Prions**

Prions are found all over the body but the ones that cause diseases are structurally different. Few of them are even resistant to proteases. The two isoforms of prions are:

### PrPc

These prion proteins are found on the cell membrane and play an important role in cell signalling and cell adhesion. More research is being carried out to discover its functions.

### PrPsc

This is the disease-causing prion and is resistant to proteases. It affects the confirmation of PrPc and changes it. They are believed to have more beta sheets than the alpha helices.

It also forms highly structured amyloid fibres. The other free proteins also attach to the end of these fibres. Similar prions with similar amino acids can only bind. However, cross-species binding is also possible, but is very rare.

## Diseases Caused by Prions

Prions are quite rare and difficult to transmit. But they are progressive neurodegenerative diseases with no cure or treatment. These diseases develop gradually.

These proteins affect many other animals in addition to humans. For eg.,scrapie in sheep, mad cow disease in cows, chronic wasting disease in deer. The prion diseases in humans are Creutzfeldt-Jakob disease, Fatal Familial Insomnia, kuru disease, etc.

Prions can spread in a person's brain for years without any symptoms. The prions start killing neurons and the symptoms strike the brain in no time. Soon the person's health starts declining.

All the prion diseases are fatal, some last a few months, and some might last for years. A few experimental pieces of evidence show that the prions are not ordinary infectious materials. It is believed to be a "self-replicating protein".

## Types of Prion Diseases

Prion diseases can be of three types- acquired, sporadic, or genetic.

### Acquired Prion Disease

The acquired prion diseases occur when a person is exposed to the infectious protein. Though scary, these prions are rarely caught by the people. For eg., in kuru diseases, the prions were transmitted to people by cannibalism. Its main source was New Guinea pig.

## Genetic Prion Disease

The familial prion diseases are caused as a result of genetic transmissions. However, it is not necessarily inherited from the ancestors. It may be caused due to the mutation in some DNA.

## Sporadic Prion Disease

Prion diseases are also believed to be sporadic. This means that its cause is not confirmed. This form of prion disease is most common to date.

### Causes of Prion Diseases

The main cause of prion diseases is the abnormal folding and clumping of prions in the brain causing brain damage. This leads to memory impairment, changes in the personality, difficulties in moving.

Prions are by far the most dangerous infections caused by the agents already present within the body and are usually fatal. However, a lot has not been discovered about prion diseases.

### Risk Factors Involved

- People with genetic history related to prion disease are at risk of Prion disease.
- Eating meat infected by “mad cow disease” increases the risk of Prion disease.
- Contaminated medical equipment or contaminated corneas can cause Prion disease.

## Symptoms of Prion Disease

Following are the symptoms of Prion diseases:

- Developing dementia
- Hallucinations
- Fatigue
- Stiffening of muscles
- Confusion
- Difficulty in speaking

## Mechanism of replication of prions

Discovering the mechanism of replication of prions has been a very difficult task. To find out how can proteins multiply without any cellular machinery was next to impossible. But this is what prions do. There are many other concepts related to prions that are unclear. Researchers are being carried out to figure out the in and outs of prions for detailed studies.

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4. Structure of viruses

- **Morphology and ultra-structure of viruses.**

**1. Size.**

The size range of viruses is from about 20 to 450 nm. On the whole, viruses are much smaller than bacteria. Most animal viruses and all plant viruses and phages are invisible under the light microscope. Electron microscope is required to observe them.

**2. Structure / Shapes of Viruses**

The intact virus unit or infectious particle is called the virion. Each virion consists of a nucleic acid core surrounded by a protein coat (capsid) to from the nucleocapsid. The nucleocapsid may be naked or may be surrounded by a loose membranous envelope. It is composed of a number of subunits called capsomeres. The capsid protects the nucleic acid core against the action of nucleases.

**Capsids**

In a virion the virus genome is enclosed in a protein coat, known as a capsid. For some viruses the genome and the capsid constitute the virion, while for other viruses there are additional components. There may be an envelope at the surface of the virion, in which case there may be protein between the envelope and the capsid, or there may be an internal lipid membrane. A few viruses produce protein occlusion bodies in which virions become embedded.

