ELECTRONIC APPENDIX

This is the Electronic Appendix to the article

Energetics of the smallest:
Do bacteria breathe at the same rate as whales?

by

Anastassia M. Makarieva, Victor G. Gorshkov and Bai-Lian Li

Proc. R. Soc. B (doi:10.1098/rspb.2005.3225)

APPENDIX

Energetics of the smallest: Do bacteria breathe at the same rate as whales?

Makarieva A.M., Gorshkov V.G., Li B.-L

I. ENDOGENOUS MASS-SPECIFIC METABOLIC RATE R_E OF PROKARYOTES

Notes: species names are given as reported in the original sources; BM refers to Holt (1984, 1986, 1989); BL refers to Balows et al. (1991); to convert dry weight to wet weight a dry to wet weight ratio of 0.2 (Clarholm & Rosswall 1980; Norland et al. 1987) was used unless otherwise stated; to convert protein to dry weight a protein-to-dry weight ratio of 0.5 was used (Otte et al. 1999; Zubkov et al. 1999; Stal & Moezelaar 1997); to convert cell nitrogen to dry weight a nitrogen to dry weight ratio of 0.1 (Altman & Dittmer 1974) was used unless otherwise stated; aerobic oxidation of endogenous substrates was assumed to yield 20 J (ml O_2)$^{-1}$

	Species	Original units	R_E (original units)	R_E (W kg^{-1})	Temp. (°C)	Cell mass (×10^{-12} g)	Source	Comments
1.	**Acholeplasma laidlawii**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	1.2	0.9	37	0.014	Abu-Amero et al. 1996	cell mass estimated from linear dimensions given in BM
2.	**Aerobacter aerogenes**	μl O_2 (mg N)$^{-1}$ hr^{-1}	67	7.4	30	0.4	Dietrich & Burris 1967	cell mass estimated from linear dimensions given in BM; synonym Klebsiella pneumoniae
3.	**Anabaena variabilis**	μl O_2 (mg dry weight)$^{-1}$ hr^{-1}	1.7	1.9	25	17	Kratz & Myers 1955	respiration of cells harvested from growing cultures and stored in darkness for 24 hours; cell mass estimated from strain PCC 7118 description at Pasteur Culture Collection http://www.pasteur.fr
4.	**Anacystis nidulans**	μl O_2 (mg dry weight)$^{-1}$ hr^{-1}	1.9-2.9	2.7	39	0.7	Kratz & Myers 1955	respiration of cells harvested from growing cultures and stored in darkness for 24 hours; cell mass estimated from strain PCC 6301 description at Pasteur Culture Collection http://www.pasteur.fr
5.	**Aphanocapsa 6714**	nmol O_2 (mg wet weight)$^{-1}$ min^{-1}	<0.02	0.15	25	10	Pelroy & Bassham 1973	stabilized respiration of cells harvested during late-log phase; cell mass estimated from linear dimensions of the corresponding images in Fig. 6 of Stanier et al. 1971
6.	**Arthrobacter crystallopoietes**	μl O_2 (mg dry weight)$^{-1}$ hr^{-1}	0.1	0.1	30	2.5	Ensign 1970	stable respiration during 24 days of starvation at 100% viability; cell mass estimated from the dry weight data for spherical cells
7.	**Azospirillum brasilense**	μmol O_2 (mg protein)$^{-1}$ min^{-1}	0.024	18	37	1	Loh et al. 1984	cells harvested during mid log-phase; constant respiration rate throughout the experiment (40 hrs); cell mass estimated from linear dimensions of the species image in BM
8.	**Azospirillum lipoferum**	μmol O_2 (mg protein)$^{-1}$ min^{-1}	0.024	18	37	4	Loh et al. 1984	cells harvested during mid log-phase; constant respiration rate throughout the experiment (40 hrs); cell mass estimated from linear dimensions of the species image in BM; synonim Spirillum lipoferum (BM)
9.	**Azotobacter agilis**	μl O_2 (mg dry weight)$^{-1}$ hr^{-1}	1.4	1.6	30	20	Sobek et al. 1966	respiration of glucose-grown cells starved for 48 hours; viability >90%; cell mass estimated from dry weight data of Gunter & Kohn 1956
10.	**Bacillus cereus**	μl O_2 (mg N)$^{-1}$ hr^{-1}	188	21	30	3.7	Dietrich & Burris 1967	cell mass estimated from linear dimensions given in BM
11.	**Bdellovibrio bacteriovorus**	μl O_2 (mg dry weight)$^{-1}$ hr^{-1}	14.8-17.3	18	30	0.5	Hespell et al. 1973	cell mass estimated from dry weight data of Hespell et al. (1973)
12.	**Beggiatoa sp.**	pmol O_2 s^{-1} (μg protein)$^{-1}$	0.07-0.20	6	23	10	Hagen & Nelson 1997	stable respiration of stationary phase >21-day-old cultures after depletion of growth substrate; cell mass estimated for strain MS-81-1c from linear dimensions given in BM
13.	**Bradyrhizobium japonicum**	nmol O_2 (mg protein)$^{-1}$ hr^{-1}	52	0.66	29	0.7	Frustaci et al. 1991	cell mass estimated from linear dimensions given in BM
14.	**Burkholderia sp. JT1500**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	19-30	37	30	0.66	Morawski et al. 1997	cell mass estimated from linear dimensions given for the strain by Morawski et al. (1997)

