Physics of Viruses

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Abstract: Bacteriophages – viruses that infect bacteria – are the most abundant biological entities on Earth and operate as autonomous nano-machines that rely on fundamental physical principles to infect hosts. These spring-loaded systems store and release potential energy, beginning in the icosahedral capsid where the DNA genome is packaged to near-liquid crystalline density. This packaging is driven by a motor protein that pushes DNA through a portal complex against intense internal pressure. The portal and other corking machinery act as a mechanical valve, retaining the pressurized DNA and controlling its eventual release into the tail tube. Designed for low-friction transport, the tail tube's interior is negatively charged to prevent DNA from sticking via electrostatic repulsion. At the end of this conduit, the tail tip complex acts as a homing unit and mechanical trigger; upon binding to a bacterium, it "unlocks" the phage, allowing the massive internal pressure to rapidly shoot the DNA into the host. By utilizing these precise physical mechanisms, the phage achieves efficient genetic delivery and replication. Constructing high-resolution structural maps of these components allows us to define the atomic interactions driving this machinery. These atomic blueprints are also essential for engineering better phages for targeted antibacterial therapeutics.