Viruses occur in following shapes-

**i. Helical (cylindrical or rod like)**

**ii. Icosahedral / Spherical**

**iii. Prolate**

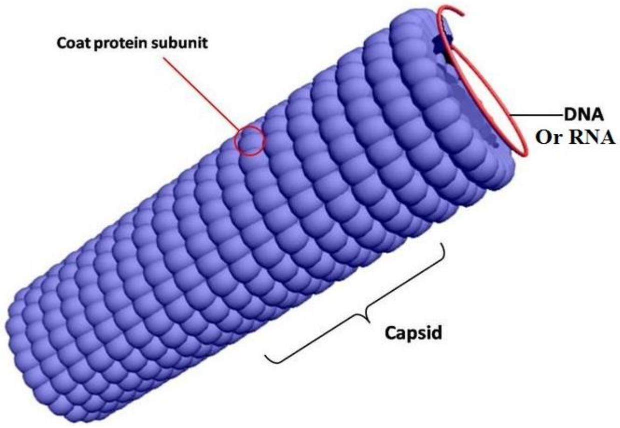
**iv. Envelope**

**v. Complex structure viruses /Tailed bacteriophages / Large Viruses with Multiple Structural Elements**

## i. Helical (cylindrical or rod like)

This virus structure has a capsid with a central cavity or hollow tube that is made by proteins arranged in a circular fashion, creating a disc like shape. The disc shapes are attached helically (like a toy slinky) creating a tube with room for the nucleic acid in the middle. **Helical capsids** are made up of a single type of protein subunit stacked around a central axis to form a helical structure. The helix may have a hollow center, which makes it look like a hollow tube. This arrangement results in rod-shaped or filamentous virions. These virions can be anything from short and very rigid, to long and very flexible. They are usually 10-20 nm wide and range in length from 300 to 900nm depending on the genome size. Helical viruses can be naked or have an envelope around them. The Tobacco Mosaic Virus was the first virus to be studied using X-ray diffraction and is an example of the naked helical virus.

Plant viruses and bacteriophages are rod-like or filamentous structures with helical symmetry. These viruses are composed of a single type of capsomere stacked around a central axis to form a helicalstructure, which may have a central cavity, or tube. This arrangement results in rod-shaped or filamentous virions. These can be short and highly rigid, or long and very flexible. The length of a helical capsid is related to the length of the nucleic acid contained within it and the diameter is dependent on the size and arrangement of capsomeres. The well-studied tobacco mosaic virus is an example of a helical virus.

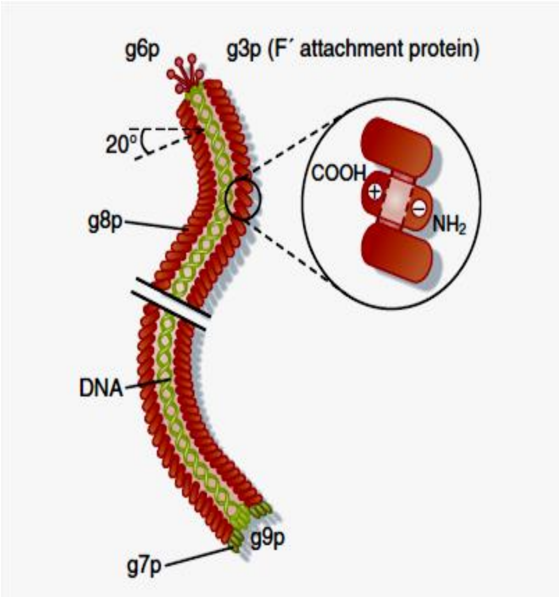


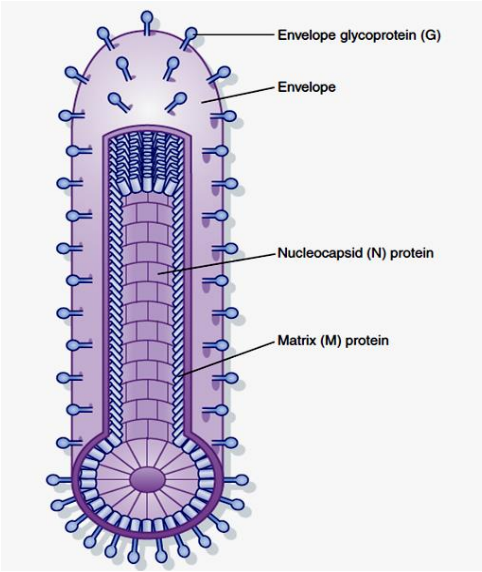

The capsids of many ssRNA viruses have helical symmetry; the RNA is coiled in the form of a helix and many copies of the same protein species are arranged around the coil. The length of the capsid is determined by the length of the nucleic acid.

For many ssRNA viruses, such as measles and influenza viruses, the helical nucleic acid coated with protein forms a nucleocapsid, which is inside an envelope.

From a structural point of view, the best-understood helical nucleocapsid is that of tobacco mosaic virus (TMV), the very first virus to be identified. The virus particle comprises a single molecule of (+) strand RNA, about 6.4 kb in length, enclosed within a helical protein coat (Fig). The coat is built from a single protein that folds into an extended structure shaped like a Dutch clog. Repetitive interactions among coat protein subunits form disks that have been likened to lock washers, which in turn assemble as a long, rod like, right-handed helix. In the interior of the helix, each coat protein molecule binds three nucleotides of the RNA genome. The coat protein subunits therefore engage in **identical** interactions with one another and with the genome, allowing the construction of a large, stable structure from multiple copies of a single protein.

**Examples- Plant viruses, Tobaco Mosaic Virus (TMV), barley stripe mosaic virus, potato virus, some bacteriophages, Animal viruses (**influenza virus (Orthomyxoviridae), mumps and measles viruses (Paramyxoviridae), rabies virus (Rhabdoviridae), Ebola viruses, vesicular stomatitis virus (VSV), **M13 and fd viruses.**






## ii) Icosahedral

The **icosahedral** viruses are also referred to as isometric viruses and generally consist of 20 triangular sides or faces and 12 corners or vertices. The word *icosa* comes from the Greek language and means *twenty*. Each side of the shape forms an equilateral triangle formed by viral proteins. These viruses have at least three viral protein subunits fit together to form the triangular face. These proteins can be different or the same. These structural units repeat to form the icosahedral capsid.

