THE GEOMETRY

Modeling microorganisms

by Christine L. Case

Students and parents know that an "infectious disease" means that a microorganism—bacterium, protozoan, or virus—is growing in the host. Few know, however, much more about these microorganisms themselves; for example, the fact that viruses are incapable of reproducing themselves might surprise quite a few people. In light of the fact that viral diseases are so prevalent and the seriousness of the AIDS epidemic today, it is important that we, as science teachers, make students aware of just what a virus is.

To provide a hands-on laboratory experience on viruses is, unfortunately, difficult. While some viruses can be cultured in a laboratory, the techniques required to grow their host cells are often not practical in middle and high schools. However, students can make models of viruses, which allows them to visualize these unusual microorganisms. Moreover, the virus models provide a lesson in geometry.

SOME BACKGROUND

Many viral diseases are common among school-age children. These include measles, mumps, rubella, and chicken pox. Viral diseases that are common in the general population include the common cold, influenza, and herpes. Other viral diseases that are important public health concerns are polio, hepatitis, and Dengue. Some have devastating effects, such as rabies and HIV (AIDS). And, some viruses cause cancer.

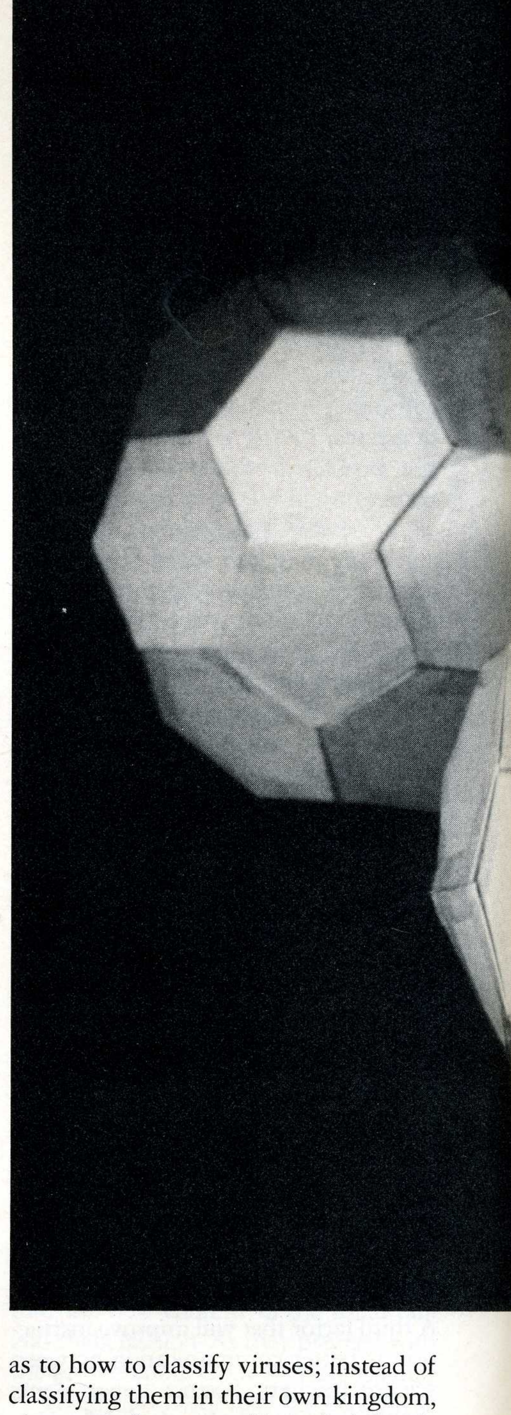
It can be said that viruses have been studied longer than bacteria; the first vaccine, developed in 1798 by Edward Jenner, was to prevent smallpox. A tumor-causing virus was demonstrated by Rous in 1911 when he transmitted tumors from infected chickens to healthy chickens with the cell-free, liquid filtrate from tumors. Early researchers said this liquid contained *contagium vivum fluidum*. They could not detect viruses by ordinary culture methods that were being developed for bacteria and they could not see viruses with light microscopy. Not until the 1930s were scientists able to see viruses with electron microscopes and culture them in animal cells.

BIOLOGY

Viruses are not composed of cells. Outside of a host they would not be defined as living; however, inside a host they are able to bring about their own reproduction. (See Figure 1 for a comparison of cells and viruses. The criteria listed represent the structure and functions that are considered essential to life.) Outside of its host cell, the virus remains inert, and the organic molecules of which it is composed will break down over time.