15.	**Cyanothece PCC 7822**	nmol glucose (mg protein)$^{-1}$ min^{-1}	0.8	0.2	30	87	Oost et al. 1989; Stal & Moezelaar 1997	anaerobic fermentation of endogenous glycogen-glucose to ethanol, lactate, formate, acetate; calculated assuming energy yield of 150 kJ (mol glucose)$^{-1}$ from the data of Gnaiger (1983); cell mass estimated from species description at Pasteur Culture Collection http://www.pasteur.fr
16.	**Desulfobulbus propionicus**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	5	3.7	30	1.8	Fuseler & Cypionka 1995	sulfate-reducing bacterium; endogenous respiration in the presence of methanol; cell mass estimated from linear dimensions given in BM
17.	**Desulfovibrio desulfuricans**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	4-14	6.7	30	1.5	van Niel & Gottschal 1998	cell mass estimated from linear dimensions given in BM
18.	**Desulfovibrio gigas**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	10	7.5	30	10	van Niel & Gottschal 1998	cell mass estimated from linear dimensions given in BM
19.	**Desulfovibrio salexigens**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	8-12	7.5	30	1.5	van Niel & Gottschal 1998	cell mass estimated from linear dimensions given in BM
20.	**Enterococcus cecorum**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	1.7	2.5	30	0.4	Bauer et al. 2000	respiration of cells from aerobic glucose-grown cultures; cell mass estimated from linear dimensions given in BM
21.	**Enterococcus sp. RfL6**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	15.1	22	30	0.8	Bauer et al. 2000	respiration of cells from aerobic glucose-grown cultures; cell mass estimated from linear dimensions given by Bauer et al. (2000)
22.	**Escherichia coli**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	8	8.9	37	1.2	Dawes & Ribbons 1965	stable respiration of aerobically grown cells starved aerobically for 150-180 mins; no loss of viability; cell mass estimated from cell volume data of Heldal et al. 1985
23.	**Ferrobacillus ferrooxidans**	µmol O_2 (5.6 mg protein)$^{-1}$ hr^{-1}	0.12	0.3	25	0.2	Silver 1970	respiration of cells during 60 min of substrate deprivation; cell mass estimated from linear dimensions given in BM
24.	**Lactococcus lactis**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	<1	1.5	30	0.2	Bauer et al. 2000	respiration of cells from aerobic glucose-grown cultures; cell mass estimated from linear dimensions given in BM
25.	**Lactococcus sp. TmLO5**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	9.1	14	30	0.8	Bauer et al. 2000	respiration of cells from aerobic glucose-grown cultures; cell mass estimated from linear dimensions given by Bauer et al. (2000)
26.	**Legionella pneumophila**	µl O_2 (mg dry weight)$^{-1}$ min^{-1}	0.3	20	37	0.4	Tesh et al. 1983	steady endogenous respiration of washed cultures harvested at mid- to late exponential growth phase; cell mass estimated from linear dimensions given at www.legionella.org
27.	**Methylosinus trichosporium**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	38	28	30	1	Lontoh et al. 1999	cell mass estimated from linear dimensions of images given in BL (p. 414, 434) and Fig. 1 of Reed & Dugan 1978
28.	**Microcoleus chthonoplastes**	nmol glucose (mg protein)$^{-1}$ min^{-1}	0.2-0.4	0.08	20	54	Moezelaar et al., 1996; Stal & Moezelaar 1997	anaerobic fermentation of endogenous glycogen-glucose to formate, ethanol, acetate; R_E calculated assuming energy yield of 150 kJ (mol glucose)$^{-1}$ from the data of Gnaiger (1983); cell mass estimated from species description at Pasteur Culture Collection http://www.pasteur.fr
29.	**Microcystis PCC 7806**	nmol glucose (mg protein)$^{-1}$ min^{-1}	0.4-0.9	0.16	19	22	Moezelaar & Stal 1994; Stal & Moezelaar 1997	anaerobic fermentation of endogenous glycogen-glucose to ethanol, acetate; calculated assuming energy yield of 150 kJ (mol glucose)$^{-1}$ from the data of Gnaiger (1983); cell mass estimated from species description at Pasteur Culture Collection http://www.pasteur.fr
30.	**Mycobacterium phlei**	µmol O_2 (mg N)$^{-1}$ hr^{-1}	4.8-7.3	11	37	0.4	Tepper 1968	cells harvested from 5-day culture; R_E calculated assuming N: dry weight ratio of 0.07:1 (Tepper 1968); cell mass estimated from linear dimensions in BM

