2.1 What is a Virus?

Viruses are infectious units with diameters of about 16 nm (circoviruses) to over 300 nm (poxviruses; Table 2.1). Their small size makes them ultrafilterable, i.e. they are not retained by bacteria-proof filters. Viruses have evolved over a long time period, and have adapted to specific organisms or their cells. The infectious virus particles, or virions, are composed of proteins and are surrounded in some species of viruses by a lipid membrane, which is referred to as an envelope; the particles contain only one kind of nucleic acid, either DNA or RNA. Viruses do not reproduce by division, such as bacteria, yeasts or other cells, but they replicate in the living cells that they infect. In them, they develop their genomic activity and produce the components from which they are made. They encode neither their own protein synthesis machinery (ribosomes) nor energy-generating metabolic pathways. Therefore, viruses are intracellular parasites. They are able to re-route and modify the course of cellular processes for the optimal execution of their own reproduction. Besides the genetic information encoding their structural components, they additionally possess genes that code for several regulatory active proteins (such as transactivators) and enzymes (e.g. proteases and polymerases).
| Virus family        | Subfamily/genus | Example                        | Envelope | Particle size/shape of the capsid or nucleocapsid | Genome: kind and size                  |
|---------------------|----------------|--------------------------------|----------|--------------------------------------------------|----------------------------------------|
| Picornaviridae       | Enterovirus    | Poliovirus, coxsackievirus, human enteroviruses, human rhinoviruses | No       | 28–30 nm/icosahedron                             | ssRNA; linear; positive strand; 7,200–8,400 nucleotides |
|                     | Cardiovirus    | Encephalomyocarditis virus, mengovirus, theilovirus                   |          |                                                  |                                        |
|                     | Aphthovirus    | Foot-and-mouth disease virus                                           |          |                                                  |                                        |
|                     | Parechovirus   | Human parechovirus                                                      |          |                                                  |                                        |
|                     | Hepatovirus    | Hepatitis A virus                                                       |          |                                                  |                                        |
|                     | Erbovirus      | Equine rhinitis B virus                                                 |          |                                                  |                                        |
|                     | Kobuvirus      | Aichi virus                                                             |          |                                                  |                                        |
|                     | Teschovirus    | Porcine teschoviruses                                                  |          |                                                  |                                        |
| Astroviridae         | Mamastrovirus  | Human, bovine and feline astroviruses                                   | No       | 27–30 nm/icosahedron                             | ssRNA; linear; positive strand; 6,800–7,900 nucleotides |
|                     | Avastrovirus   | Avian astroviruses                                                      |          |                                                  |                                        |
| Caliciviridae        | Norovirus      | Norwalk virus                                                           | No       | 27–34 nm/icosahedron                             | ssRNA; linear; positive strand; 7,500–8,000 nucleotides |
|                     | Sapovirus      | Sapporo virus                                                           |          |                                                  |                                        |
|                     | Vesivirus      | Feline calicivirus                                                      |          |                                                  |                                        |
|                     | Lagovirus      | Rabbit haemorrhagic disease virus                                        |          |                                                  |                                        |
|                     | Nebovirus      | Newbury-1 virus                                                         |          |                                                  |                                        |
| Family | Genus | Virus Name | Properties | Structure | RNA | Genomes |
|--------|-------|------------|------------|-----------|-----|---------|
| Hepeviridae | Hepevirus | Hepatitis E virus | No | 27–34 nm/icosahedron | ssRNA; linear; positive strand; 7,200 nucleotides |
| Flaviviridae | Flavivirus | Yellow fever virus, dengue virus, West Nile virus, tick-borne encephalitis virus | Yes | 40–50 nm/icosahedron | ssRNA; linear; positive strand; 10,000 nucleotides |
| | Pestivirus | Classical swine fever virus, bovine viral diarrhoea virus |
| | Hepacivirus | Hepatitis C virus |
| Togaviridae | Alphavirus | Sindbis virus, Semliki Forest virus, equine encephalitis viruses | Yes | 60–70 nm/icosahedron | ssRNA; linear; positive strand; 12,000 nucleotides |
| | Rubivirus | Rubella virus |
| Arteriviridae | Arterivirus | Equine arteritis virus, porcine reproductive and respiratory syndrome virus | Yes | 40–60 nm/icosahedron | ssRNA; linear; positive strand; 12,000–16,000 nucleotides |
| Coronaviridae | Coronavirinae/Alphacoronavirus | Human coronaviruses 229E and NL63, feline coronavirus, porcine transmissible gastroenteritis virus | Yes | 120–160 nm/helix | ssRNA; linear; positive strand; 25,000–35,000 nucleotides |
| | Coronavirinae/Betacoronavirus | SARS-associated coronavirus, mouse hepatitis virus, bat coronaviruses HKU5 and HKU9 |
| | Coronavirinae/Gammacoronavirus | Avian infectious bronchitis virus |
| | Torovirinae/Torovirus | Bovine and equine toroviruses |

