A general theory for temperature dependence in biology

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$$B \propto M^{3/4}$$

Kleiber's law

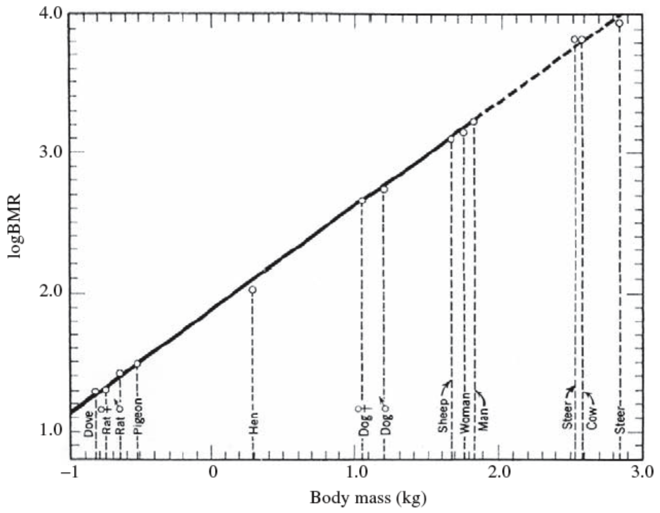
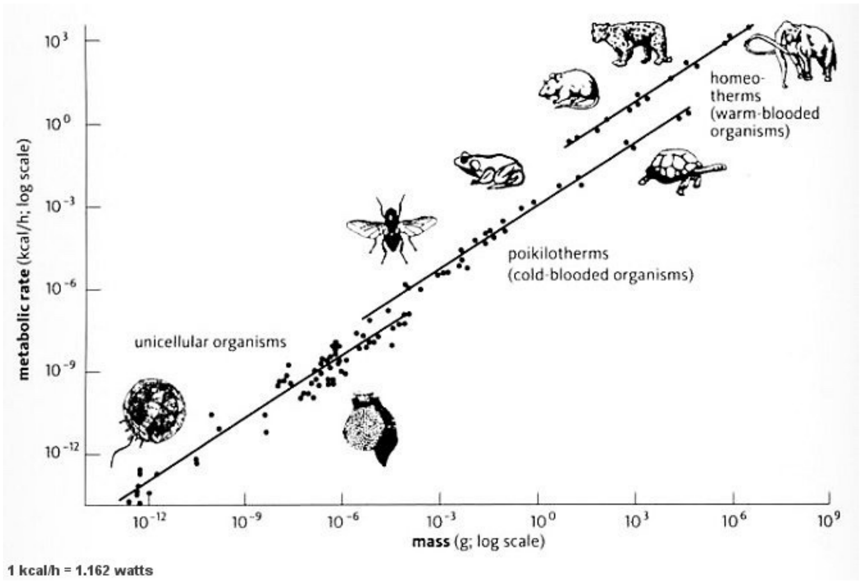


Fig. 1. Kleiber's original 1932 plot of the basal metabolic rate of mammals and birds (in kcal/day) plotted against mass (M_b in kg) on a log–log scale (Kleiber, 1975). The slope of the best straight-line fit is 0.74, illustrating the scaling of metabolic rate as $M_b^{3/4}$. The diameters of the circles represent his estimated errors of 10% in the data.



A General Model for the Origin of Allometric Scaling Laws in Biology

Geoffrey B. West, James H. Brown,* Brian J. Enquist

Allometric scaling relations, including the 3/4 power law for metabolic rates, are characteristic of all organisms and are here derived from a general model that describes how essential materials are transported through space-filling fractal networks of branching tubes. The model assumes that the energy dissipated is minimized and that the terminal tubes do not vary with body size. It provides a complete analysis of scaling relations for mammalian circulatory systems that are in agreement with data. More generally, the model predicts structural and functional properties of vertebrate cardiovascular and respiratory systems, plant vascular systems, insect tracheal tubes, and other distribution networks.