By nature of the fact that viruses require a living cell to reproduce, they are obligate parasites. Once the virus gains access to a host, it attaches to a cell membrane and enters a cell. Once inside, the virus' genes "take over" the cell, directing the host cell's metabolic machinery to produce viruses instead of normal cellular components. In a matter of minutes, as many as 2000 new viruses may be produced. The "new" viruses then leave the cell by budding ("popping") out of the cell membrane to infect neighboring cells.

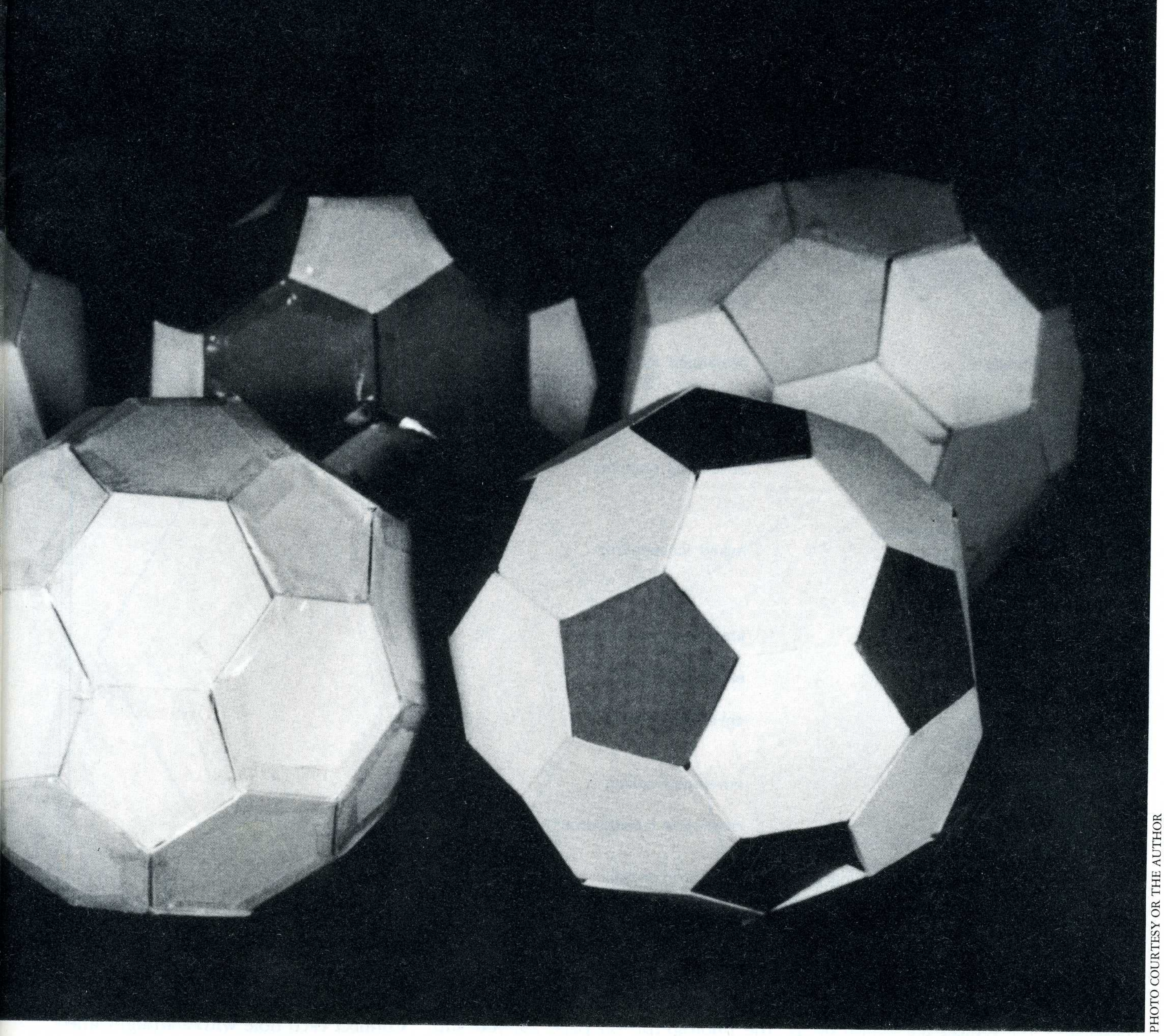
It is not surprising that viruses are identified or named according to their host—animal viruses, plant viruses, and bacterial viruses, for example—they seem to be more closely related to their hosts than to each other. Support for this assertion lies in the fact that while a virus is directing its host-cell, some viral genes can become incorporated into the host's chromosome. There has been quite a bit of debate over the years as to how to classify viruses; instead of classifying them in their own kingdom, viruses can be grouped into their host's kingdom. Some viruses that infect humans are listed in Figure 2.