31.	**Neisseria gonorrhoeae**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	0.6	0.45	37	0.2	Kenimer & Lapp 1978	respiration of cells harvested during early stationary phase after 18-20 hours of incubation; cell mass estimated from linear dimensions given in BM
32.	**Nocardia corallina**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	1	1.1	30	2.4	Robertson & Batt 1973	cells harvested during at the end of growth phase; respiration measured after 45 hours of starvation; viability more than 90%; cell mass estimated from linear dimensions given by Robertson & Batt (1973)
33.	**Nostoc muscorum**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	1.1	1.2	25	17	Kratz & Myers 1955	respiration of cells harvested from growing cultures and starved in darkness for 24 hours; cell mass estimated from species description at Pasteur Culture Collection http://www.pasteur.fr
34.	**Oscillatoria limnetica**	nmol glucose (mg protein)$^{-1}$ min^{-1}	1.7	0.43	35	12	Stal & Moezelaar 1997; Oren & Shilo 1979	anaerobic fermentation of endogenous glycogen-glucose to lactate; calculated assuming energy yield of 150 kJ (mol glucose)$^{-1}$ from the data of Gnaiger (1983); cell mass estimated from species description at http://protist.i.hosei.ac.jp
35.	**Oscillatoria limosa**	nmol glucose (mg protein)$^{-1}$ min^{-1}	0.8-1.1	0.25	20	900	Heyer et al., 1989; Stal & Moezelaar 1997	anaerobic fermentation of endogenous glycogen-glucose to lactate and ethanol; calculated assuming energy yield of 150 kJ (mol glucose)$^{-1}$ from the data of Gnaiger (1983); cell mass estimated from species description at http://protist.i.hosei.ac.jp and Fig. 1C in Bergman et al. 1997
36.	**Phaeospirillum fulvum**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	25.3	19	28	2	Berg et al. 2002	dark respiration of cells harvested during exponential growth phase; cell mass estimated from linear dimensions given in BM
37.	**Picrophilus oshimae**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	22.7	17	60	1	Van de Vossenberg et al. 1998	starvation for several hours; cell mass estimated from linear dimensions given by Schleper et al. (1995) assuming spherical shape
38.	**Phormidium luridum**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	4-6	5.6	25	4.4	Biggins 1969	dark endogenous respiration; stable for 8 hrs after harvesting the cells from a photoautotrophic culture; from strain PCC 7602 description at Pasteur Culture Collection http://www.pasteur.fr
39.	**Plectonema boryanum**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	5-10	5.6	25	4.4	Padan et al. 1971	dark endogenous respiration; stable during 6 days of starvation; from strain PCC 73110 description at Pasteur Culture Collection http://www.pasteur.fr
40.	**Prochloron sp.**	µmol O_2 (mg Chl)$^{-1}$ min^{-1} × 10^{-9}	0.9	19	28	5,600	Alberte et al. 1986	dark respiration of low-light colonies of Prochloron sp. isolated from Lissoclinum patella; R_E calculated using chlorophyll *a* to protein ratio of 26:1 (Stal & Moezelaar 1997); cell size estimated from diameter data of 22 µm assuming spherical shape (Cox 1986)
41.	**Pseudomonas fluorescens**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	5.9	6.6	26	1.2	Gunter & Kohn 1956	respiration of washed cell suspensions harvested from 16 to 18-hr yeast agar plates; cell mass estimated from dry weight data given by Gunter & Kohn (1956)
42.	**Pseudomonas perfectomarinus**	10^{-9} µl O_2 h^{-1} cell^{-1}	0.22-0.82	1.8	10	1.7	Christensen et al. 1980	stable steady-state respiration after termination of growth; cell mass estimated from dry weight data of Christensen et al. (1980)
43.	**Rhizobium leguminosarum**	µl O_2 (mg N)$^{-1}$ hr^{-1}	57	6.3	30	0.6	Dietrich & Burris 1967	cell mass estimated from linear dimensions given in BM
44.	**Rhodopseudomonas spheroides**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	20.8	23	26	1.2	Gunter & Kohn 1956	respiration of washed cell suspensions harvested from 16 to 18-hr yeast agar plates; cell mass estimated from dry weight data given by Gunter & Kohn (1956); synonym Rhodobacter sphaeroides (BM)
45.	**Rhodospirillum rubrum**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	3.4	2.5	28	9	Berg et al. 2002	dark respiration of cells harvested during exponential growth phase; cell mass estimated from linear dimensions given in BM

46.	**Sarcina lutea**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	0.7	0.78	37	1.1	Burleigh & Dawes 1967	respiration of peptone-grown cells starved for 29 hours; viability 95%; cell mass estimated from linear dimensions given in BM; synonym Micrococcus luteus
47.	**Staphylococcus aureus**	µmol O_2 (mg dry weight)$^{-1}$ hr^{-1}	0.19	4.7	37	0.1	Krzemiński et al. 1972	cells starved for 3 hours with no loss of viability; cell size estimated from mean linear dimensions established by Watson et al. (1998) for growing and long-term-starved S. aureus cells; spherical shape assumed
48.	**Staphylococcus epidermidis**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	16	18	30	0.5	Jacobs & Conti 1965	aerobically grown culture; cell mass estimated from linear dimensions given in BM
49.	**Streptococcus agalactiae**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	5.5	6	37	0.3	Mickelson 1961	cell mass estimated from linear dimensions in BM
50.	**Streptococcus faecalis**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	0.16	0.18		0.2	Bryan-Jones & Whittenbury 1969	respiration of resting suspensions of cells grown aerobically with glucose; cell mass estimated from linear dimensions given in BM
51.	**Sulfolobus sp.**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	13.5	10	60	0.11	Schäfer 1996	steady-state respiration on endogenous substrate; cell mass estimated from linear dimensions given for the genus by Schäfer (1996)
52.	**Thiobacillus thiooxidans**	µl O_2 (mg N)$^{-1}$ hr^{-1}	22	2.4	28	0.5	Vogler 1942	cell mass estimated from linear dimensions given by Mahoney & Edwards (1966)
53.	**Thioploca araucae**	nmol NH_4^+ (mg protein)$^{-1}$ min^{-1}	1	0.6*	12	20,000	Otte et al. 1999	respiration of intact trichome bundles without addition of external substrate; presumed reaction is oxidation of internally stored elemental sulfur to sulfate and reduction of internally stored nitrate to ammonium; metabolic rate calculated assuming energy yield of 316 kJ (mol NH_4^+)$^{-1}$ from the data of Kelly (1991); cell size reported by Schulze & Jørgensen 2001; dry to wet weight ratio 0.24, protein to dry weight of cytoplasm 0.5:1, cytoplasm constitutes 10% of cell volume (Otte et al. 1991)
54.	**Vibrio anguillarum**	10^{-9} µl O_2 cell^{-1} hr^{-1}	0.77-3.9	19	10	0.8	Christensen et al. 1980	respiration after termination of growth; cell mass estimated from dry weight data of Christensen et al. (1980) recalculated for the senescence phase
55.	**Vibrio fischeri**	n atoms O (mg dry weight)$^{-1}$ min^{-1}	20	15	20	0.6	Droniuk et al. 1987	respiration at 100 mM Na$^+$; cell mass estimated from linear dimensions given by Allen and Baumann (1971)
56.	**Vibrio sp. DW1**	ng O_2 atoms (10^9 viable cells^{-1}) min^{-1}	9	5.3	26	0.37	Kjelleberg et al. 1982	respiration of viable cells starved for 5 days; cell mass estimated from cell volume data of Kjelleberg et al. (1982)