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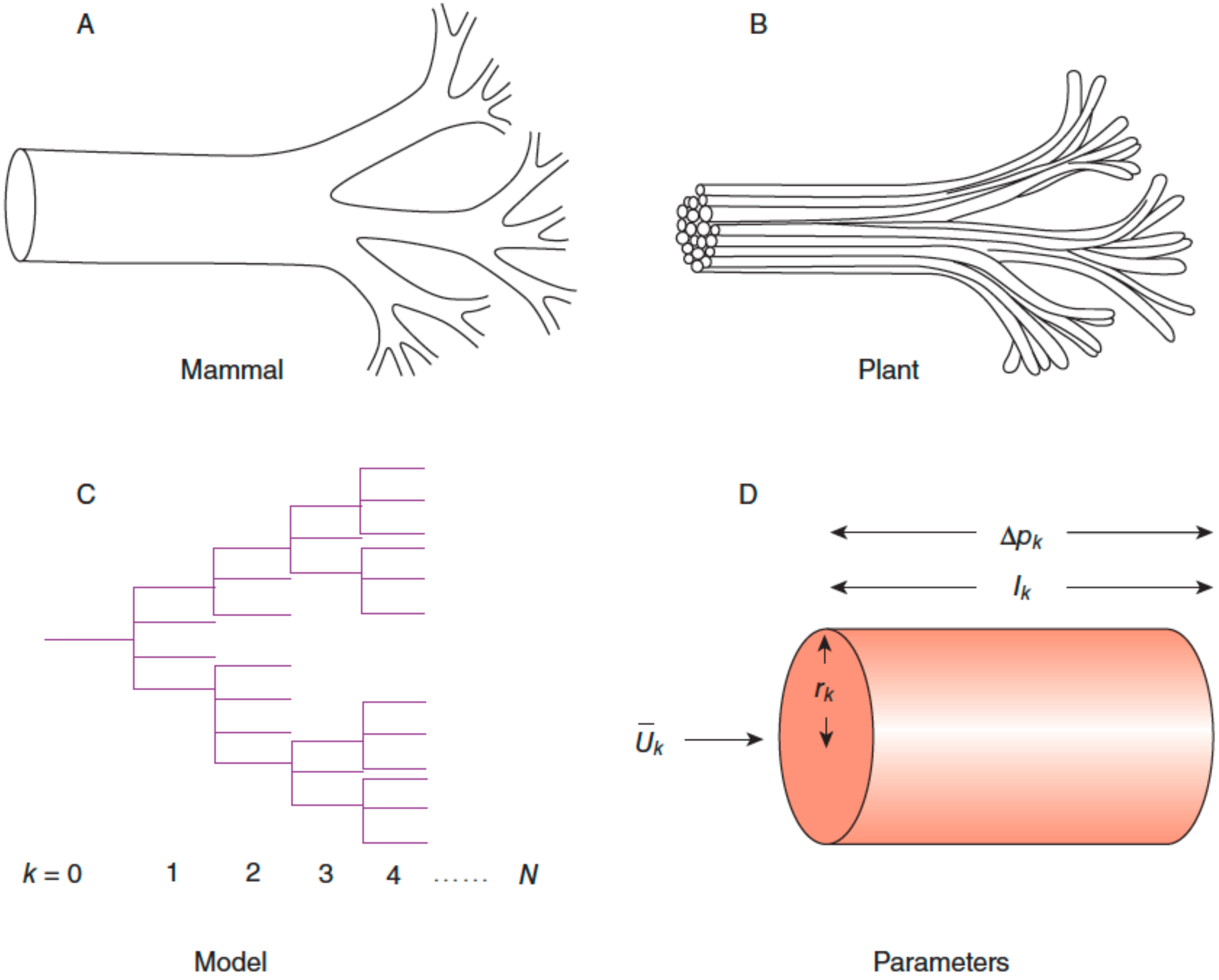
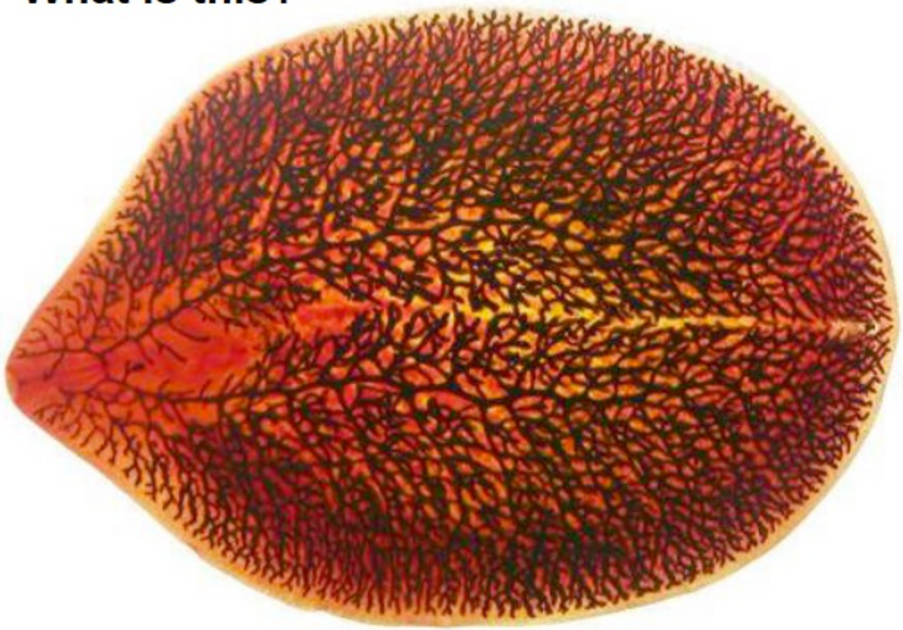