GEOMETRY

The simplest viruses consist of a single molecule of DNA or RNA surrounded

OF VIRUSES



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by a protein coat called the **capsid.** Capsids are either icosahedrons or helices; we will look at the icosahedral type. The capsid is made of subunits called **capsomeres** which are made of peptides (protein). Capsomeres are either six-sided *hexamers* or five-sided *pentamers.* Viral genes cause the host to make capsomeres, which then spontaneously come together around the newly synthesized viral genes.

An icosahedron has 20 faces, each face being an equilateral triangle. In a virus, these faces are hexamers (see Figure 3). Twelve vertices form the pentamers. The icosahedron has three axes of symmetry, as shown in Figure 4. A rod placed through the center of

an edge divides the capsid into two identical parts. The capsid can be rotated into three identical positions if a rod is put through the midpoint of any face. And, the capsid rotated around a rod through a vertex will produce five identical positions.

FIGURE 1. A comparison of cells and viruses.

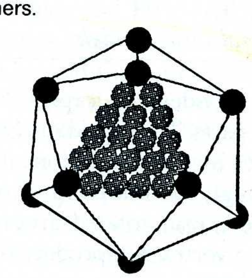
CELL	VIRUS
cell membrane phospholipid (fat) requires enzymes to produce	capsid protein spontaneous, self-assembly
produces energy from food	no energy-synthesizing mechanism
possesses DNA and RNA	possesses DNA or RNA. Total genetic complement is nearly 100 000 times smaller than that of cell.

FIGURE 2. Some common human viruses.

VIRUS GROUP (specific virus)	SHAPE	NUMBER OF CASPOMERES
VIRUSES CONTAINING DNA		
parvovirus (fifth disease)	**icosahedron**	12 pentamers
papovavirus (warts)	**icosahedron**	72
herpes viruses (cold sores, chicken pox, Epstein-Barr)	**enveloped icosahedron**	16
poxviruses (smallpox, vaccinia)	**enveloped complex***	
VIRUSES CONTAINING RNA		
picornaviruses (poliovirus, common cold, hepatitis A)	**naked icosahedron**	32
rubella	**enveloped icosahedron**	32
influenza	**enveloped helical**	
paramyxoviruses (measles, mumps)	**enveloped helical**	
rabies virus	**enveloped helical**	
retroviruses (AIDS)	**enveloped icosahedron****	

*Poxviruses are brick-shaped rather than an icosahedron or helix.
**In Human Immunodeficiency viruses (AIDS), the RNA is inside a protein core surrounded by the capsid, and the capsid itself is inside an envelope derived from the host cell membrane.

FIGURE 3. Each face is composed of hexamers. (One face is shown with hexamers.) The vertices are formed by pentamers.



BUILDING

To make the 32-sided virus shown in the photograph on page 29, you will need 12 pentamers and 20 hexamers. Pentamers and hexamers should be different colors to help students visualize faces and vertices. White index cards can be colored with felt-tipped pens, or, of course, you can use colored cards.

- Place a template for hexamers (six-sided, equilateral figures) over a few index cards or pieces of construction paper and mark the vertices by poking a hole through the template with a pin. Connect each hole with a straight line to complete the hexamer and cut out each hexamer.
- Repeat step 1 using a template for pentamers (five-sided, equilateral figures).
- Fold a 5-mm margin around the edge of each piece. The pieces will be glued together along the margins.
- Attach a hexamer to each edge of one pentamer. Add five pentamers at

FIGURE 4. Axes of symmetry of an icosahedral virus.
A. A line through an edge divides the capsid into two like parts.
B. The midpoint in a face divides the capsid into three identical parts.
C. The capsid can be divided into five parts at the vertex.