(continued)
| Virus family       | Subfamily/genus          | Example                                           | Envelope | Particle size/shape of the capsid or nucleocapsid | Genome: kind and size                      |
|-------------------|--------------------------|---------------------------------------------------|----------|---------------------------------------------------|---------------------------------------------|
| **Rhabdoviridae** | Vesiculovirus            | Vesicular stomatitis virus                        | Yes      | 65–180 nm/helix                                   | ssRNA; linear; negative strand; 12,000 nucleotides |
|                   | Lyssavirus               | Rabies virus                                      |          |                                                   |                                             |
|                   | Ephemovirus              | Bovine ephemeral fever virus                      |          |                                                   |                                             |
|                   | Novirhabdovirus          | Infectious haematopoietic necrosis virus, viral haemorrhagic septicæmia virus |          |                                                   |                                             |
| **Bornaviridae**  | Bornavirus               | Borna disease virus                               | Yes      | 90 nm/helix                                       | ssRNA; linear; negative strand; 9,000 nucleotides |
|                   |                         |                                                   |          |                                                   |                                             |
| **Paramyxoviridae** | Respirovirus            | Parainfluenza virus                               | Yes      | 150–250 nm/helix                                  | ssRNA; linear; negative strand; 16,000–20,000 nucleotides |
|                   | Rubulavirus              | Mumps virus                                       |          |                                                   |                                             |
|                   | Avulavirus               | Newcastle disease virus                           |          |                                                   |                                             |
|                   | Morbillivirus            | Measles virus, canine distemper virus, rinderpest virus |          |                                                   |                                             |
|                   | Henipavirus              | Hendra virus, Nipah virus                         |          |                                                   |                                             |
|                   | Pneumovirus              | Respiratory syncytial virus                       |          |                                                   |                                             |
|                   | Metapneumovirus          | Human metapneumovirus                             |          |                                                   |                                             |
| Family            | Genus              | Species                                | Segments | Diameter | Envelope | Replication | vRNA Type         |
|-------------------|--------------------|----------------------------------------|----------|----------|----------|-------------|-------------------|
| Filoviridae       | Marburgvirus       | Marburg marburgvirus                   | Yes      | 80–700 nm/helix | ssRNA; linear; negative strand; 19,000 nucleotides |
|                   | Ebola              | Zaire ebolavirus, Reston ebolavirus    |          |          |          |             |                   |
| Arenaviridae      | Arenavirus         | Lymphocytic choriomeningitis virus, Lassa virus, Junin virus | Yes      | 50–300 nm/helix | ssRNA; linear; 2 segments; ambisense strands; 10,000–12,000 nucleotides |
| Bunyaviridae      | Orthobunyavirus    | California encephalitis virus          | Yes      | 100–120 nm/helix | ssRNA; linear; 3 segments; negative strand (ambisense in phleboviruses); 12,000 nucleotides |
|                   | Phlebovirus        | Rift Valley fever virus, sandfly fever virus |          |          |          |             |                   |
|                   | Nairovirus         | Crimean-Congo fever virus, Nairobi sheep disease virus |          |          |          |             |                   |
|                   | Hantavirus         | Hantaan virus, Puumala virus, Sin Nombre virus |          |          |          |             |                   |
|                   | Topsoirus          | Tomato spotted wilt virus              |          |          |          |             |                   |
| Orthomyxoviridae  | Influenza A virus  | Influenza A virus                      | Yes      | 120 nm/helix | ssRNA; linear; 7 or 8 segments; negative strand; 13,000–14,000 nucleotides |
|                   | Influenza B virus  | Influenza B virus                      |          |          |          |             |                   |
|                   | Influenza C virus  | Influenza C virus                      |          |          |          |             |                   |
|                   | Thogotovirus       | Thogoto virus, Dhori virus              |          |          |          |             |                   |
|                   | Isavirus           | Infectious salmon anaemia virus        |          |          |          |             |                   |
| Birnaviridae      | Avibirnavirus      | Gumboro virus                          | No       | 60 nm/icosahedron | dsRNA; linear; 2 segments; 5,800–6,400 base pairs |
|                   | Aquabirnavirus     | Infectious pancreatic necrosis virus   |          |          |          |             |                   |
|                   | Entomobirnavirus   | Drosophila X virus                     |          |          |          |             |                   |