Figure 2.2 Framework for the West et al. (1997) model showing diagrammatic examples of segments of biological distribution networks: (A) mammalian circulatory and respiratory systems composed of branching tubes; (B) plant vessel-bundle vascular system composed of diverging vessel elements; (C) topological representation of such networks, where k specifies the order of the level, beginning with the aorta ($k = 0$) and ending with the capillary ($k = N$); and (D) parameters of a typical tube at the kth level. (From West et al. 1997.)

What is this?



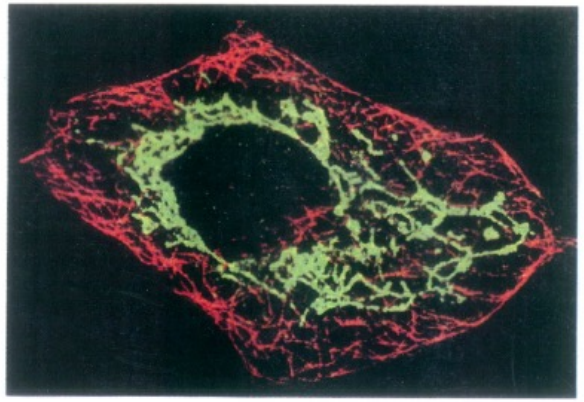
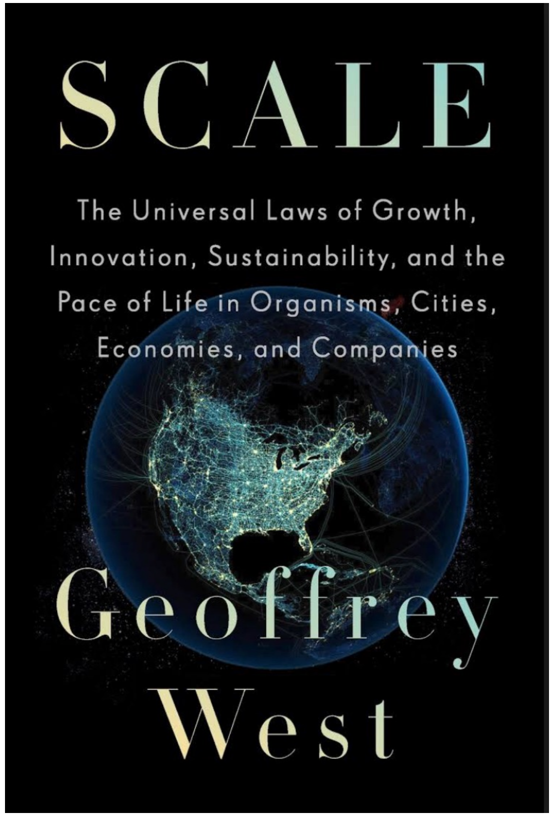