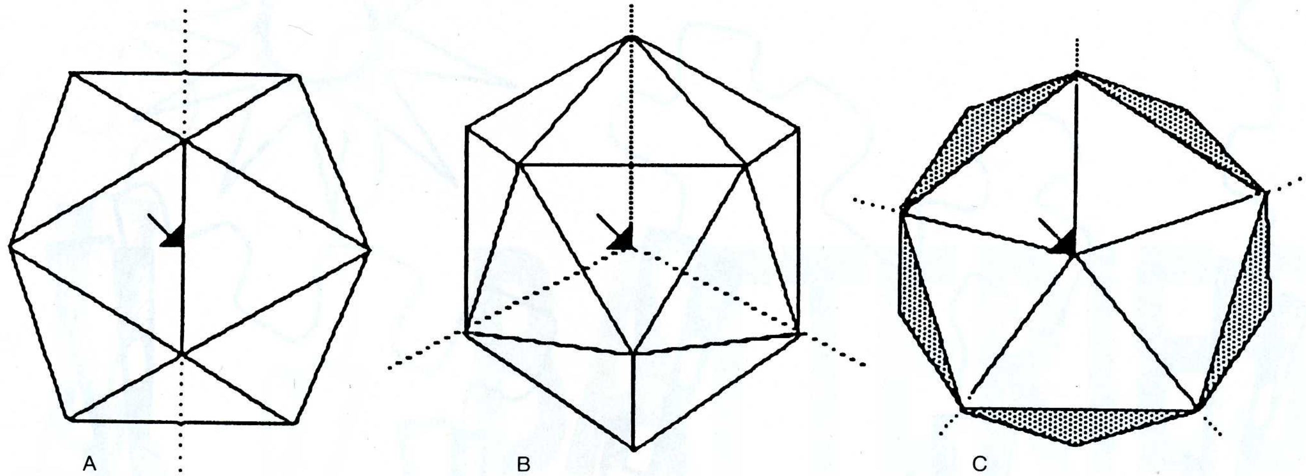
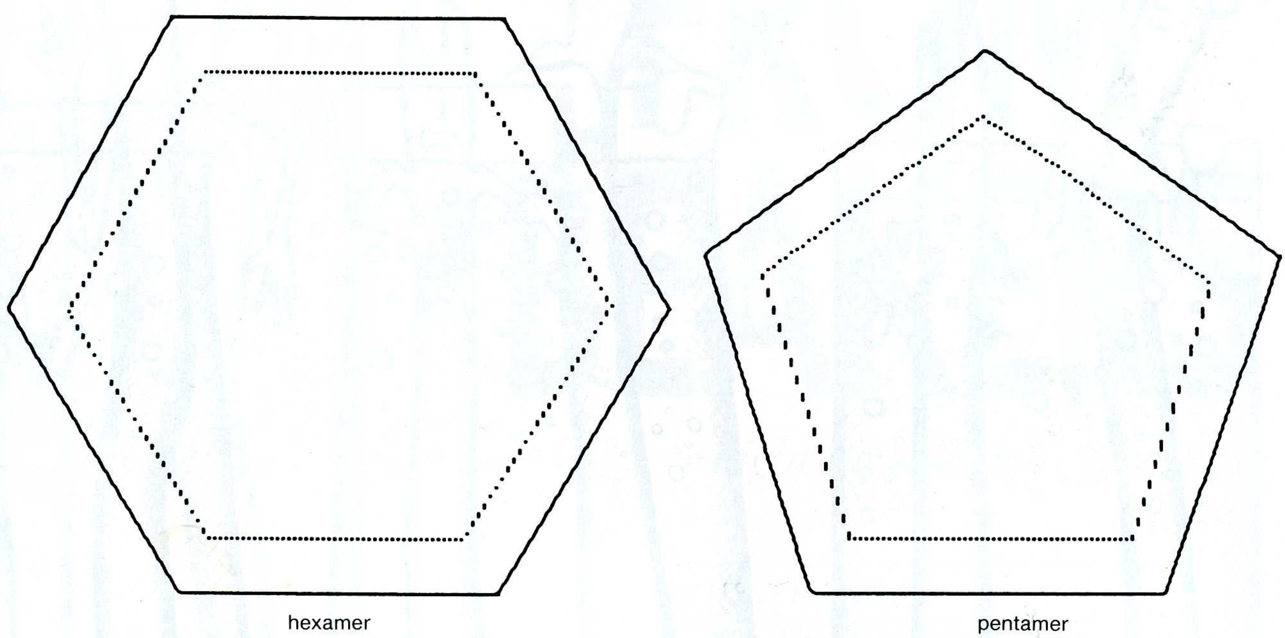


FIGURE 5. Templates. Cut along the solid line and fold on the dotted line.



regular intervals, followed by hexamers, five more pentamers, hexamers, and the last pentamer.

QUESTIONS FOR STUDENTS

- What color are the pentamers?
- What color are the vertices?
- How many capsomers does the model have?
- Measure the diameter of your virus model in centimeters. How many millillimeters is this?
- If a real virus has a diameter of 100 nm (1nm = 10^{-9} m or 1/1 000 000 000 m) how many real viruses will fit into your model?

NOTE: Number of viruses =

$$\frac{\text{mm model}}{\text{nm virus}} \times \frac{1\text{ m}}{1000\text{ mm}} \times \frac{1\text{ nm}}{10^{-9}\text{m}}$$

- Show the 2:3:5 symmetry.

The models shown in the photograph on page 29 were made by students. Generally students enjoy their product and do keep it. Older students have made virus models at home out of ceramic tiles or fabric stuffed with pillow-foam.

REFERENCES
Bardell, D. 1986, The biological nature of AIDS virus. *American Biology Teacher* 48(2):75-77.

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