*calculated per unit mass of cytoplasm

II. MASS-SPECIFIC METABOLIC RATE R_G OF PROKARYOTES GROWING IN THE PRESENCE OF VARIOUS SUBSTRATES

	Species	Original units	R_G (original units)	R_G (W kg^{-1})	Temp. (°C)	Cell mass ($\times10^{-12}$ g)	Source	Comments
1.	**Acholeplasma laidlawii**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	9.5	7.1	37	0.014	Abu-Amero et al. 1996	respiration in the presence of glucose and other substrates; cell mass estimated from linear dimensions given in BM
2.	**Aerobacter aerogenes**	µl O_2 (mg N)$^{-1}$ hr^{-1}	1228	136	30	0.4	Dietrich & Burris 1967	respiration in the presence of glucose; cell mass estimated from linear dimensions given in BM; synonym Klebsiella pneumoniae
3.	**Alteromonas haloplanktis**	n atoms O (mg dry weight)$^{-1}$ min^{-1}	380	280	25	1	Khanna et al. 1984	oxidation of NADH; cell mass estimated from linear dimensions in BM
4.	**Azospirillum brasilense**	µmol O_2 (mg protein)$^{-1}$ min^{-1}	0.14	105	37	1	Loh et al. 1984	respiration in the presence of succinate; cell mass estimated from linear dimensions of the species image in BM
5.	**Azospirillum lipoferum**	µmol O_2 (mg protein)$^{-1}$ min^{-1}	0.15	112	37	4	Loh et al. 1984	respiration in the presence of succinate; cell mass estimated from linear dimensions of the species image in BM; synonim Spirillum lipoferum (BM)
6.	**Azotobacter agilis**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	2240	2500	30	19	Altman & Dittmer 1974	glucose; cell mass estimated from dry weight data of Gunter & Kohn (1956)
7.	**Azotobacter chroococcum**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	2700	3000	30	12	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BL
8.	**Bacillus cereus**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	86	96	30	3.7	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
9.	**Bacillus licheniformis**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	196	218	37	0.8	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
10.	**Bacillus macerans**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	21	23	37	1	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
11.	**Bacillus subtilis**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	170	190	37	1.1	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
12.	**Bdellovibrio bacteriovorus**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	24.8	28	30	0.5	Hespell et al. 1973	respiration in the presence of peptone; cell mass estimated from dry weight data of Hespell et al. (1973)
13.	**Beggiatoa sp.**	pmol O_2 s^{-1} (µg protein)$^{-1}$	1.6	72	23	10	Hagen & Nelson 1997	early growth stage in the presence of H_2S; cell mass estimated for strain MS-81-1c from linear dimensions given in BM
14.	**Bradyrhizobium sp.**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	131	98	30	0.7	Allen & Elkan 1990	growth with succinate; cell mass estimated from linear dimensions in BM
15.	**Burkholderia sp. JT1500**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	220	330	30	0.66	Morawski et al. 1997	respiration in the presence of 2-naphthoate; cell mass estimated from linear dimensions given for the strain by Morawski et al. (1997)
16.	**Corynebacterium sp.**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	96	107	30	0.5	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions of the genus in BM
17.	**Desulfobulbus propionicus**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	47	28	30	1.8	Fuseler & Cypionka 1995	sulfate-reducing bacterium; respiration in the presence of sulfide; RG calculated assuming 16 J (mol O_2)$^{-1}$ when sulfide is oxidized to sulfate (Kelly 1991); cell mass estimated from linear dimensions given in BM
18.	**Enterococcus cecorum**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	58.9	90	30	0.4	Bauer et al. 2000	respiration of cells from aerobic glucose-grown cultures; cell mass estimated from linear dimensions given in BM
19.	**Enterococcus sp. RfL6**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	69.1	103	30	0.8	Bauer et al. 2000	respiration of cells from aerobic glucose-grown cultures; cell mass estimated from linear dimensions given by Bauer et al. (2000)
20.	**Escherichia coli**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	272	300	32	1.2	Altman & Dittmer 1974	glucose; cell mass estimated from cell volume data of Heldal et al. 1985
21.	**Ferrobacillus ferrooxidans**	µmol O_2 (5.6 mg protein)$^{-1}$ hr^{-1}	28.6	64	25	0.2	Silver 1970	growth in the presence of $S_4O_6^{2-}$ and glucose; cell mass estimated from linear dimensions given in BM
22.	**Lactobacillus bulgaricus**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	55	61	45	1.3	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM; synonym L. delbruckei ssp. bulgaricus
23.	**Lactobacillus casei**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	21	23	30	1.9	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
24.	**Lactobacillus plantarum**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	19.5	22	30	3.8	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM

25.	**Lactococcus lactis**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	24.8	37	30	0.2	Bauer et al. 2000	respiration of cells from aerobic glucose-grown cultures; cell mass estimated from linear dimensions given in BM
26.	**Lactococcus sp. TmLO5**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	23.4	35	30	0.8	Bauer et al. 2000	respiration of cells from aerobic glucose-grown cultures; cell mass estimated from linear dimensions given by Bauer et al. (2000)
27.	**Leptospira sp.**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	80	89	30	0.07	Baseman & Cox 1969	maximum respiration rate in the presence of sodium oleate; cell mass estimated from linear dimensions given in BM
28.	**Methylosinus trichosporium**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	630	470	30	1	Lontoh et al. 1999	growth in the presence of methane and formate; cell mass estimated from linear dimensions of images given in BL (p. 414, 434) and Fig. 1 of Reed & Dugan 1978
29.	**Mycobacterium phlei**	µmol O_2 (mg N)$^{-1}$ hr^{-1}	46	96	37	0.4	Tepper 1968	respiration of glucose-grown cells in the presence of glycerol; R_E calculated assuming N: dry weight ratio of 0.083:1 in glucose-grown cells (Tepper 1968); cell mass estimated from linear dimensions in BM
30.	**Mycoplasma bovis**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	5-15	7.5	37	0.014	Abu-Amero et al. 1996	respiration in the presence of glucose and other substrates; cell mass estimated from linear dimensions given in BM as low range for the genus
31.	**Mycoplasma capricolum**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	5-15	7.5	37	0.06	Abu-Amero et al. 1996	respiration in the presence of glucose and other substrates; cell mass estimated from linear dimensions given in BM as geometric mean for the genus
32.	**Mycoplasma gallisepticum**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	5-15	7.5	37	0.26	Abu-Amero et al. 1996	respiration in the presence of glucose and other substrates; cell mass estimated from linear dimensions given in BM as upper range for the genus
33.	**Neisseria gonorrhoeae**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	42.1	31	37	0.2	Kenimer & Lapp 1978	respiration of cells harvested during early stationary phase after 18-20 hours in the presence of NADH; cell mass estimated from linear dimensions given in BM
34.	**Neisseria meningitidis**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	56	62	37	0.3	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
35.	**Phaeospirillum fulvum**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	59.9	45	30	2	Berg et al. 2002	growth in the presence of propionate; cell mass estimated from linear dimensions given in BM
36.	**Picrophilus oshimae**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	65.0	49	60	1	Van de Vossenberg et al. 1998	growth on yeast extract; cell mass estimated from linear dimensions given by Schleper et al. (1995) assuming spherical shape
37.	**Pseudomonas aeruginosa**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	137	152		0.6	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
38.	**Pseudomonas fluorescens**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	58	64	26	1.2	Altman & Dittmer 1974	cell mass estimated from dry weight data given by Gunter & Kohn (1956)
39.	**Pseudomonas natrigiens**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	268	300	30	1	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions of the species image in BM; synonym Vibrio natrigiens
40.	**Pseudomonas perfectomarinus**	10^{-9} µl O_2 h^{-1} cell^{-1}	26.8	88	10	1.7	Christensen et al. 1980	growth in the presence of peptone; cell mass estimated from dry weight data of Christensen et al. (1980)
41.	**Pseudomonas putida**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	299	223	28	1.9	O'Connor et al. 1996	cells growing in the presence of styrene and phenylacetaldehyde; cell mass estimated from linear dimensions in BM
42.	**Rhizobium leguminosarum**	µl O_2 (mg N)$^{-1}$ hr^{-1}	330	37	30	0.6	Dietrich & Burris 1967	respiration in the presence of glucose; cell mass estimated from linear dimensions given in BM
43.	**Rhodobacter sphaeroides**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	33.8	25	30	1.2	Berg et al. 2002	growth in the presence of propionate; cell mass estimated from dry weight data of Gunter & Cohn (1956); synonym Rhodopseudomonas spheroides (BM)
44.	**Rhodospirillum rubrum**	nmol O_2 (mg protein)$^{-1}$ min^{-1}	40.4	30	30	9	Berg et al. 2002	growth in the presence of succinate; cell mass estimated from linear dimensions given in BM
45.	**Staphylococcus epidermidis**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	67	74	30	0.5	Jacobs & Conti 1965	growth in the presence of glucose; cell mass estimated from linear dimensions given in BM

46.	**Streptococcus agalactiae**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	110	122	37	0.3	Mickelson 1961	glucose; cell mass estimated from linear dimensions in BM
47.	**Streptococcus faecalis**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	106	118	38	1	Altman & Dittmer 1974	growth in the presence of glucose; cell mass estimated from linear dimensions given in BM
48.	**Streptococcus pneumoniae**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	27	30	37	0.25	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
49.	**Streptococcus pyogenes**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	63	70	37.5	0.18	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
50.	**Streptococcus thermophilus**	µl O_2 (mg dry weight)$^{-1}$ hr^{-1}	10	11	50	0.26	Altman & Dittmer 1974	glucose; cell mass estimated from linear dimensions in BM
51.	**Thioploca araucae**	nmol HS^- (mg protein)$^{-1}$ min^{-1}	20.4	15*	12	20,000	Otte et al. 1999	in vivo maximum rate of HS^- consumption; presumed reaction is oxidation of HS^- to sulfate by nitrate; metabolic rate calculated assuming energy yield of 361 kJ (mol H_2S)$^{-1}$ from the data of Kelly (1991); cell size reported by Schulze & Jørgensen 2001; dry to wet weight ratio 0.24, protein to dry weight of cytoplasm 0.5:1, cytoplasm constitutes 10% of cell volume (Otte et al. 1991)
52.	**Thiovulum majus**	mol O_2 cell^{-1} s^{-1}	2.6×10^{-16}	33	20	3,000	Jørgensen & Revsbech 1983	growth under optimal conditions in veils with H_2S oxidized to sulfate or elemental sulfur; R_G calculated assuming mean energy yield of 17 J (mol H_2S)$^{-1}$ (Kelly 1991); cell size reported by Schulze & Jørgensen 2001
53.	**Vibrio anguillarum**	10^{-9} µl O_2 h^{-1} cell^{-1}	13.8	29	10	2.6	Christensen et al. 1980	growth in the presence of glucose; cell mass estimated from dry weight data of Christensen et al. (1980) recalculated for the senescence phase
54.	**Vibrio sp. DW1**	ng O_2 atoms (10^9 viable cells^{-1}) min^{-1}	243	115	26	0.45	Kjelleberg et al. 1982	respiration, after addition of casamino acids, of viable cells starved for 5 days; cell mass estimated from cell volume data of Kjelleberg et al. (1982)
55.	**Zymomonas mobilis**	nmol O_2 (mg dry weight)$^{-1}$ min^{-1}	130	194	30	0.60	Zikmanis et al. 1997	growth with glucose; cell mass estimated from linear dimensions in BM

*calculated per unit mass of cytoplasm

PROKARYOTE REFERENCES

Abu-Amero K.K., Halablab M.A. Miles R.J. (1996) Nisin resistance distinguishes *Mycoplasma* spp. from *Acholeplasma* spp. and provides a basis for selective growth media. Appl. Environ. Microbiol. 62: 3107-3111.

Alberte R.S., Cheng L., Lewin R.A. (1986) Photosynthetic characteristics of Prochloron sp./ascidian symbioses I. Light and temperature responses of the algal symbiont of Lissoclinum patella. Mar. Biol. 90: 575-587.

Allen R.D., Baumann P. (1971) Structure and Arrangement of Flagella in Species of the Genus Beneckea and Photobacterium fischeri. J. Bact. 107: 295-302.