Fig. 1. Mitochondrial network in a mammalian fibroblast. A COS-7 cell labeled to visualize mitochondria (green) and microtubules (red) was analyzed by indirect immunofluorescence confocal microscopy. Mitochondria were labeled with antibodies to the β subunit of the F_1-ATPase and a rhodamine-conjugated secondary antibody. Microtubules were labeled with antibody to tubulin and a fluorescein-conjugated secondary antibody. Pseudocolor was added to the digitized image. Scale: 1 cm = 10 μm.

From M. P. Yaffe, *Science,* **283,** 1493 (1999).


SCALE
The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies
Geoffrey West

Metabolic Rate, *B*, and Body Mass, *M*

Blood volume

Number of Terminal units

Volume of Terminal units

Mass

$$M \propto V_b = \sum_{levels} n_k \pi r_k^2 l_k \propto N_T^{4/3} V_T \propto B^{4/3}$$

Met Rate

Follows from Energy Min.

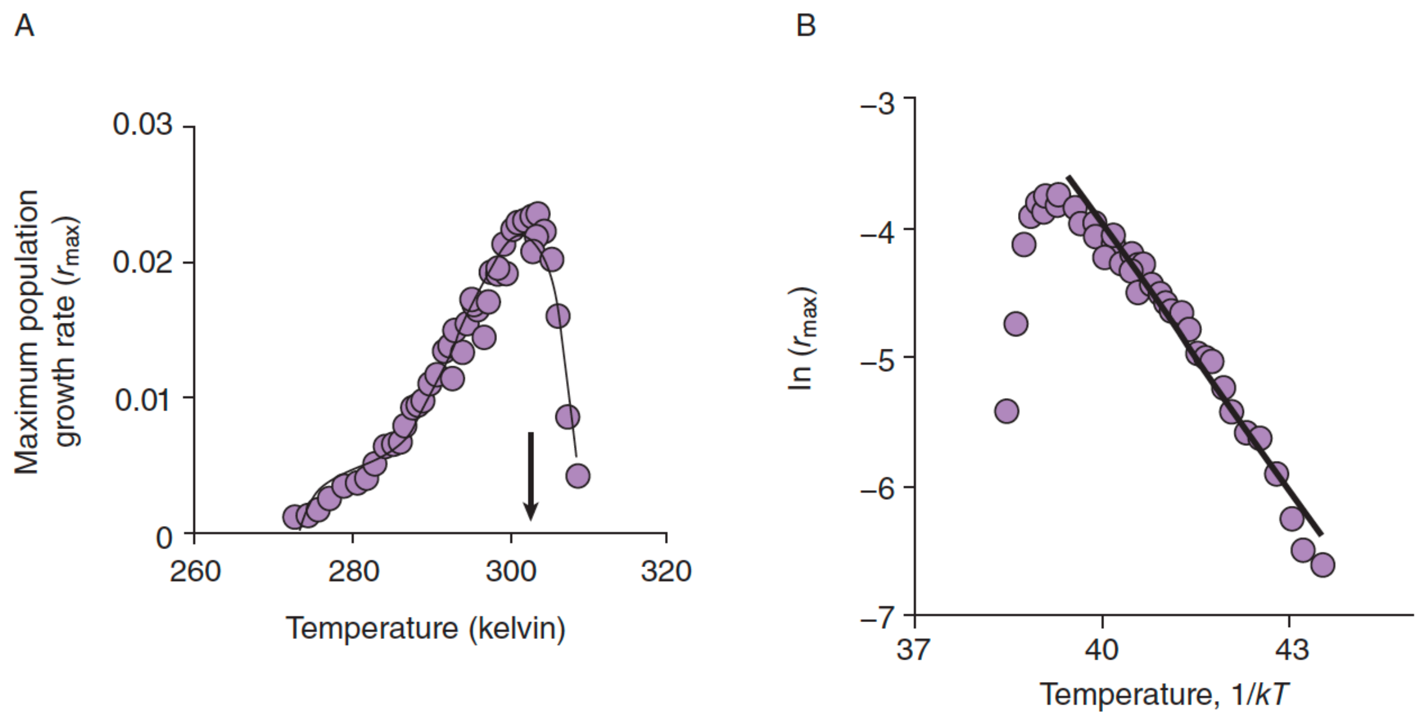
Use scale factors to relate each level to terminal units.