(continued)
| Virus family | Subfamily/genus | Example | Envelope | Particle size/shape of the capsid or nucleocapsid | Genome: kind and size |
|--------------|-----------------|---------|----------|-----------------------------------------------|-----------------------|
| **Reoviridae** | Orthoreovirus | Reoviruses | No | 70–80 nm/icosahedron | dsRNA; linear; 10/11/12 segments; 18,000–19,000 base pairs |
| | Orbivirus | Bluetongue virus, African horse sickness virus |  |  | |
| | Rotavirus | Rotaviruses |  |  | |
| | Coltivirus | Colorado tick fever virus |  |  | |
| | Aquareovirus | Golden shiner virus |  |  | |
| **Retroviridae** | Alpharetrovirus | Rous sarcoma virus | Yes | 100 nm/icosahedron or cone | ssRNA; linear; positive strand, transcription into dsDNA; integration; 7,000–12,000 nucleotides |
| | Betaretrovirus | Mouse mammary tumour virus, Jaagsiekte sheep retrovirus (ovine pulmonary adenomatosis virus) |  |  | |
| | Gammaretrovirus | Feline leukaemia virus, murine leukaemia virus |  |  | |
| | Deltaretrovirus | Human T-lymphotropic viruses 1 and 2, bovine leukaemia virus |  |  | |
| | Epsilonretrovirus | Diverse fish retroviruses |  |  | |
| | Lentivirus | Human immunodeficiency viruses |  |  | |
| | Spumavirus | Simian foamy virus |  |  | |
| Virus Family | Virus Type | Species | Presence | Diameter | Genotype |
|--------------|------------|---------|----------|----------|----------|
| Hepadnaviridae | Orthohepadnavirus | Hepatitis B virus | Yes | 42 nm | DNA; partially double stranded; circular; 3,000–3,300 base pairs |
|              | Avihepadnavirus | Duck hepatitis B virus |          |          |          |
|              | Deltavirus (virusoid); infection along with hepatitis B virus as helper virus | Hepatitis D virus | Yes, composition to similar the envelope of hepatitis B viruses |          |          |
| Polyomaviridae | Polyomavirus | BK polyomavirus, JC polyomavirus, simian virus 40 | No | 45 nm/icosahedron | dsDNA; circular; 5,000 nucleotides |
| Papillomaviridae | Alphapapillomavirus | Human papillomaviruses 6, 10, 16, 18 and 32 (mucosa, oral/genital) | No | 55 nm/icosahedron | dsDNA; circular; 8,000 nucleotides |
|              | Betapapillomavirus | Human papillomaviruses 5, 9 and 49 (dermal) |          |          |          |
|              | Gammapapillomavirus | Human papillomaviruses 4, 48 and 50 (dermal) |          |          |          |
|              | Deltaapillomavirus | Ruminant papillomaviruses (cattle, sheep, deer) |          |          |          |
|              | Lambdapapillomavirus | Canine and feline papillomaviruses |          |          |          |
| Adenoviridae | Mastadenovirus | Human and canine adenoviruses | No | 70–80 nm/icosahedron | dsDNA; linear; 36,000–38,000 base pairs |
|              | Aviadenovirus | Avian adenoviruses |          |          |          |
|              | Siadenovirus | Turkey haemorrhagic enteritis virus |          |          |          |
|              | Atadenovirus | Chicken egg drop syndrome virus |          |          |          |

