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Allometric Scaling in Biology

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The unity of life is expressed not only in the universal basis of inheritance and energetics at the molecular level, but also in the pervasive scaling of traits with body size at the whole-organism level. More than 75 years ago, Kleiber and Brody and Proctor independently showed that the metabolic rates, B, of mammals and birds scale as the three-quarter power of their mass, M. Subsequent studies showed that most biological rates and times scale as $M^{-1/4}$ and $M^{1/4}$ respectively, and that these so called quarter-power scaling relations hold for a variety of organisms, from unicellular prokaryotes and eukaryotes to trees and mammals. The wide applicability of Kleiber's law, across the 22 orders of magnitude of body mass from minute bacteria to giant whales and sequoias, raises the hope that there is some simple general explanation that underlies the incredible diversity of form and function. We will present a general theoretical framework for understanding the relationship between metabolic rate, B, and body mass, M. We show how the pervasive quarter-power biological scaling relations arise naturally from optimal directed resource supply systems. This framework robustly predicts that: 1) whole organism power and resource supply rate, B, scale as $M^{3/4}$; 2) most other rates, such as heart rate and maximal population growth rate scale as $M^{-1/4}$; 3) most biological times, such as blood circulation time and lifespan, scale as $M^{1/4}$; and 4) the average velocity of flow through the network, $\bar{v}$, such as the speed of blood and oxygen delivery, scales as $M^{1/12}$. Our framework is valid even when there is no underlying network. Our theory is applicable to unicellular organisms as well as to large animals and plants. This work was carried out in collaboration with Amos Maritan along with Jim Brown, John Damuth, Melanie Moses, Andrea Rinaldo, and Geoff West.