Allen G.C., Elkan G.H. (1990) Growth, respiration, and polypeptide patterns of Bradyrhizobium sp. (Arachis) strain 3G4b2O from succinate- or oxygen-limited continuous cultures. Appl. Environ. Microbiol. 56: 1025-1032.

Altman P.L., Dittmer D.S. (1974) *Biology Data Book*. Fed. Am. Soc. Exp. Biol., Bethesda, MD, pp. 1648-1650.

Balows A., Trüper H.G., Dworkin M., Harder W., Schleifer K.H. (1991) *The Prokaryotes*. Springer, New York.

Baseman J.B., Cox C.D. (1969) Intermediate metabolism of Leptospira. J. Bact. 97: 992-1000.

Bauer S., Tholen A., Overmann J., Brune A. (2000) Characterization of abundance and diversity of lactic acid bacteria in the hindgut of wood- and soil-feeding termites by molecular and culture-dependent techniques. Arch. Microbiol. 173: 126-137.

Berg I.A., Filatova L.V., Ivanovsky R.N. (2002) Inhibition of acetate and propionate assimilation by itaconate via propionyl-CoA carboxylase in isocitrate lyase-negative purple bacterium Rhodospirillum rubrum. FEMS Microbiology Letters 216: 49-54.

Bergman B., Gallon J.R., Rai A.N., Stal L.J. (1997) N_2 Fixation by non-heterocystous cyanobacteria. FEMS Microbiology Reviews 19: 139-185.

Biggins J. (1969) Respiration in blue-green algae. J. Bact. 99: 570-575.

Bryan-Jones D.G., Whittenbury R. (1969) Haematin-dependent oxidative phosphorylation in Streptococcus faecalis. J. General Microbiology 58: 247-260.

Burleigh I.G., Dawes E.A. (1967) Studies on the endogenous metabolism and senescence of starved Sarcina lutea. Biochemical Journal 102: 236-250.

Christensen J.P., Owens T.G., Devol A.H., Packard T.T. (1980) Respiration and physiological state in marine bacteria. Mar. Biol. 55: 267-276.

Cox G. (1986) Comparison of Prochloron from different hosts I. Structural and ultrastructural characteristics. New Phytologist 104: 429-445.

Dawes E.A., Ribbons D.W. (1965) Studies on the endogenous metabolism of Escherichia coli. Biochem. J. 95: 332-343.

Dietrich S.M.C., Burris R.H. (1967) Effect of exogenous substrates on the endogenous respiration of bacteria. J. Bact. 93: 1467-1470.

Droniuk R., Wong P.T.S., Wisse G., Macleod R.A. (1987) Variation in Quantitative Requirements for Na^+ for Transport of Metabolizable Compounds by the Marine Bacteria Alteromonas haloplanktis 214 and Vibrio fischeri. Appl. Environ. Microbiol. 53: 1487-1495.

Ensign J.C. (1970) Long-term starvation survival of rod and spherical cells of Arthrobacter crystallopoietes. J. Bact. 103: 569-577.

Frustaci J.M., Sangwan I., O'Brian M.R. 1991 Aerobic growth and respiration of a δ-aminolevulinic acid synthase (hemA) mutant of Bradyrhizobium japonicum. J. Bact. 173: 1145-1150.

Fuseler K., Cypionka H. (1995) Elemental sulfur as an intermediate of sulfide oxidation with oxygen by Desulfobulbus propionicus. Arch. Microbiol. 164: 104-109.

Gunter S.E., Kohn H.I. (1956) Effect of X-rays on the survival of bacteria and yeast II. Relation of cell concentration and endogenous respiration to sensitivity. J. Bact. 72: 422-428.

Hagen K.D., Nelson D.C. (1997) Use of reduced sulfur compounds by *Beggiatoa* spp.: enzymology and physiology of marine and freshwater strains in homogeneous and gradient cultures. Appl. Environ. Microbiol. 63: 3957-3964.

Heldal M., Norland S., Tumyr O. (1985) X-ray microanalytic method for measurement of dry matter and elemental content of individual bacteria. Appl. Environ. Microbiol. 50: 1251-1257.

Hespell R.B., Rosson R.A., Thomashow M.F., Rittenberg S.C. (1973) Respiration of Bdellovibrio bacteriovorus strain 109j and its energy substrates for intraperiplasmic growth. J. Bact. 113: 1280-1288.

Heyer H., Stal L., Krumbein W.E. (1989) Simultaneous heterolactic and acetate fermentation in the marine cyanobacterium Oscillatoria limosa incubated anaerobically in the dark. Arch. Microbiol. 151: 558-564.

Holt J.G. (ed.) (1984, 1986, 1989) *Bergey's Manual of Systematic Bacteriology*, Vols. 1-4. Williams & Wilkins, Baltimore.

Jacobs N.J., Conti S.F. (1965) Effect of Hemin on the Formation of the Cytochrome System of Anaerobically Grown Staphylococcus epidermidis. J. Bact. 89: 675-679.

Jørgensen B.B., Revsbech N.P. (1983) Colorless sulfur bacteria, Beggiatoa spp. and Thiovulum spp., in O_2 and H_2S microgradients. Appl. Environ. Microbiol. 45: 1261-1270.

Kelly D.P. (1991) The chemolithotrophic prokaryotes. In *The Prokaryotes* (eds. A. Balows, H.G. Trüper, M. Dworkin, W. Harder, K.H. Schleifer), pp. 331-343. Springer, New York.

Kenimer E.A., Lapp D.F. (1978) Effects of elected inhibitors on electron transport in Neisseria gonorrhoeae. J. Bact. 134: 537-545.

Khanna G., DeVoe L., Brown L., Niven D.F., MacLeod R.A. (1984) Relationship between ion requirements for respiration and membrane transport in a marine bacterium. J. Bact. 157: 59-63.

Kjelleberg S. Humphrey B.A. Marshall K.C. (1982) Effect of interfaces on small, starved marine bacteria. Appl. Environ. Microbiol. 43: 1166-1172.