Invariance of terminal units $B = N_T B_T$

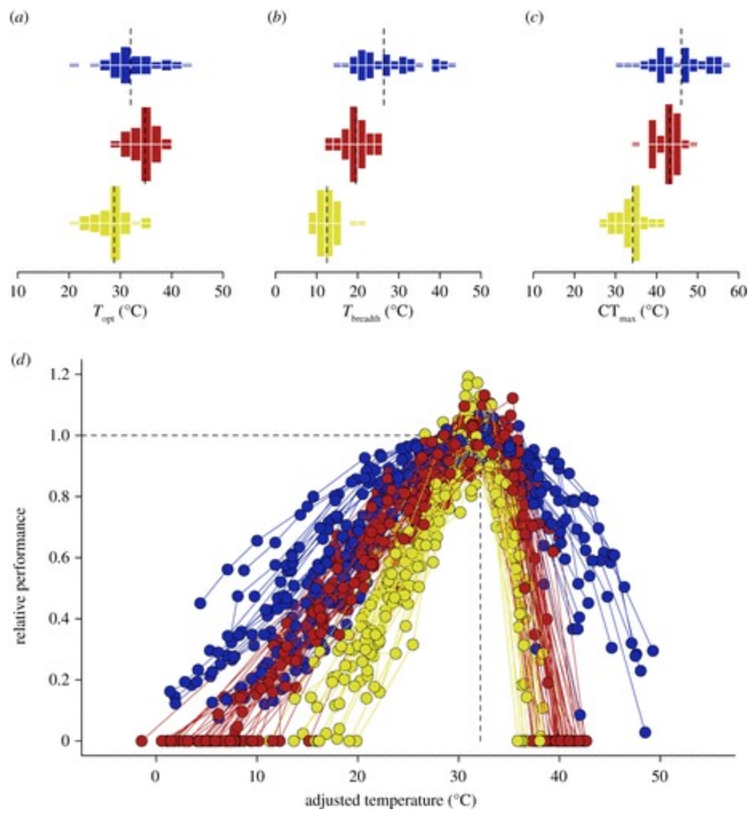
$$B \propto M^{3/4}$$

West et al. *Science* (1997)

