form nearly equivalent bonds to neighbours.

In their electron density map, Rayment *et al.* find unexpectedly that the hexavalent capsomere is a pentamer, as is the pentavalent capsomere. Thus there appear to be only $(12 \times 5) + (60 \times 5) = 360$ subunits of the major coat protein VP1 in the capsid, rather than the expected 420. The authors buttress their observation by citing studies of the molecular weights of the capsid and VP1 protein which suggest that there are indeed fewer than 420 copies.

Another consequence of the hexavalent unit being a pentamer is that the bonding among coat protein subunits is distinctly non-equivalent. This is illustrated clearly in Fig. 7 on page 114, where the non-equivalence can be seen by comparing panel *c* with panel *d*, and by comparing in panel *d* the various relationships of the five protein subunits of the central capsomere to the six surrounding capsomeres. Figure 7*f* illustrates that the observed structure can be accounted for by three types of contact between neighbouring pentamers, a much more complicated pattern than the expected single type of contact.

Such an unexpected result, even from the laboratory of a co-author of the Caspar–Klug theory which the result seems to challenge, will no doubt face some scepticism. The refinement method used to obtain the phases for the 22.5 Å resolution electron density map is not the thoroughly tested and trusted multiple isomorphous replacement. In place of heavy atoms to constrain phases, the refinement is constrained only by the icosahedral symmetry and overall dimensions of the capsid. Rayment *et al.* present control calculations that suggest the phase refinement procedure leads to a correct and unique result, and they conclude that "the similarity of the hexavalent and pentavalent capsomeres seen in the electron density map is an intrinsic feature of the virus capsid structure rather than some unaccounted artefact of the refinement procedure". The authors go on to suggest that simian virus 40 and other members of the papova family may all have capsids built of pentameric capsomeres. Some workers in the field of biological structure, while finding all of this intriguing, may reserve final judgement until the study of polyoma structure has reached higher resolution, presumably with the aid of isomorphous replacement.

If the capsomeres of polyoma and related viruses are in fact built all of pentomers, the ideas of Caspar and Klug are in need of some revision. They sought to explain why icosahedral shells had been selected for the design of closed containers built from many identical subunits. They came up with the elegant idea of quasiequivalence: in an icosahedral shell built from $60T$ identical units, each unit can have nearly the same environment and hence form nearly equivalent bonds to neighbours. If subunits do not all have similar environments, then the reason for the icosahedral shells is unexplained.

The result of Rayment *et al.* seems to transfer the problem of virus structure and assembly from the realm of completely symmetric structures, such as the quaternary structures of oligomeric enzymes, for which the principles are obvious, one step towards the realm of asymmetric structures, such as the ribosome and the tertiary structures of enzymes, where the principles still elude us.

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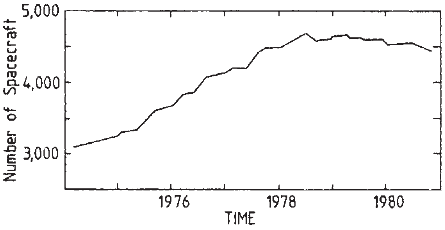
1. Caspar, D.L.D. & Klug, A. *Cold Spring Harb. Symp. quant. Biol.* **27**, 1 (1962).
2. Harrison, S.C., Olson, A.J., Schutt, C.E., Winkler, F.K. & Bricogne, G. *Nature* **276**, 368 (1978).
3. Abad-Zapatero, C. *et al. Nature* **286**, 33 (1980).

Spacecraft collisions

from David W. Hughes

THE region of near Earth space, extending to about 5,000 km above the Earth's surface, contains many orbiting satellites and bits of satellites. Collisions between them are inevitable and an estimate of just how frequently this will occur has now been made by L. Schnal and L. Pospíšilová of the Astronomical Institute of the Czechoslovak Academy of Sciences. Their findings are published in a recent edition of the *Bulletin of the Astronomical Institutes of Czechoslovakia* (**32**, 310; 1981).

First, it was necessary to calculate the number of spacecraft per unit volume of space. Satellites are continually tracked by radar systems in the US and the results published in *NASA Satellite Situation Reports.* The figure below shows how the number of trackable orbiting bodies in near Earth space has varied in recent years.



Between 1975 and 1978 the number was increasing at a rate of about 400 per year but more recently it has remained constant at just over 4,500. Radar sensitivity is sufficient to detect a large majority of objects bigger than 10 cm. Sensitivity is less at high altitudes and for objects below heights of 500 km. The number of small untrackable objects probably exceeds the number of trackable objects by a factor of 2.

Orbital perturbations cause the argument of perihelion and the longitude of the orbit's ascending node to change fairly rapidly and this results in a uniform distribution of spatial density as a function of geocentric longitude. Analysis of the orbital data leads to a value for the spatial density as a function of distance from the Earth and geocentric latitude. The density is highest in the equatorial regions since every satellite must cross the equatorial plane twice per orbit. To calculate the number of impacts per unit time one needs to know the relative impact velocity. Schnal and Pospíšilová came to the conclusion that 7km s^{-1} was a reasonable overall value in near Earth space, agreeing with the previous estimate made by D.J. Kessler and B.G. Cour-Palais (*J. geophys. Res.* **86**, 2637; 1978). The computed mean is an averaged value resulting from two sets of collision velocities. Satellite orbital inclinations are unevenly distributed, the majority being due to satellites moving from west to east. One velocity set peaks at about 13 km s^{-1} and is due to head–on collisions between satellites orbiting in opposite directions. The other set is peaked around the 1 –3 km s^{-1} region and is due to satellites catching each other up.

The authors assume that the mean cross-section of a trackable body is 1.5 m^2 and that the untrackable objects have a mean cross-section of 0.001 m^2. The collision frequency, ΔC, is then given by

$$\Delta C = \tfrac{1}{2} \Sigma A \, V D^2 \, \Delta S$$

where A is the assumed average cross-sectional area, V is the relative velocity, D the spatial density and ΔS an element of volume. Integrating over all the regions out to a distance of 4,000 km from the Earth's surface results in an average collision frequency per year of 0.017. This is equivalent to around one spacecraft collision per 60 years, the estimated uncertainties being about 50 per cent.

This collision probability has remained reasonably constant over the last few years because the annual number of new launches has remained at about 120 per year. Also, the recent solar maximum caused the atmosphere to expand and this has 'cleaned up' the lower regions by enhancing atmospheric drag and causing the small debris to spiral in quickly. 'Killer' satellite tests and the accidental explosions of rocket motors have also decreased, thus lowering the number of small objects in near Earth space.

A space crash would cause a rapid increase in the number of small orbiting bodies, some of which may be capable of fragmenting another satellite and thus creating even more fragments. But still, with a rate of only one collision per 60 years or so, Schnal and Pospíšilová conclude that inner space is relatively safe. ☐

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