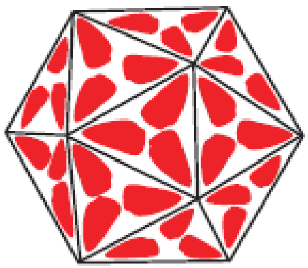
The number of protein units that form a side is called the triangulation number. The triangulation number of different viruses indicates the number of structural units that form the triangular face. Some viruses have more than 25 triangulation numbers. Increasing the number of triangulation numbers increases the size of the capsid. Research shows that icosahedral symmetry is preferred often as it requires less energy. Just like helical viruses, icosahedral viruses can be enveloped or naked.

An icosahedron is a solid with 20 triangular faces and 12 vertices related by two-, three-, and fivefold axes of rotational symmetry. Virus particles can be readily seen to be icosahedral. However, most closed capsids **look** spherical, and they often possess prominent surface structures or viral glycoproteins in the envelope that do not conform to the underlying icosahedral symmetry of the capsid shell.

In solid geometry, each of the 20 faces of icosahedrons is an equilateral triangle, and five such triangles interact at each of the 12 vertices. In the simplest protein shells, a trimer of a single viral protein (the **subunit)** corresponds to each triangular face of the icosahedrons. Such trimers interact with one another at the five-, three-, and twofold axes of rotational symmetry that define an icosahedron.

As an icosahedron has 20 faces, 60 identical subunits (3 per face 20 faces) is the minimal number needed to build a capsid with icosahedral symmetry.

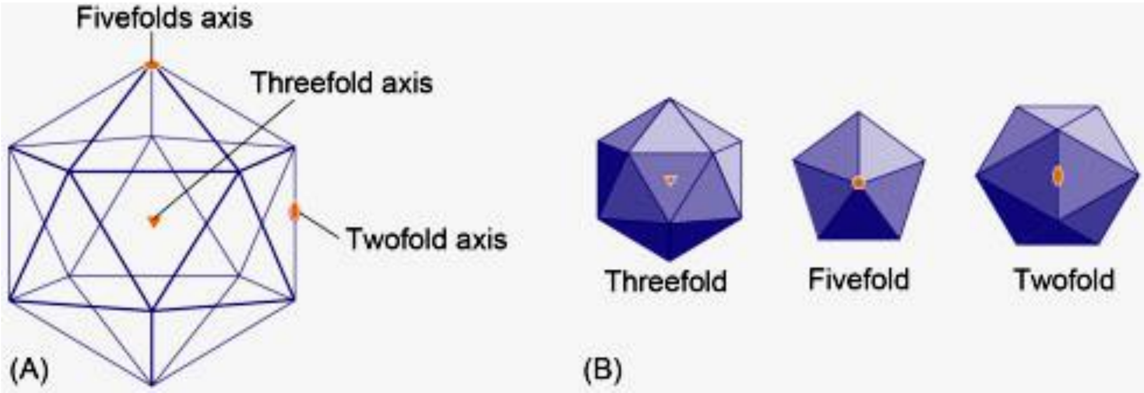
To construct an icosahedron from identical protein molecules the minimum number of molecules required is three per triangular face, giving a total of 60 for the icosahedrons.

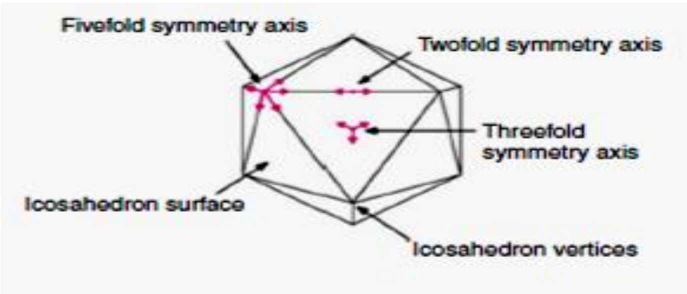


An icosahedron has

- 20 faces, each an equilateral triangle;
- 12 vertices, each formed where the vertices related by two-, three-, and five fold axes of rotational symmetry of five triangles meet;
- 30 edges, at each of which the sides of two triangles meet.

An icosahedron has five-, three- and two-fold axes of rotational symmetry.



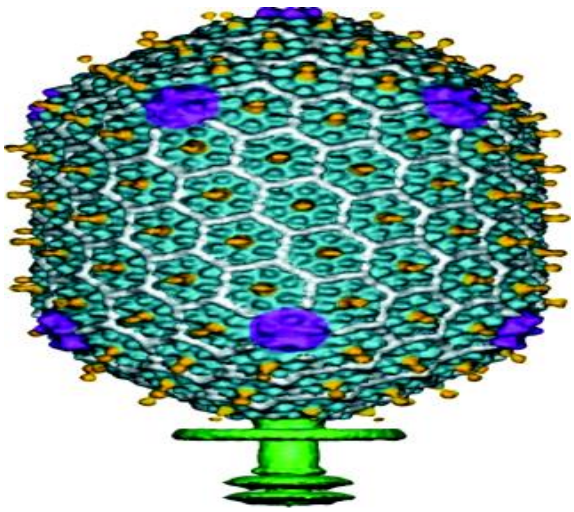

For an icosahedron, the rules are based on the rotational symmetry of the solid, known as 2, 3, 5 symmetry,
which has the following features:

- An axis of two-fold rotational symmetry through the center of each edge
- An axis of three-fold rotational symmetry through the center of each face
- An axis of five-fold rotational symmetry through the center of each corner (vertex)

**Examples: -Human papillomavirus, rhinovirus, hepatitis B virus, and herpesviruses**

### iii). Prolate

This is an icosahedron elongated along the fivefold axis and is a common arrangement of the heads of bacteriophages. This structure is composed of a cylinder with a cap at either end.