Temperature and its impact on scaling

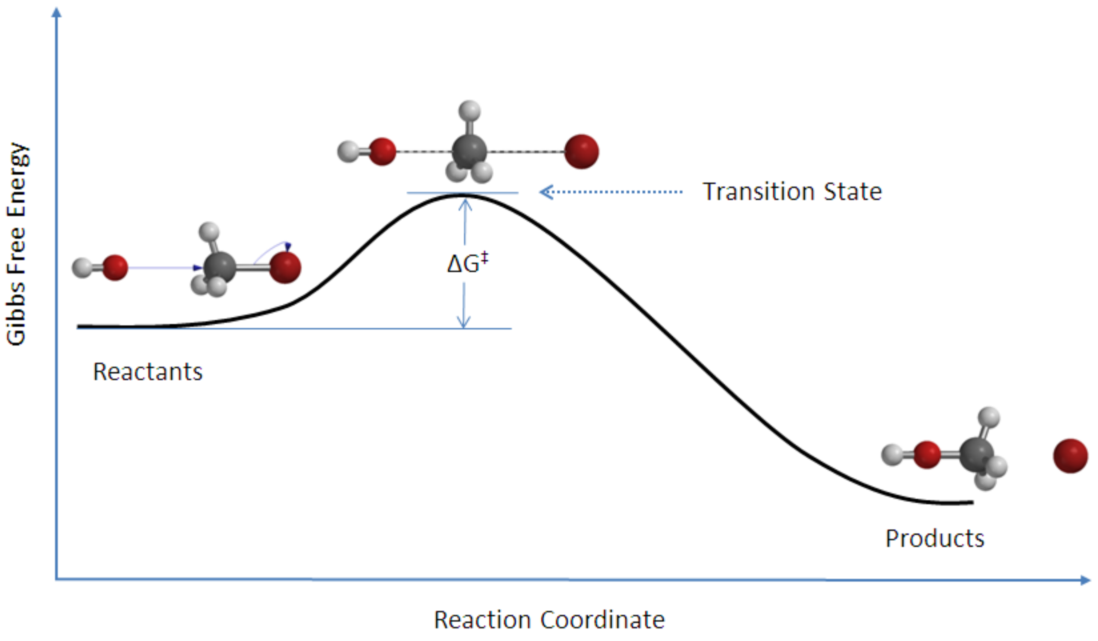


$$B = B_0 M^{\alpha} e^{-E/kT}$$



Thermal performance across levels of biological organization, Volume: 374, Issue: 1778, DOI: (10.1098/rstb.2018.0549)

Transition State Theory



Reaction: $HO^- + CH_3Br \rightarrow [HO\text{---}CH_3\text{---}Br]^\ddagger \rightarrow CH_3OH + Br^-$

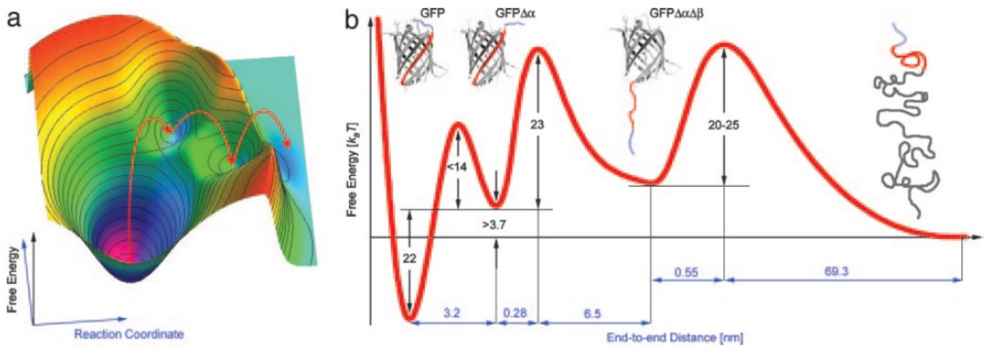


Fig. 6. Free energy surface. (*a*) Cartoon of the multidimensional energy landscape of GFP. The red arrows indicate the course of the mechanical unfolding pathway. (*b*) Projection of the energy landscape along the unfolding pathway onto one reaction coordinate.

Dietz et al. 2014, PNAS

Transition state theory. (2022, August 3). In *Wikipedia*. https://en.wikipedia.org/wiki/Transition_state_theory

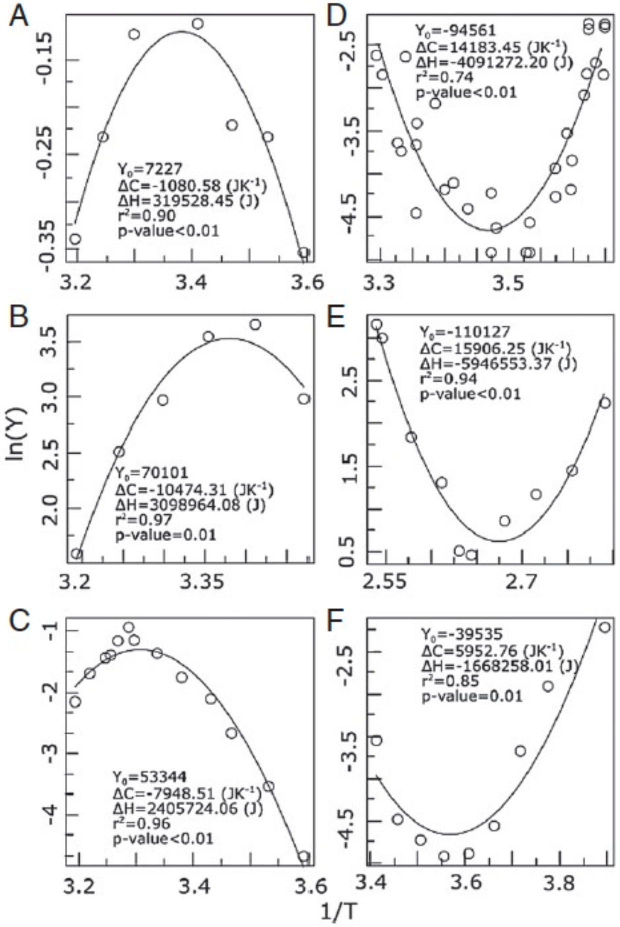
The Eyring–Evans–Polanyi (EEP) transition state theory (TST)

