The Structure of Viruses

- Purified virus particles are composed of 50-90% protein
  - Protein has 3 functions
    - Protects NA from nuclease degradation
    - Comprises cell identification and genome release systems (only gets into appropriate target cells)
    - Provides enzymes that are essential for virus infectivity

- A coding triplet of Nucleic acid has a relative molecular mass (Mr) of ~ 1000, but it specifies a single amino acid with and average Mr of ~ 100 (I.e., NA can at best specify only 1/10th of its weight in protein
- While it may be possible for only one single protein to envelop the NA, generally there is more than one type of protein that each virus is capable of making

- Viruses are constructed from subunits of proteins
    - The same identical subunit can be repeated -or-
    - The subunits may be different
  - There is greater stability for the virus when the coat is made from subunits (reducing the size of the subunits lessens the chance of a disadvantageous mutation occurring in the gene specifying it
  - Watson & Crick predicted that there were only two ways in which asymmetrical subunits could be assembled to form virus particles
    - **Cubical symmetry** --or--
    - **Helical symmetry**

Filamentous Viruses

- The simplest way to arrange non-symmetrical components is to place them around the circumference of a circle to form discs
  - These can be stacked on top of each other to get a "stacked disc" and can ultimately generate a symmetrical structure from non-symmetrical components
    - The nucleic acid can be placed in the center (circle) portion (– as in tobacco mosaic virus)-- this ultimately makes a **HELICAL** arrangement

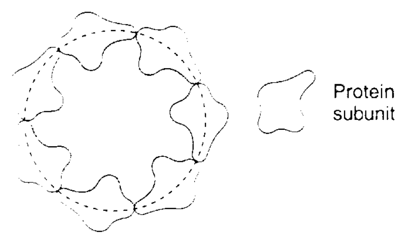

Fig. 3.2 Arrangement of identical asymmetrical components around the circumference of a circle to yield a symmetrical arrangement.

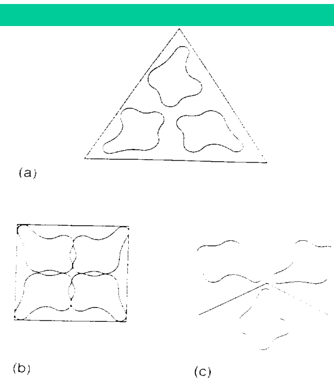

Fig. 3.3 Symmetrical arrangement of identical asymmetrical subunits by placing them on the faces of objects with cubic symmetry. (a) Asymmetrical subunits located at vertices of each triangular facet. (b) Asymmetrical subunits placed at vertices of each square facet. (c) Arrangement of asymmetrical subunits placed at each corner of a cube with faces as represented in (b).

Isometric Viruses

- Arrangement of the smallest number of subunits possible around the vertices (or faces) of an object with cubic symmetry (e.g., tetrahedron, cube, octahedron [cube],… or **icosahedron** (constructed from 20 equilateral triangles)
  – Multiplying the minimum number of subunits per face by the number of faces gives the smallest number of subunits that can be arranged around such an object

- **The minimum number of subunits is determined by the symmetry of the face (a square face will have four subunits, a triangular face will have three subunits (one at each vertice)**
  - **A tetrahedron – the smallest number of subunits will is 12 (4 faces X 3 subunits in a triangular face)**
  - **An icosahedron will have 60 minimum subunits (20 X 3)**

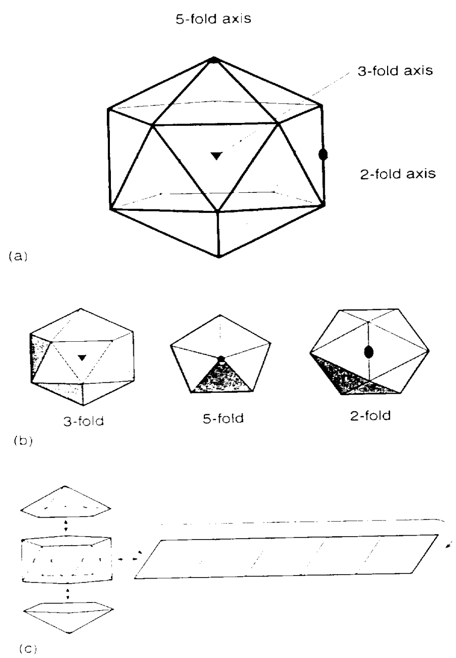

Fig. 3.4 (a) Properties of a regular icosahedron. Each triangular face is equilateral and has the same orientation whichever way it is inserted. Axes of symmetry intersect in the middle of the icosahedron. There are 12 vertices, which have fivefold symmetry, meaning that rotation of the icosahedron by one-fifth of a revolution achieves a position such that it is indistinguishable from its starting orientation; each of the 20 faces has a threefold axis of symmetry and each of the 30 edges has a twofold axis of symmetry—see (b). (c) The icosahedron is built up of five triangles at the top, five at the bottom and a strip of ten around the middle. (Copyright 1991, from *Introduction to Protein Structure* by C. Branden & J. Tooze. Reproduced by permission of Routledge, Inc., part of The Taylor & Francis Group.)