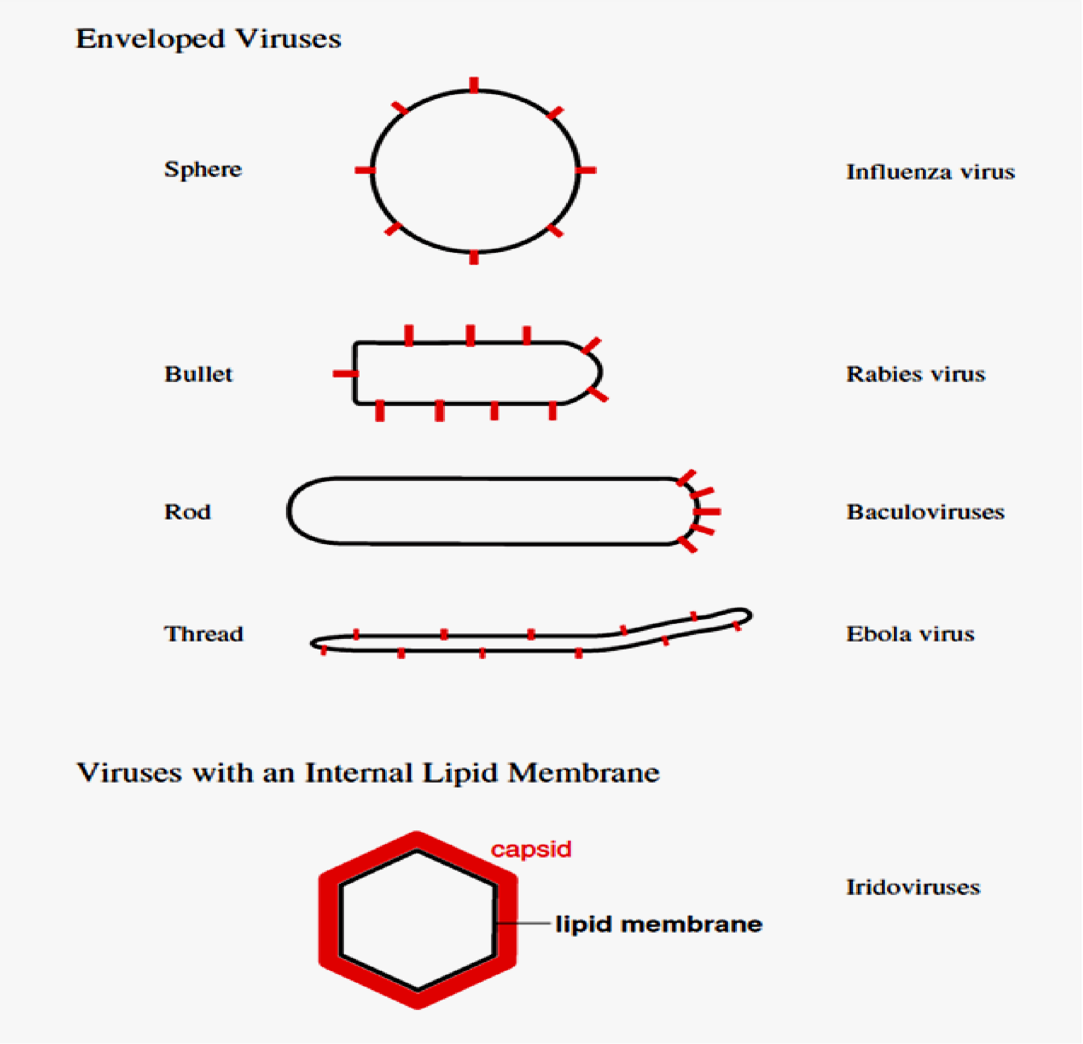


### iv). Envelope

Some species of virus envelop themselves in a modified form of one of the cell membranes, either the outer membrane surrounding an infected host cell or internal membranes such as nuclear membrane or endoplasmic reticulum, thus gaining an outer lipid bilayer known as a viral envelope. This membrane is studded with proteins coded by the viral genome and host genome; the lipid membrane itself and any carbohydrates present originate entirely from the host. The influenza virus and HIV use this strategy.

The foundation of the envelopes of all animal viruses is a lipid membrane acquired from the host cell during assembly. The precise lipid composition is variable, for viral envelopes can be derived from different kinds of cellular membranes. Embedded in the membrane are viral proteins, the great majority of
which are **glycoproteins** that carry covalently linked sugar chains, or **oligosaccharides** .