$$k = \frac{k_B}{h} T e^{\Delta S/R} e^{-\Delta H/RT}.$$

Metabolism

Germination rate

Growth rate



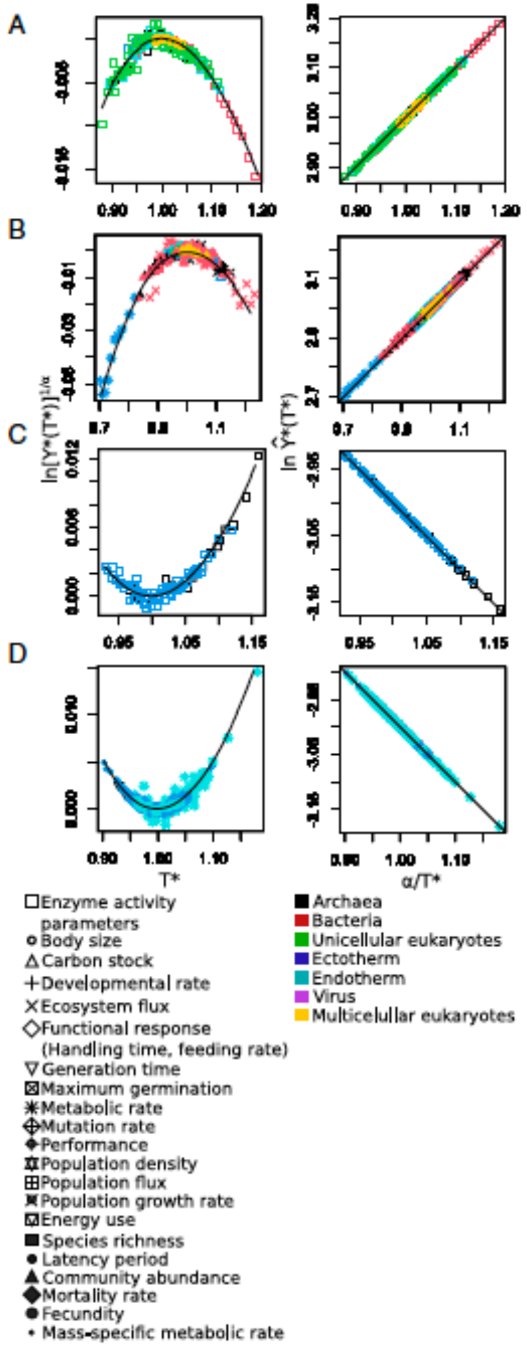
Mortality rate

Generation time

Metabolic rate

$$Y(T) \approx Y_0 \left(\frac{1}{T}\right)^{\frac{-\overline{\Delta C}}{R} - \alpha} e^{\frac{-\overline{\Delta H}}{RT}}.$$

Arroyo et al. (2022) PNAS



$$Y^{*1/a} = T^* e^{1/T^* - 1},$$

$$\hat{Y}^*(T^*) \equiv (e/T^*)^a Y^*(T^*) = e^{a/T^*}$$

Arroyo et al. (2022) PNAS