Kratz W.A., Myers J. (1955) Photosynthesis and respiration of three blue-green algae. Plant Physiology 30: 275-280.

Krzemiński Z., Mikucki J., Szarapińska-Kwaszewska J. (1972) Endogenous metabolism of Staphylococcus aureus. Folia Microbiol., 17: 46-54.

Loh W.H.-T. (1984) Intermediary carbon metabolism of Azospirillum braziliense. J. Bact. 158: 264-268.

Lontoh S., DiSpirito A.A., Semrau J.D. (1999) Dichloromethane and trichloroethylene inhibition of methane oxidation by the membrane-associated methane monooxygenase of Methylosinus trichosporium OB3b. Arch. Microbiol. 171: 301-308.

Mahoney R.P., Edwards M.R. (1966) Fine Structure of Thiobacillus thiooxidans. J. Bact. 92: 487-495.

Mickelson M.N. (1967) Aerobic Metabolism of Streptococcus agalactiae. J. Bact. 94: 184-191.

Moezelaar R. , Stal L.J. (1994) Fermentation in the unicellular cyanobacterium Microcystis PCC7806. Arch. Microbiol. 162: 63-69.

Moezelaar R., Bijvank S.M., Stal L.J. (1996) Fermentation and Sulfur Reduction in the Mat-Building Cyanobacterium *Microcoleus chthonoplastes*. Appl. Environ. Microbiol. 62: 1752-1758.

Morawski B., Eaton R.W., Rossiter J.T., Guoping S., Griengl H., Ribbons D.W. (1997) 2-Naphthoate catabolic pathway in *Burkholderia* strain JT 1500 J. Bact. 179: 115-121.

Norland S., Heldal M., Tumyr O. (1987) On the relation between dry matter and volume of bacteria. Microb. Ecol. 13: 95-101.

O'Connor K., Duetz W., Wind B., Dobson A.D.W. (1996) The effect of nutrient limitation on styrene metabolism in *Pseudomonas putida* CA-3. Appl. Environ. Microbiol. 62: 3594-3599.

Oren A., Shilo M. (1979) Anaerobic heterotrophic dark metabolism in the cyanobacterium Oscillatoria limnetica: Sulfur respiration and lactate fermentation. Arch. Microbiol. 122: 77-84.

Otte S., Kuenen J.G., Nielsen L.P., Paerl H.W., Zopfi J., Schulz H.N., Teske A., Strotmann B., Gallardo V.A., Jørgensen B.B. (1999) Nitrogen, carbon, and sulfur metabolism in natural *Thioploca* samples. Appl. Environ. Microbiol. 65: 3148-3157.

Padan E., Raboy B., Shilo M. 1971 Endogenous dark respiration of the blue-green alga, Plectonema boryanum. J. Bact. 106: 45-50.

Pelroy R.A., Bassham J.A. (1973) Efficiency of energy conversion by aerobic glucose metabolism in Aphanocapsa 6714. J. Bact. 115: 937-942.

Reed W.M., Dugan P.R. (1979) Study of developmental stages of Methylosinus trichosporium with the aid of fluorescent-antibody staining techniques. Appl. Environ. Microbiol. 38: 1179-1183.

Robertson J.G., Batt R.D. (1973) Survival of Nocardia corallina and degradation of constituents during starvation. J. Gen. Microbiol. 78: 109-117.

Schäfer G. (1996) Bioenergetics of the archaebacterium Sulfolobus. Biochimica et Biophysica Acta 1277: 163-200.

Schleper C., Puehler G., Holz I., Gambacorta A., Janekovic D., Santarius U., Klenk H.-P., Zillig W. (1995) *Picrophilus* gen. nov., fam. nov.: a Novel Aerobic, Heterotrophic, Thermoacidophilic Genus and Family Comprising Archaea Capable of Growth around pH 0. J. Bact. 177: 7050-7059.

Schulz H.N., Jørgensen B.B. (2001) Big bacteria. Annu. Rev. Microbiol. 55: 105-137.

Sobek J.M., Charba J.F., Foust W.N. (1966) Endogenous metabolism of Azotobacter agilis. J. Bact. 92: 687-695.

Stal L.J., Moezelaar R. (1997) Fermentation in cyanobacteria. FEMS Microbiology Reviews 21: 179-211.

Stanier R.Y., Kunisawa R., Mandel M., Cohen-Bazire G. (1971) Purification and properties of unicellular blue-green algae (order Chroococcales). Bacteriological Reviews 35: 171-205.

Tepper B.S. (1968) Differences in the utilization of glycerol and glucose by Mycobacterium phlei. J. Bact. 95: 1713-1717.

Tesh M.J., Morse S.A., Miller R.D. (1983) Intermediary Metabolism in Legionella pneumophila: Utilization of Amino Acids and Other Compounds as Energy Sources. J. Bact. 154: 1104-1109.

Van de Vossenberg J.L.C.M., Driessen A.J.M., Zillig W., Konings W.N. (1998) Bioenergetics and cytoplasmic membrane stability of the extreme acidophilic thermophilic Archaeon Picrophilus oshimae. Extremophiles 2: 67-74.

Van der Oost J., Bulthuis B.A., Feitz S., Krab K., Kraayenhof R. (1989) Fermentation metabolism of the unicellular cyanobacterium Cyanothece PCC 7822. Arch. Microbiol. 152: 415-419.

Van Niel E.W.J., Gottschal J.C. (1998) Oxygen consumption by *Desulfovibrio* strains with and without polyglucose. Appl. Environ. Microbiol. 64: 1034-1039.

Vogler K.G. (1942) The presence of an endogenous respiration in the autotrophic bacteria. J. Gen. Physiol. 25: 617-622.

Watson S.P., Clements M.O., Foster S.J. (1998) Characterization of the starvation-survival response of Staphylococcus aureus. J. Bact. 180: 1750-1758.

Zikmanis P., Krúče R., Auziņa L. (1997) An elevation of the molar growth yield of Zymomonas mobilis during aerobic exponential growth. Arch. Microbiol. 167: 167-171.