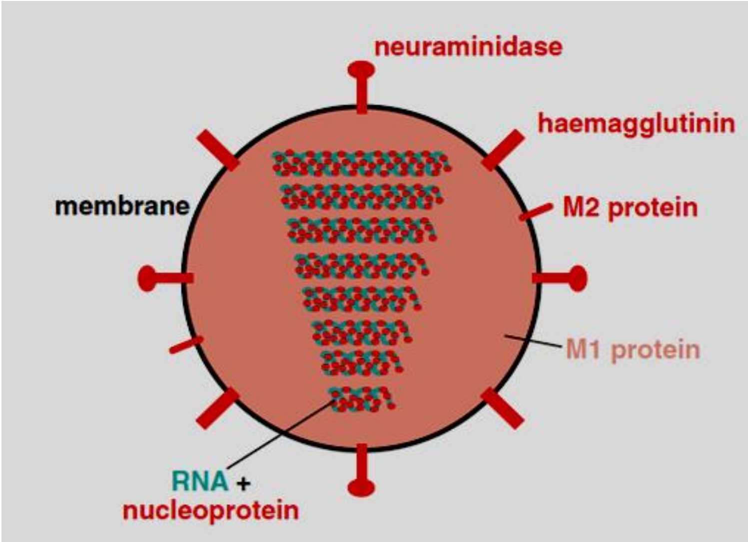
Many viruses have a lipid membrane component. In most of these viruses the membrane is at the virion surface and is associated with one or more species of virus protein. This lipid–protein structure is known as an envelope and it encloses the nucleocapsid (nucleic acid plus capsid). The virions of most enveloped viruses, such as herpesviruses, are spherical or roughly spherical, but other shapes exist (Figure). Some viruses have a membrane located not at the virion surface, but within the capsid.




Components in black represent lipid bilayers:

Components in red represent protein.

Associated with the membranes of an enveloped virus are one or more species of protein. Most of these proteins are integral membrane proteins and most are O- and/or N-glycosylated. Many of the glycoproteins in virion envelopes are present as multimers. The envelope of influenza A virus contains two glycoprotein species: a haemagglutinin present as trimers and a neuraminidase present as tetramers. There is also a third protein species (M2) that is not glycosylated.



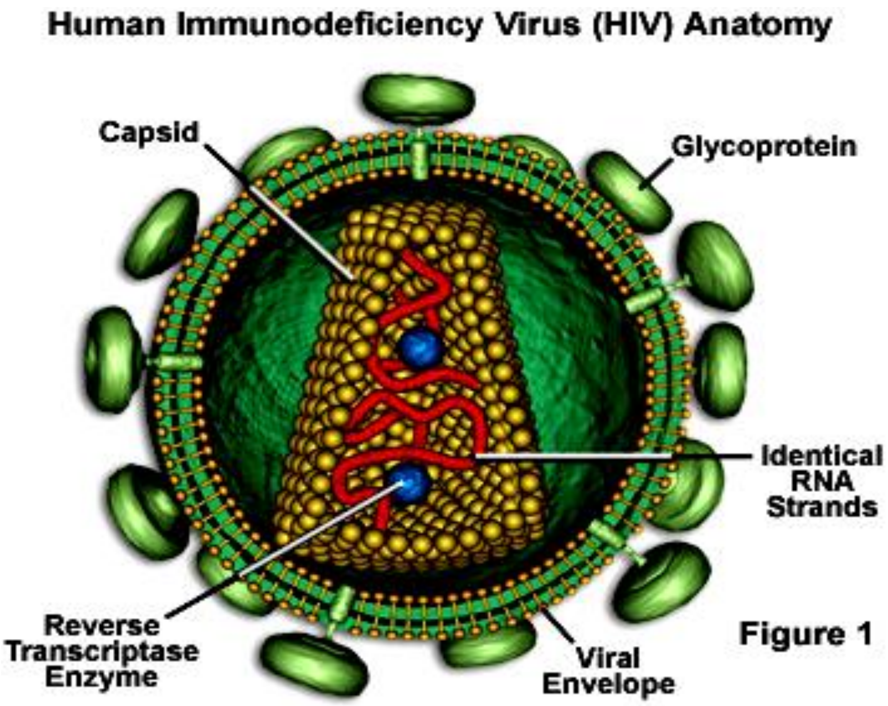

Many enveloped viruses, including influenza viruses and retroviruses, have a layer of protein between the envelope and the nucleocapsid. This protein is often called a matrix protein. In some viruses, however, such as yellow fever virus, there is no such layer and the nucleocapsid interacts directly with the internal tails of the integral membrane protein molecules.

***Virions with internal membranes***

There are several viruses that have a lipid membrane within the virion rather than at the surface.

***Membrane lipids***

Most virion membranes are derived from host cell membranes that undergo modification before incorporation into virions. For example, the HIV-1 envelope is derived from the plasma membrane of the host cell, but the virus envelope contains more cholesterol and sphingomyelin, and less phosphatidylcholine and phosphatidylinositol.