(continued)
| Virus family   | Subfamily/genus        | Example                                                                 | Envelope | Particle size/shape of the capsid or nucleocapsid | Genome: kind and size                                      |
|---------------|------------------------|-------------------------------------------------------------------------|----------|--------------------------------------------------|----------------------------------------------------------|
| Herpesviridae | Alphaherpesvirinae     | Herpes simplex viruses, varicella-zoster virus, bovine, equine, porcine, canine, feline and gallid herpesviruses | Yes      | 250–300 nm/icosahedron                           | dsDNA; linear; 150,000–250,000 base pairs                |
|               | Betaherpesvirinae      | Cytomegalovirus, human herpesvirus 6                                     |          |                                                  |                                                          |
|               | Gammaherpesvirinae     | Epstein-Barr virus, human herpesvirus 8, alcelaphine herpesvirus 1 (bovine malignant catarrhal fever virus) |          |                                                  |                                                          |
| Poxviridae    | Orthopoxvirus          | Variola viruses, vaccinia virus, bovine and simian variola viruses      | Yes      | 350–450 nm/complex                              | dsDNA; linear; 130,000–350,000 base pairs                |
|               | Parapoxvirus           | Orf virus                                                                |          |                                                  |                                                          |
|               | Avipoxvirus            | Canarypox virus                                                          |          |                                                  |                                                          |
|               | Molluscipoxvirus       | Molluscum contagiosum virus                                              |          |                                                  |                                                          |
|               | Suipoxvirus            | Swinepox virus                                                           |          |                                                  |                                                          |
|               | Yatapoxvirus           | Tanapox virus, Yaba monkey tumour virus                                   |          |                                                  |                                                          |
| Family          | Genus                     | Virus Name                                      | Size/Shape | RNA/DNA | Strandedness |
|-----------------|---------------------------|-------------------------------------------------|------------|---------|--------------|
| **Asfarviridae** | Asfivirus                 | African swine fever virus                        | Yes        | 200 nm | dsDNA; linear; 180,000 base pairs |
| **Paroviridae** | Parovirus                 | Feline panleucopenia virus, canine parvovirus, porcine parvovirus | No         | 20–25 nm/icosahedron | ssDNA; linear; 5,000 nucleotides |
|                 | Erythrovirus              | Parvovirus B19                                   |            |         |              |
|                 | Bocavirus                 | Human bocavirus, bovine bocavirus, canine minute virus |            |         |              |
|                 | Amdovirus                 | Aleutian mink disease virus                      |            |         |              |
|                 | Dependovirus              | Adeno-associated viruses                         |            |         |              |
| **Circoviridae**| Gyrovirus                 | Chicken anaemia virus                            | No         | 16–24 nm/icosahedron | ssDNA; circular; 1,700–2,000 nucleotides |
|                 | Circovirus                | Porcine circovirus, beak and feather disease virus |            |         |              |
| **Anelloviridae**| Alphatorquevirus          | Torque teno virus                                |            |         |              |
|                 | Betatorquevirus           | Torque teno mini virus                           |            |         |              |
|                 | Gammatorquevirus          | Torque teno midi virus                           |            |         |              |

*ssDNA* single-stranded DNA, *dsDNA* double-stranded DNA, *ssRNA* single-stranded RNA, *dsRNA* double-stranded RNA
Viruses exist in different conditions. They can actively replicate in cells, and produce a great number of progeny viruses. This is known as a replicationally active state. After infection, some virus types can transition into a state of latency by integrating their genetic information into the genome of the host cell, or maintain it as an episome in an extrachromosomal status within infected cells. Certain viral genes can be transcribed during that time, contributing to the maintenance of latency (herpesviruses). In other cases, the expression of the viral genome is completely repressed over long periods of time (e.g. in some animal pathogenic retroviruses). In both cases, cellular processes or external influences can reactivate the latent genomes, leading to a new generation of infectious viruses. Depending on the virus type, the infection can have different consequences for the host cell:
1. It is destroyed and dies.
2. It survives, but continuously produces small numbers of viruses and is chronically (persistently) infected.
3. It survives and the viral genome remains in a latent state without producing infectious particles.
4. It is immortalyzed, thus gaining the capability of unlimited cell division, a process that can be associated with malignant transformation into a tumour cell.