Symmetry of an Icosahedron

- Made up of 20 triangular faces–
  - 5 at top, five at bottom and 10 around the middle
- Has 12 vertices

Axes of symmetry

- Each triangular face is equilateral and has same orientation whatever way it is inserted
- Axes of symmetry intersect in the middle of the icosahedron
  - There are 12 vertices which have **5 fold symmetry**
  - Each of the 12 faces has **3 fold symmetry**
  - Each edge exhibits **2 fold symmetry**

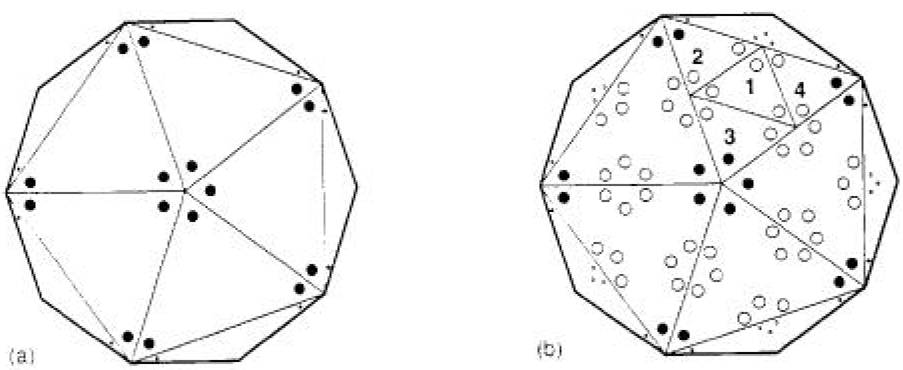

Fig. 3.7 Arrangement of 60n identical subunits on the surface of an icosahedron. (a) n = 1 and the 60 subunits are distributed such that there is one subunit at the vertices of each triangular face. Note that each subunit has the same arrangement of neighbours and so all the subunits are equivalently related. (b) n = 4. Each triangular face is divided into four smaller, but identical, equilateral triangular facets and a subunit is again located at each vertex. In total, there are 240 subunits. Note that, in contrast to the arrangements shown in Fig. 3.5, each subunit, whether represented by an open or closed circle, has the identical arrangement of neighbours—see the face in which triangles 1–4 have been drawn. However, as some subunits are arranged in pentamers and others in hexamers, the members of each set are only 'quasi-equivalently' related.

- The size of the capsid will determine the size of the NA that can be encapsulated within that capsid.
  - **For an icosahedron structure where there are 60 subunits you can arrange the subunits by having multiples of the 60 subunit structure (e.g., 60*n*)**
    - **Arrange the subunits around each vertice**
      - **There are 12 vertices and each will have 5 subunits around it**
      - **Subdivide each face into 4 smaller and identical equilateral triangles (have 240 subunits)**
    - **At the vertices of each of the original icosahedron faces, there will be rings of 5 subunits= pentamers**
    - **At all the other vertices generated by the triangular facets of the smaller triangles, there will be rings of 6 subunits= hexamers**

Laws of Solid Geometry

- $T= Pf^2$
  - T= triangulation number 9the number of smaller, identical equilateral triangles)
  - f= 1, 2, 3, 4, ….
  - $P= h^2 + hk + k^2$ (where h and k are any pair of integers without common factors (e.g., h and k cannot be multiplied or divided by any number to give the same values) ☺ ☺ ???
- For viruses examined so far the values of P are 1 (h=1, k=0) 3 (h=1, k=1) and 7 (h=1, k=2)

- T= 1 (the smallest virus) (***Tobacco necrosis virus satellite virus***)
  - No independently replicating virus is known to consist of only 60 protein subunits (satellite viruses do!)
    - These viruses encode one coat protein but depend on co-infection with other viruses (helper viruses) to provide missing replicative functions
    - TNVS-
      - ssRNA (1239 nucleotides)
      - 18nm diameter (versus at least 30 nm for replicative viruses)

- T=3 Tomato Bushy Stunt Virus (TBSV)
  - Plant virus
  - 180 subunits (60T where T=3☺☺)
  - Encode a single virion polypeptide

- T=3 Picornavirus (has icosahedra structure made of 4 different polypeptides)
  - Made of 60 copies of each of the four polypeptides VP1, VP2, VP3 and VP4