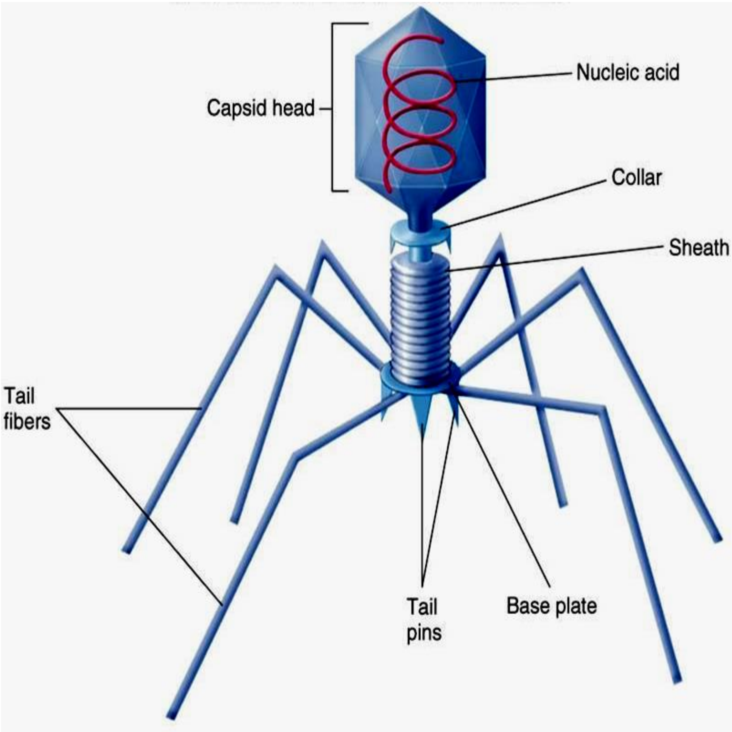



**Occlusion bodies**

Some viruses provide added protection to the virions whilst outside their hosts by occluding them in protein crystals. These occlusion bodies, as they are known, are produced by many of the viruses that infect invertebrates, including most baculoviruses. There are two major types of occlusion body in which baculoviruses embed their rod-shaped virions; the granuloviruses form small granular occlusion bodies, generally with a single virion in each, while the nucleopolyhedroviruses form large occlusion bodies with many virions in each.

**v). Complex structure viruses /Tailed bacteriophages / Large Viruses with Multiple Structural Elements**

These viruses possess a capsid that is neither purely helical nor purely icosahedral, and that may possess extra structures such as protein tails or a complex outer wall. Some bacteriophages, such as Enterobacteria phage T4, have a complex structure consisting of an icosahedral head bound to a helical tail, which may have a hexagonal base plate with protruding protein tail fibres. This tail structure acts like a molecular syringe, attaching to the bacterial host and then injecting the viral genome into the cell.

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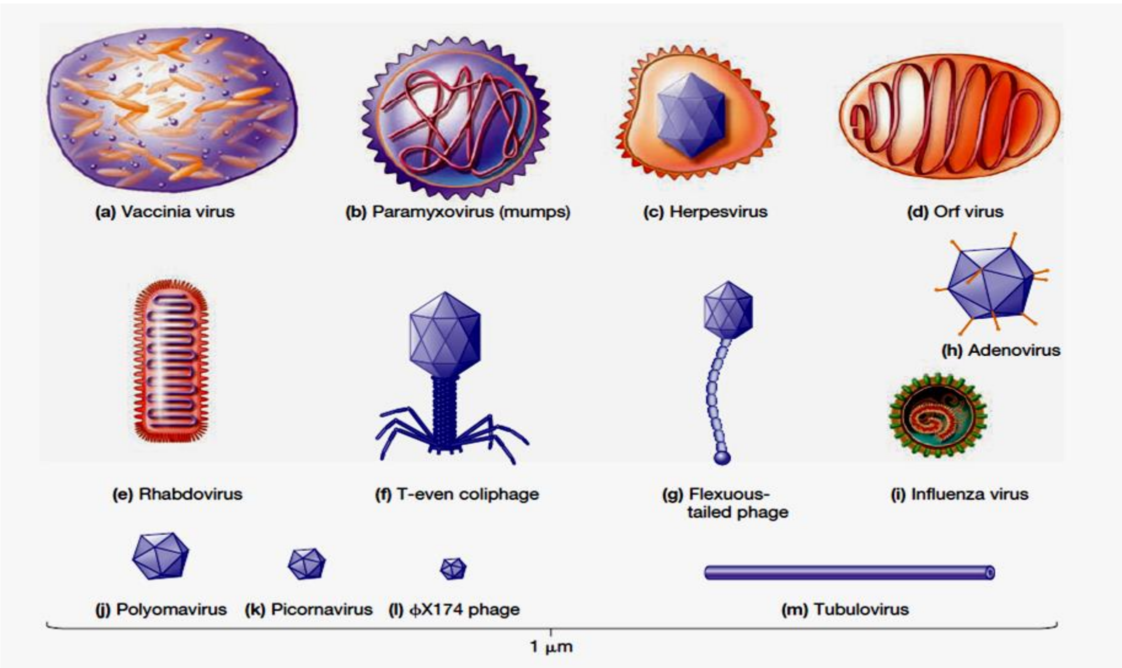

**3. Absence of cellular structure.** Viruses do not have any cytoplasm, and thus cytoplasmic organelles like mitochondria, Golgi complexes, lysosomes, ribosomes, etc., are absent. They do not have any limiting cell membrane. They utilize the ribosomes of the host cell for protein synthesis during reproduction.