2.2 How are Viruses Structured, and what Distinguishes them from Virusoids, Viroids and Prions?

2.2.1 Viruses

Infectious virus particles – also referred to as virions – are constituted of various basic elements (Fig. 2.1): inside, they contain an RNA genome or a DNA genome. Depending on the virus type, the nucleic acid is single-stranded or double-stranded, linear, circular or segmented. Single-stranded RNA and DNA genomes can have different polarity, and in certain cases the RNA genome is similar to messenger RNA, e.g. in picornaviruses and flaviviruses. A single-stranded genome that has the same polarity as the messenger RNA is referred to as a positive or plus strand.
The genome forms a nucleocapsid complex with cellular histones (polyomaviruses) or viral proteins (e.g. rhabdoviruses, paraviruses, orthomyxoviruses, adenoviruses and herpesviruses). This nucleic acid-protein complex can be surrounded by particular protein structures, the capsids (in polyomaviruses, papillomaviruses, adenoviruses and herpesviruses). In some cases (such as picornaviruses, flaviviruses, togaviruses and paroviruses), the nucleic acid interacts directly with the capsids. In viruses containing an envelope, the capsid layer can be absent (as in coronaviruses, rhabdoviruses, paramyxoviruses, orthomyxoviruses, bunyaviruses and arenaviruses).

Capsids are rod-shaped or cubic-spherical protein structures. In some virus types, they consist of multimeric units of only one polypeptide, in other cases they are composed of heteromeric complexes. The capsid protein subunits can aggregate into discrete subunits or even into so-called capsomeres, i.e. morphologically distinct structural components. Rod-shaped capsids have a helical symmetry. The two planes of symmetry, i.e. the longitudinal and the transversal axes, differ in length (Fig. 2.2a). By contrast, spherical capsids have an icosahedral structure with...
a rotational symmetry; an icosahedron consists of 20 equilateral triangles and 12 vertices (Fig. 2.2b). The symmetry axes have the same length: the fivefold symmetry axis is located at the vertices of the icosahedron; the threefold axis passes through the centre of a triangle, the twofold axis passes along the edges. The number of subunits of an icosahedron can be calculated by the formula $10(n - 1)^2 + 2$, where $n$ indicates the number of morphologically distinguishable structures on the face of a triangle.

The three-dimensional structures of the particles of a number of viruses have been resolved by X-ray structural analyses. Prerequisite is knowledge of the basic composition of the virus, i.e. information on which proteins form the capsid or the virus, as well as the nature of the viral genetic information and the sequence of the structural proteins. In addition, purification of virus particles must be possible and these must be available as a stable highly concentrated virus suspension on the order of several milligrams per millilitre. Finally, the purified virions or, alternatively, viral capsids, which are produced in cell culture or by genetic engineering, must be able to crystallize.

In some virus types, the capsids are surrounded by a lipid bilayer envelope, which is derived from cellular membrane systems. Viral and cellular proteins are embedded in the envelope, and are frequently modified into glycoproteins by sugar groups. Usually, viral surface components are clearly exposed, and they can protrude up to 20 nm from the particle surface. If such a membrane envelope is present, it renders the virus sensitive to inactivation by solvents and detergents. A tegument layer can be situated between the membrane and the capsid (herpesviruses), and contains additional viral protein components.

The exposed proteins and protein domains on the surface of the virus – either in the envelope or in the capsid – are subject to selection pressure by the immune system. Therefore, viruses change by mutation and selection preferentially the amino acid sequences of antibody-binding regions or epitopes, which are responsible for binding neutralizing immunoglobulins. In some species of viruses, this variability of the surface regions leads to the formation new subtypes. In addition to this continuous change of the surface of exposed regions that is determined by mutation and selection, in some virus types another source of variability is possible by genetic recombination, by which even large nucleic acid regions can be exchanged between different viruses. This can lead to substantial changes in the viruses involved and to the generation of new viral species.

2.2.2 Virusoids (Satellite Viruses), Viroids, Mimiviruses and Virophages

Satellite viruses, or virusoids, are small RNA or DNA molecules that code for one or two proteins with which they are associated. Their replication and spread is dependent on the presence of another virus. Virusoids are usually found together
with plant viruses, but also hepatitis D virus, which can only proliferate when the cell is simultaneously infected with hepatitis B virus, is a virusoid (▶ Sect. 19.1.5). Viroids are plant pathogens and consist of a circular RNA (about 200–400 nucleotides) that does not code for proteins and exhibits a complex two-dimensional structure. A central sequence motif is highly conserved and essential for replication of these nucleic acid molecules. Other regions are variable and may be responsible for virulence. These infectious RNA molecules are replicated by cellular polymerases in a rolling circle mechanism (▶ Sect. 3.4), whereby secondary structures are formed at the transitions, which are known as a hammerhead because of their form. They have RNase activity, and autocatalytically cleave the concatemeric RNA strands that result after replication. Ribozymes, small RNA species with sequence-specific RNase activity (▶ Sect. 9.3), are derived from the hammerhead-like RNA structures.

