

Molecular Machinery: A Tour of the Protein Data Bank

Cells build many complex molecular machines that perform the biological jobs needed for life. Some of these machines are molecular scissors that cut food into digestible pieces. Others then use these pieces to build new molecules when cells grow or tissues need to be repaired. Some molecular machines form sturdy beams that support cells, and others are motors that use energy to crawl along these beams. Some recognize attackers and mobilize defenses against infection.

Researchers around the world are studying these molecules at the atomic level. These 3D structures are freely available at the Protein Data Bank (PDB), the central storehouse of biomolecular structures. A few examples from the ~100,000 structures held in the PDB are shown here at a magnification of about 3,500,000 times, with each atom represented as a small sphere. The enormous range of molecular sizes is illustrated here, from the water molecule (H₂O) with only three atoms (shown at the left) to the ribosomal subunits with hundreds of thousands of atoms.

Digestive Enzymes: breaking food into small nutrient molecules

1. Amylase 1smd
2. Phospholipase 1poe
3. Deoxyribonuclease 2dnj
4. Lysozyme 1lzl
5. Pepsin 5pep
6. Trypsin 2ptc
7. Carboxypeptidase 3cpa
8. Ribonuclease 5rsa

Blood Plasma Proteins: transporting nutrients and defending against injury

9. Factor X 1xka, 1iod
10. Thrombin 1ppb
11. Fibrin 1m1j, 2baf
12. Serum Albumin 1e7i

Viruses and Antibodies: engaging in constant battle in the bloodstream

13. Antibody 1igt
14. Rhinovirus 4rhv

Hormones: carrying molecular messages through blood

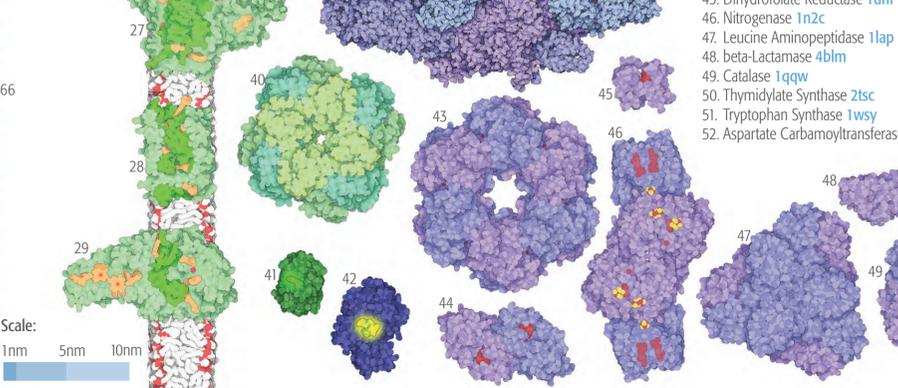
15. Glucagon 1gcn
16. Insulin 2hiu
17. Epidermal Growth Factor 1egf

Channels, Pumps and Receptors: getting back and forth across the membrane

18. Ras Protein 5p21
19. Beta2-Adrenergic Receptor/Gs Protein 3sn6
20. Acetylcholine Receptor 2bg9
21. Epidermal Growth Factor Receptor 1ivo, 2jwa, 2gs6
22. Rhodopsin 1f88
23. P-glycoprotein 3g61
24. Potassium Channel 3lut
25. Calcium Pump 1su4
26. Cyclooxygenase 1prh

Photosynthesis: harvesting energy from the sun

27. Photosystem II 1ssi
28. Light-harvesting Complex 1rvt
29. Photosynthetic Reaction Center 1prc



Scale:
1nm 5nm 10nm
1nm (nanometer) = 10⁻⁶ millimeters

Extracellular Proteins Membrane Proteins

Intracellular Proteins: Cytosol

Energy Production: powering the processes of the cell

30. Cytochrome c Oxidase (Complex IV) 1oco
31. Cytochrome c 3cyt
32. Cytochrome bc1 (Complex III) 1bgy
33. Succinate Dehydrogenase (Complex II) 1nek
34. NADH-Quinone Oxidoreductase (Complex I) 3m9s, 3rko
35. ATP Synthase 1e79, 1c17, 1l2p, 2a7u
36. Myoglobin 1mbd
37. Hemoglobin 4hbb

