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This Week's Citation Classic®

Bradley D E. Ultrastructure of bacteriophages and bacteriocins.
Bacteriol. Rev. 31:230-314, 1967.
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This first extensive electron microscopic study of bacterial viruses (bacteriophages) revealed their distinctive geometrical architecture. They were divided into several clearly defined morphological groups subsequently used in taxonomic classification. Species-specific bactericidal proteins called bacteriocins were also surveyed. One class contained structural components of bacteriophages, and the other, small protein molecules. [The *SCI*® indicates that this paper has been cited in over 670 publications.]

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During the 1950s and 1960s, advances in electron microscopy permitted the resolution of the structural protein subunits of viruses.[1] As an electron microscopist at the University of Edinburgh, I had published a number of papers on bacteriophage structure when *Bacteriological Reviews*, now *Microbiological Reviews*, invited me to write a paper on the entire viral kingdom. This was too daunting a prospect, and I persuaded the editors to consider an article on my specialty.

Bacteriophages (phages) come in various shapes and sizes, many resembling tadpoles, complete with heads and tails, others being in the form of filaments or small spheres. In the course of writing the review and taking many of the electron micrographs, it became clear that phages fell naturally into five morphological groups. These groups have been used by numerous workers in their descriptions of new bacteriophages, and this is probably the main reason the paper has been cited frequently. A formal classification of viruses including bacteriophages was initiated near the time of writing by the then newly formed International Committee for the Nomenclature of Viruses. Morphology was a principal criterion. Electron micrographs illustrating the infective processes of several phages were an important part of the review, giving new insights into each step. Phage particles attach to the bacterial surface and then inject their nucleic acid. Many phage progeny are assembled within the cell, and the organism finally bursts, releasing them.

The review also dealt with phage-related entities called bacteriocins. They are synthesized by a bacterial strain and kill other strains, but only within the same species. Comparatively few papers about bacteriocins had appeared at the time of writing, the most recent review being two years previously.[2] Bacteriocin structure was an almost new field. In one entertaining study carried out especially for the paper, bacteriocinogenic strains of several species were induced with mitomycin C. The products released were studied by electron microscopy, revealing a curious collection of structures. Most resembled phage components. One can hardly imagine such a study being published today!

The most notable feature of the article was the number of micrographs required to cover the subject matter: 187, grouped in 50 figures. Many were generously contributed by other workers, but all printing and mounting was done in our laboratory, where most of the bench space was occupied for many weeks.

Morphological studies of phages naturally led to research on their receptors, in particular filamentous ones called pili. *Pseudomonas aeruginosa* has pili that can move cells around on a solid surface; RNA-containing phages that use them as receptors helped in elucidating the mechanism.[3] Other pili acting as receptors are involved in conjugation,[4] a process in which drug-resistance plasmids are transferred from one cell to another. My participation in the study of recently isolated pilus-specific phages (three examples[5,6]) connected the work described in the review with my current research on the role of pili in conjugation; these phages are valuable tools in many experiments.

1. **Horne R W & Wildy P.** Symmetry in virus architecture. *Virology* 15:348-73, 1961. (Cited 205 times.)
2. **Reeves P.** The bacteriocins. *Bacteriol. Rev.* 29:24-45, 1965. (Cited 165 times.)
3. **Bradley D E.** A function of *Pseudomonas aeruginosa* polar pili: twitching motility. *Can. J. Microbiol.* 26:146-54, 1980. (Cited 20 times.)
4. ————. Morphological and serological relationships of conjugative pili. *Plasmid* 4:155-69, 1980. (Cited 55 times.)
5. **Bradley D E, Sirgel F A, Coetzee J N, Hedges R W & Coetzee W F.** Phages C-2 and J: IncC and IncJ plasmid-dependent phages respectively. *J. Gen. Microbiol.* 128:2485-98, 1982. (Cited 10 times.)
6. **Coetzee J N, Bradley D E, Hedges R W, Tweehuizen M & Du Toit L.** Phage tf-1: a filamentous bacteriophage specific for bacteria harbouring the IncT plasmid pIN25. *J. Gen. Microbiol.* 133:953-60, 1987.

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