**4. No independent metabolism.** Viruses cannot multiply outside a living cell. No virus has been cultivated in a cell-free medium. Viruses do not have an independent metabolism. They are metabolically inactive outside the host cell because they do not possess enzyme systems and protein synthesis machinery. Viral nucleic acid replicates by utilizing the nucleic acid synthesis machinery of the host. It codes for the synthesis of a limited number of viral proteins, including the subunits or capsomeres of the capsid, the tail protein and some enzymes concerned with the synthesis or the release of virions.

**5. Nucleic acids**. Viruses have only one nucleic acid, either DNA or RNA. Typical cells have both DNA and RNA. Genomes of certain RNA viruses can be transcribed into complementary DNA strands in the infected host cells, e. g. Rous Sarcoma Virus (RSV). Such RNA viruses are therefore also called RNA-DNA viruses.

**6. Crystallization.** Many of the smaller viruses can be crystallized, and thus behave like chemicals.

**7. No growth and division.** Viruses do not have the power of growth and division. A fully formed virus does not increase in, size by addition of new molecules. The virus itself cannot divide. Only its genetic material (RNA or DNA) is capable of reproduction and that too only in a host cell. It will thus be seen that viruses do not show all the characteristics of typical living organisms. They, however, possess two fundamental characteristics of living systems. Firstly, they contain nucleic acid as their genetic material.

The nucleic acid contains instructions for the structure and function of the virus. Secondly, they can reproduce themselves, even if only by using the host cells synthesis machinery. The debate as to whether viruses are living or non-living is actually superfluous. A decision on this matter would ultimately depend upon the criteria adopted to distinguish between living and non-living.

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## 5. Viral genomes

Viruses are small submicroscopic, obligate intracellular parasites, which contains either DNA or RNA as genome protected by a virus-encoded protein coat called capsid.

Viruses have genetic material of either single-stranded DNA, double-stranded DNA, single-stranded RNA, and double-stranded RNA. All four types are found in animal viruses. Most plant viruses have single-stranded RNA genomes, and most bacterial viruses contain double-stranded DNA. The size of viral genetic material also varies greatly. The smallest genomes (those of the MS2 and Q viruses) are around 4,000 nucleotides, just large enough to code for three or four proteins. MS2, Qβ, and some other viruses even save space by using overlapping genes. At the other extreme, T-even bacteriophages, herpesvirus, and vaccinia virus have genomes of 1.0 to 2.0 X $10^5$ nucleotides and may be able to direct the synthesis of over 100 proteins.

### A) DNA viruses

1) Double Stranded DNA viruses

2) Single Stranded DNA viruses

### B) RNA viruses

1) Positive sense single stranded viruses

2) Negative sense single stranded viruses

3) Double stranded RNA viruses

4) Retroviruses

## A) DNA viruses

A DNA virus is a virus that has a genome made of deoxyribonucleic acid (DNA) that is replicated by a DNA polymerase. They can be divided between those that have two strands of DNA in their genome, called double-stranded DNA (dsDNA) viruses, and those that have one strand of DNA in their genome, called single-stranded DNA (ssDNA) viruses.

### 1) Double Stranded DNA viruses

These viruses have two strands of DNA in their genome, called double-stranded DNA (dsDNA) viruses. DNA may linear or circular. Some DNA genomes can switch from one form to the other. For instance, the E. coli phage lambda has a genome that is linear in the capsid, but is converted into a circular form once the genome enters the host cell. Another important characteristic of DNA viruses is that their genomes often contain unusual nitrogenous bases. For example, the T-even phages of E. coli have 5-hydroxymethylcytosine instead of cytosine, and the hydroxymethyl group is often modified by attachment of a glucose moiety.

On the basis of structure of dsDNA, there are 4 types of dsDNA viruses.

| Sr No. | dsDNA structure | Examples of dsDNA viruses |
|---|---|---|
| 1 | Linear, double-stranded DNA | Herpesviruses (herpes simplex viruses, cytomegalovirus, Epstein-Barr virus), adenoviruses, T coliphages, lambda phage, and other bacteriophages |
| 2 | Linear, double-stranded DNA with single chain breaks | T5 coliphage |
| 3 | Double-stranded DNA with cross-linked ends | Vaccinia, smallpox viruses |
| 4 | Closed, circular, double-stranded DNA | Polyomaviruses (SV-40), papillomaviruses, PM2 phage, cauliflower mosaic virus |

### 2) Single Stranded DNA viruses

These have single-stranded DNA (ssDNA) genomes. DNA can be either linear or circular.

On the basis of structure of ssDNA, there are 2 types of ssDNA viruses.

| Sr No. | ssDNA structure | Examples of ssDNA viruses |
|---|---|---|
| 1 | Linear, single-stranded DNA | Parvoviruses |
| 2 | Circular, single-stranded DNA | φX174, M13, fd phages |

## B) RNA viruses

RNA viruses also can be either double-stranded (dsRNA) or single-stranded (ssRNA). Although relatively few RNA viruses have dsRNA genomes, dsRNA viruses are known to infect animals, plants, fungi, and at least one bacterial species. More common are the viruses with ssRNA genomes.