Mimiviruses are a family of very large DNA viruses which were discovered by Didier Raoult in the amoeba Acanthamoeba polyphaga only in 2004. These viruses were originally regarded as bacteria because of the extraordinary size of their spherical capsids (400 nm) and protein filaments, which protrude extremely from the surface, conferring the virions with an apparent size of up to 800 nm. Therefore, they were denominated “mimiviruses” as an abbreviation for “mimicking viruses”. The DNA genome of mimiviruses comprises 1.2 million base pairs and encompasses more than 1,200 putative genes. Even larger mamaviruses have been discovered in amoebae, which can be infected by parasitic viruses. These significantly smaller viruses (sputnikvirus), also known as virophages, can multiply in amoebae only if they are concurrently infected by mamaviruses. However, sputniks do not use mamaviruses only as a helper virus, but also inhibit their proliferation and morphogenesis, thus making them virtually sick.

2.2.3 Prions

In animals and humans, prions always cause fatal neurodegenerative disorders. They can be transmitted within a species, and – albeit limited – to other organisms beyond species boundaries (▶ Chap. 21). The pathogen responsible (prion, from “proteaceous infectious particle”) does not require a coding nucleic acid in the infectious agent. Prions are composed of the pathological isoform (PrPSc), which exists especially in β-sheet conformation, and of a non-pathological cellular prion protein (PrPC), which is present predominantly in α-helical conformation. The conversion of the PrPC α-helical conformation into the β-sheet PrPSc variant is associated with completely different biochemical properties, and is the key pathogenetic basic principle of prion diseases. After its synthesis, the cellular protein PrPC arrives in the cytoplasmic membrane. PrPSc is active at the cell surface only for a limited time, and is subsequently degraded in the endosomes. During this process, a small proportion of PrPC proteins are constantly transformed into PrPSc variants. This process is referred to as prion conversion. PrPSc proteins cannot be efficiently degraded and accumulate in the cells. The function of PrPC has not been completely resolved.
Experiments with knockout mice containing a deletion of the PrP coding genome sequences revealed that PrP<sup>C</sup> appears to be dispensable for development and survival of the mice. However, without PrP<sup>C</sup> they cannot develop a prion disease.

Human prion diseases include Creutzfeldt-Jakob disease, kuru and variant Creutzfeldt-Jakob disease. In animals, the most famous representatives are scrapie (sheep), bovine spongiform encephalopathy (cattle) and chronic wasting disease (deer). The peculiarity of prion diseases is that they appear in three manifestations: acquired infectious (exogenous), sporadic (endogenous) and genetic (endogenous). Inasmuch as prions are restricted to the central nervous system, their infectious transmission is generally limited.

### 2.3 What Criteria Determine the Classification System of Virus Families?

The taxonomic classification of viruses into different families is done by an international commission of virologists and is continuously adapted to current insights. It is based on the following main criteria:

1. The nature of the genome (RNA or DNA) and the form in which it is present, i.e. as a single or a double strand, in positive or negative sense, linear or circular, segmented or continuous; also the arrangement of genes on the nucleic acid is important for the definition of individual families.
2. The symmetry form of the capsids.
3. The presence of an envelope.
4. The size of the virion.
5. The site of viral replication within the cell (cytoplasm or nucleus).

The further subdivision into genera and virus types is largely based on serological criteria and the similarity of genome sequences. The different virus families and their important human and animal pathogenic prototypes are summarized in Table 2.1.

### Further Reading

Chiu W, Burnett RM, Garcea RL (1997) Structural biology of viruses. Oxford University Press, New York

Fauquet CM, Mayo MA, Maniloff J, Desselberger U, Ball LA (2005) Virus taxonomy. VIIIth report of the international committee on taxonomy of viruses. Academic, San Diego

Fraenkel-Conrat H (1985) The viruses. Catalogue, characterization, and classification. Plenum, New York

International Committee on Taxonomy of Viruses (2012) ICTV home. http://ictvonline.org/

Knipe DN, Howley PM (eds) (2006) Fields virology, 5th edn. Lippincott-Raven, New York

Nermuth MV, Steven AC (1987) Animal virus structure. Elsevier, Amsterdam

Richman DD, Whitley RJ, Hayden FG (2002) Clinical virology, 2nd edn. ASM Press, Washington, DC