Storage: containing nutrients for future consumption

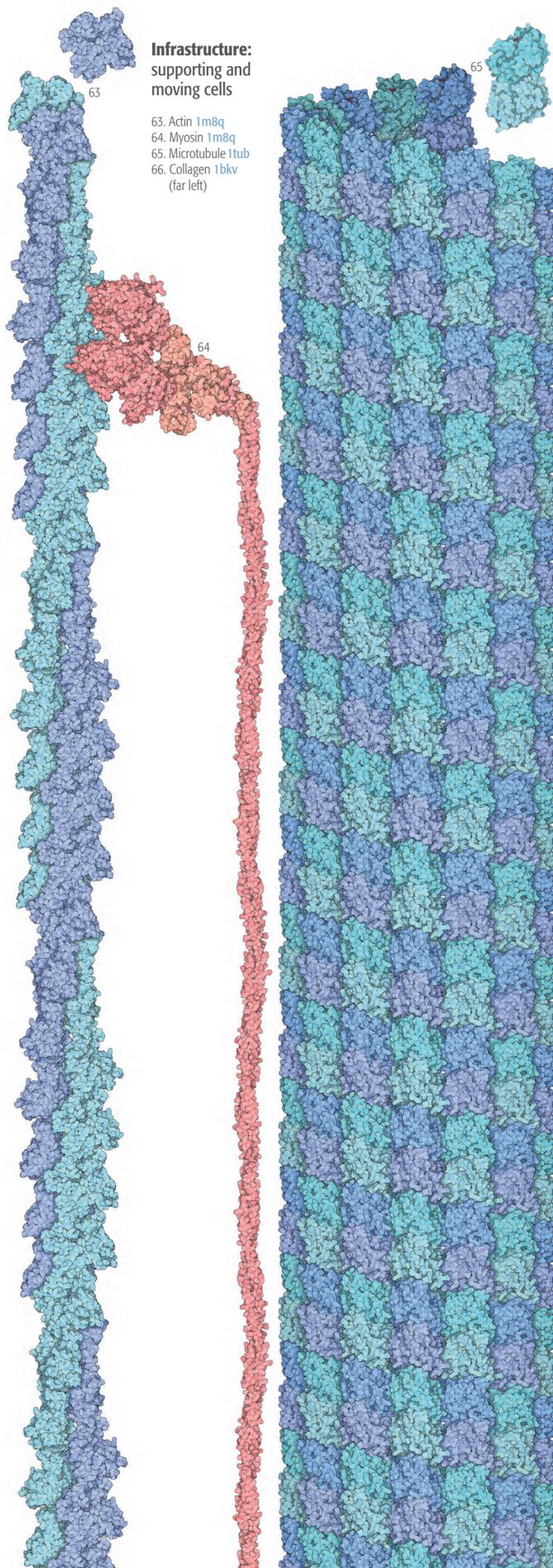
38. Ferritin 1hrs

Enzymes: cutting and joining the molecules of life

39. Fatty Acid Synthase 2uvb, 2uvc
40. RuBisCo: Ribulose Biphosphate Carboxylase/Oxygenase 1rcx
41. Green Fluorescent Protein 1gfl
42. Luciferase 2dlis
43. Glutamine Synthetase 2gls
44. Alcohol Dehydrogenase 2ohx
45. Dihydrofolate Reductase 1dhf
46. Nitrogenase 1nzc
47. Leucine Aminopeptidase 1lap
48. beta-Lactamase 4blm
49. Catalase 1qqw
50. Thymidylate Synthase 2tsc
51. Tryptophan Synthase 1wsy
52. Aspartate Carbamoyltransferase 4atl
53. Hexokinase 1dtk
54. Phosphoglucose Isomerase 1hox
55. Phosphofructokinase 4pik
56. Aldolase 4ald
57. Triosephosphate Isomerase 2ypi
58. Glyceraldehyde-3-phosphate Dehydrogenase 3gpd
59. Phosphoglycerate Kinase 3pgk
60. Phosphoglycerate Mutase 3pgm
61. Enolase 5enl
62. Pyruvate Kinase 1a3w