### 1) Positive sense single stranded ssRNA viruses

Positive-strand RNA viruses (+ssRNA viruses) are a group of related viruses that have positive-sense, single-stranded genomes made of ribonucleic acid. The positive-sense genome can act as messenger RNA (mRNA) and can be directly translated into viral proteins by the host cell's ribosomes.

Positive-strand RNA viruses have genetic material that can function both as a genome and as messenger RNA; it can be directly translated into protein in the host cell by host ribosomes.

Positive-strand RNA viruses encode an RNA-dependent RNA polymerase (RdRp) which is used during replication of the genome to synthesize a negative-sense antigenome that is then used as a template to create a new positive-sense viral genome.

Positive-sense RNA viruses include pathogens such as the Hepatitis C virus, West Nile virus, dengue virus, and the MERS, SARS, and SARS-CoV-2 corona viruses, as well as less clinically serious pathogens such as the corona viruses and rhinoviruses that cause the common cold.

Positive-strand RNA virus genomes usually contain relatively few genes, usually between three and ten, including an RNA-dependent RNA polymerase. Coronaviruses have the largest known RNA genomes, between 27 and 32 kilobases in length.

The replication of the positive-sense RNA genome proceeds through double-stranded RNA intermediates. All positive-strand RNA virus genomes encode RNA-dependent RNA polymerase, a viral protein that synthesizes RNA from an RNA template.

On the basis of structure of Positive sense single stranded ssRNA, there are 3 types of Positive sense single stranded ssRNA viruses.

| **Sr. No.** | **Positive sense single stranded ssRNA** | **Examples of Positive sense single stranded ssRNA** |
|---|---|---|
| 1 | Linear, single-stranded, positive-strand RNA | Picornaviruses (polio, rhinoviruses), togaviruses, RNA bacteriophages, TMV, and most plant viruses |
| 2 | Linear, single-stranded, segmented, positive-strand RNA | Brome mosaic virus (individual segments in separate virions) |
| 3 | Linear, single-stranded, diploid (two identical single strands), positive-strand RNA | Retroviruses (Rous sarcoma virus, human immunodeficiency virus) |

## 2) Negative sense single stranded viruses

Negative-strand RNA viruses (−ssRNA viruses) are a group of related viruses that have negative-sense, single-stranded genomes made of ribonucleic acid. They have genomes that act as complementary strands from which messenger RNA (mRNA) is synthesized by the viral enzyme RNA-dependent RNA polymerase (RdRp).

During replication of the viral genome, RdRp synthesizes a positive-sense antigenome that it uses as a template to create genomic negative-sense RNA. Negative-strand RNA viruses also share a number of other characteristics: most contain a viral envelope that surrounds the capsid, which encases the viral genome, −ssRNA virus genomes are usually linear, and it is common for their genome to be segmented.

Prominent arthropod-borne −ssRNA viruses include the Rift Valley fever virus and the tomato spotted wilt virus. Notable vertebrate −ssRNA viruses include the Ebola virus, hantaviruses, influenza viruses, the Lassa fever virus, and the rabies virus.

On the basis of structure of negative sense single stranded ssRNA, there are 2 types of negative sense single stranded ssRNA viruses.

| Sr. No. | Negative sense single stranded ssRNA | Examples of negative sense single stranded ssRNA |
|---|---|---|
| 1 | Linear, single-stranded, negative-strand RNA | Rhabdoviruses (rabies), paramyxoviruses (mumps, measles) |
| 2 | Linear, single-stranded, segmented, negative-strand RNA | Paramyxoviruses, orthomyxoviruses (influenza) |

### 3) Double stranded RNA viruses

Double-stranded RNA viruses (dsRNA viruses) are a polyphyletic group of viruses that have double-stranded genomes made of ribonucleic acid. The double-stranded genome is used to transcribe a positive-strand RNA by the viral RNA-dependent RNA polymerase (RdRp). The positive-strand RNA may be used as messenger RNA (mRNA) which can be translated into viral proteins by the host cell's ribosomes. The positive-strand RNA can also be replicated by the RdRp to create a new double-stranded viral genome.

Double-stranded RNA viruses include the rotaviruses, known globally as a common cause of gastroenteritis in young children, and bluetongue virus, an economically significant pathogen of cattle and sheep. The family Reoviridae is the largest and most diverse dsRNA virus family in terms of host range.

### 4) Retroviruses

Retroviruses are viruses with RNA as genetic material. They belong to the family Retroviridae of Retroviruses. Once it has infected a cell, it converts its RNA into DNA by reverse transcription. This viral DNA is then inserted into the DNA of the host cell where it starts replicating. For eg., Human Immunodeficiency Virus (HIV).

The virus uses its own reverse transcriptase enzyme to produce DNA from its RNA genome inside the host cell's cytoplasm (RNA to DNA), the reverse of the usual pattern (DNA to RNA), thus retro means backwards form RNA to DNA. The new DNA is then incorporated into the host cell genome by an integrase enzyme, at which point the retroviral DNA is referred to as a provirus.

The host cell then treats the viral DNA as part of its own genome, transcribing and translating the viral genes along with the cell's own genes, producing the proteins required to assemble new copies of the virus. Many retroviruses cause serious diseases in humans, other mammals, and birds.

The retroviral genome is packaged as viral particles. These viral particles are dimers of single-stranded, positive-sense, linear RNA molecules.