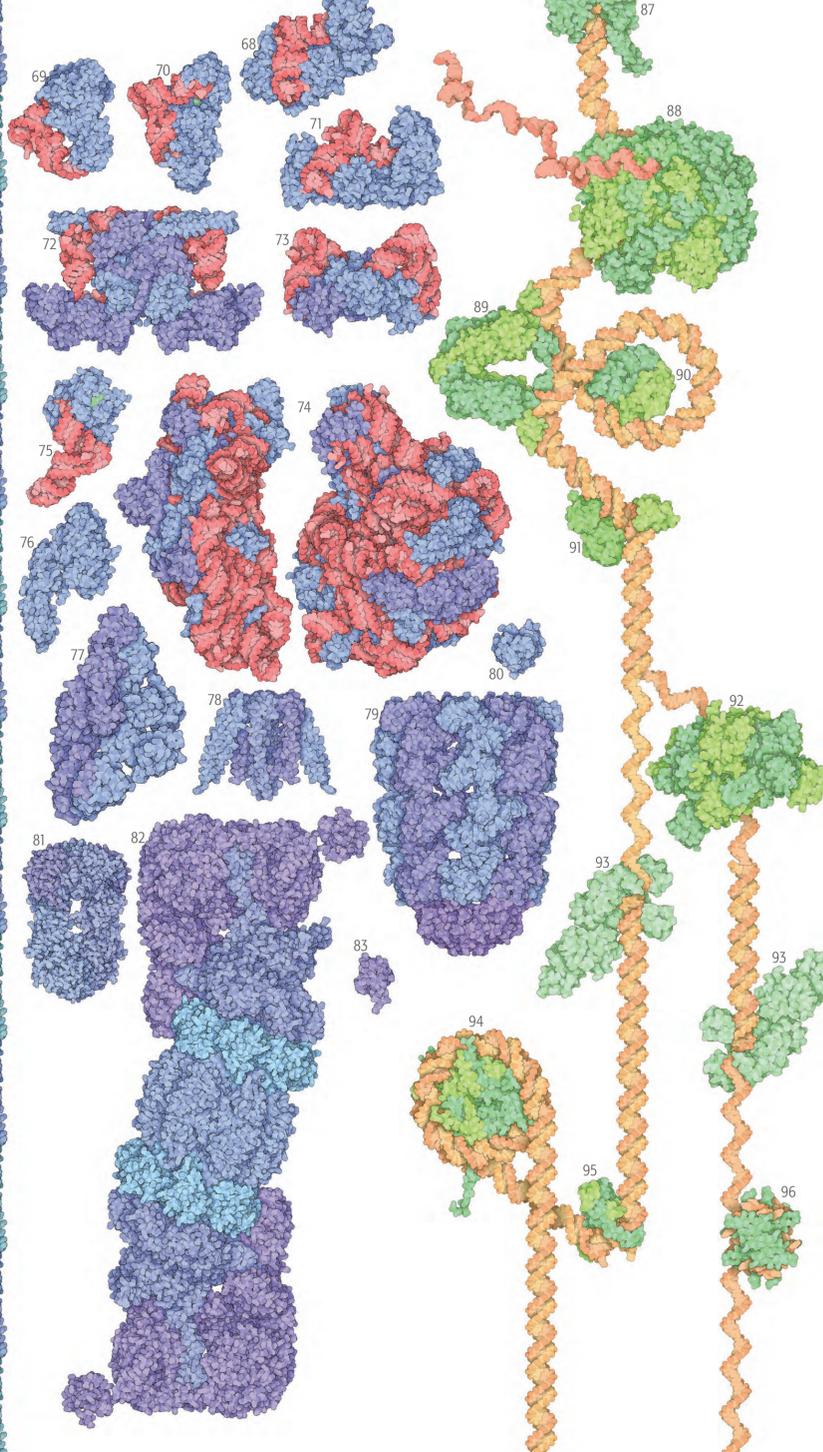
Infrastructure: supporting and moving cells

63. Actin 1m8q
64. Myosin 1m8q
65. Microtubule 1tub
66. Collagen 1bkv (far left)



Protein Synthesis: building new molecular machines

67. Transfer RNA 4tna
68. Valyl-tRNA Synthetase 1gax
69. Threonyl-tRNA Synthetase 1qf6
70. Glutamyl-tRNA Synthetase 1euq
71. Isoleucyl-tRNA Synthetase 1ffy
72. Phenylalanyl-tRNA Synthetase 1eiy
73. Aspartyl-tRNA Synthetase 1asy
74. Ribosome 1j5e, 1jj2
75. Elongation Factor Tu/tRNA 1ttt
76. Elongation Factor G 1dar
77. Elongation Factor Ts and Tu 1efu
78. Prefoldin 1fxk
79. Chaperonin GroEL/ES 1aon
80. Proline cis/trans Isomerase 2cpl
81. Heat Shock Protein Hsp90 2cg9
82. Proteasome 4bat
83. Ubiquitin 1ubq



DNA: storing and reading genetic information

84. DNA 1bna
85. Restriction Endonuclease EcoRI 1eri
86. DNA Photolyase 1tez
87. Topoisomerase 1a36
88. RNA Polymerase 2e2i
89. lac Repressor 1lbh 1efa
90. Catabolite Gene Activator Protein 1cgp
91. TATA-binding Protein/Transcription Factor IIB 1ais
92. DNA Helicase 4esv
93. DNA Polymerase 1tau
94. Nucleosome 1aoi
95. HU Protein 1p5i
96. Single-stranded DNA-binding Protein 3a5u

Intracellular Proteins: Cytosol

Intracellular Proteins: Nucleus