Zubkov M.V. Fuchs B.M., Eilers H., Burkill P.H., Amann R. (1999) determination of total protein content of bacterial cells by SYPRO staining and flow cytometry. Appl. Environ. Microbiol. 65: 3251-3257.

III. MASS-SPECIFIC METABOLIC RATE R_{MIN} OF ORGANISMS IN VARIOUS ENERGY-SAVING REGIMES

Species	Body mass (g)	R_{MIN} (W kg^{-1})	Temp. (°C)	Comment on physiological or ecological state	Reference	Taxon
1. **Abra tenuis**	0.005	0.03	15	anoxia, 12 hours	Wang & Widdows 1993	bivalve
2. **Agelastica alni**	0.031	0.08	21.7	anoxia, 5 hours	Kölsch et al. 2002	insect
3. **Anguilla anguilla**	78	0.086	20	anoxia, 1.5 hour	van Ginneken et al. 2001	Fish
4. **Carassius auratus**	9.5	0.10	20	anoxia, 3 hours	van Waversveld et al. 1989	Fish
5. **Chrysemys picta**	952.5	0.00063	3	anoxic hibernation, 12 weeks	Herbert & Jackson 1985	turtle
6. **Halicryptus spinulosus**	0.25	0.0012	10	anoxia, 14 days	Oeschger et al. 1992	priapulid worm
7. **Locusta migratoria**	1.52	0.084	20.3	anoxia, 3 hours	Moratzky et al. 1993	Insect
8. **Lumbriculus variegatus**	0.014	0.076	20	anoxia, 17 hours	Gnaiger & Staudigl 1987	oligochaete worm
9. **Manduca sexta**	2.18	0.096	20.3	anoxia, 10 hours	Moratzky et al. 1993	insect
10. **Mytilus galloprovincialis**	5.5	0.035	20	anoxia, several days	de Zwaan et al. 1991	bivalve
11. **Rana temporaria**	30.6	0.033	20.8	anoxia, 2 hours	Moratzky et al. 1993	frog
12. **Ruditapes decussatus**	1.5	0.023	20	anoxia, 24 hours	Sobral & Widdows 1997	Bivalve
13. **Saduria entomon**	1.2*	0.25	4	anoxia, 40 hours	Normant et al. 1998	crustacean
14. **Scapharca inaequivalis**	5.8	0.009	20	anoxia, several days	de Zwaan et al. 1991	bivalve
15. **Sipunculus nudus**	40	0.006	15	anoxia, 24 hours	Hardewig et al. 1991	marine worm
16. **Tubifex tubifex**	0.1	0.16	15	anoxia, 20 hours	Famme & Knudsen 1984	annelid worm
17. **Acrobates pygmaeus**	14	0.39	7	hibernation	Geiser 1988	mammal
18. **Barbastella barbastellus**	7	0.22	4.5	hibernation	Geiser 1988	mammal
19. **Burramys parvus**	44.3	0.35	6	hibernation	Geiser 1988	mammal
20. **Cercartetus concinnus**	18.6	0.19	6.6	hibernation	Geiser 1988	mammal
21. **Cercartetus lepidus**	12.6	0.26	6.8	hibernation	Geiser 1988	mammal
22. **Cricetus cricetus**	330	0.18	7.5	hibernation	Geiser 1988	mammal
23. **Elephantulus myurus**	63	0.13	5	hibernation	Lovegrove et al. 2001	mammal
24. **Elephantulus rozeti**	45	0.43	5	hibernation	Lovegrove et al. 2001	mammal
25. **Eliomys quercinus**	70	0.19	7.5	hibernation	Geiser 1988	mammal
26. **Eptesicus fuscus**	10.4	0.56	10	hibernation	Geiser 1988	mammal
27. **Erinaceus europaeus**	700	0.089	5.2	hibernation	Geiser 1988	mammal
28. **Eutamias amoenus**	60	0.23	1.2	hibernation	Geiser 1988	mammal
29. **Glis glis**	200	0.14	7	hibernation	Geiser 1988	mammal
30. **Marmota flaviventris**	2500	0.12	7.5	hibernation	Geiser 1988	mammal
31. **Marmota monax**	4000	0.18	7	hibernation	Geiser 1988	mammal
32. **Mesocricetus auratus**	90	0.39	5	hibernation	Geiser 1988	mammal
33. **Myotis lucifugus**	5.2	0.12	2	hibernation	Geiser 1988	mammal
34. **Myotis myotis**	25	0.22	4.5	hibernation	Geiser 1988	mammal
35. **Myotis natteri**	8	0.17	9	hibernation /torpor	Geiser & Brigham 2000	mammal
36. **Nyctalus noctula**	23.8	0.17	5.3	hibernation	Geiser 1988	mammal
37. **Nyctophilus geoffroyi**	7	0.20	2.7	hibernation/torpor	Geiser & Brigham 2000	mammal
38. **Nyctophilus gouldi**	10	0.29	3	hibernation/torpor	Geiser & Brigham 2000	mammal
39. **Pipistrellus pipistrellus**	7.4	0.13	6	hibernation	Geiser 1988	mammal
40. **Scotorepens balstoni**	7	0.24	7	hibernation/torpor	Geiser & Brigham 2000	mammal
41. **Spermophilus lateralis**	200	0.25	5.4	hibernation	Geiser 1988	mammal
42. **Spermophilus mexicanus**	200	0.33	8	hibernation	Geiser 1988	mammal
43. **Spermophilus parryi**	650	0.35	7	hibernation	Geiser 1988	mammal
44. **Spermophilus richardsonii**	400	0.11	5	hibernation	Geiser 1988	mammal
45. **Spermophilus saturatus**	257	0.17	3.6	hibernation	Geiser 1988	mammal
46. **Tachyglossus aculeatus**	2800	0.37	5.7	hibernation	Geiser 1988	mammal
47. **Tadarida brasiliensis**	16.9	0.56	10	hibernation	Geiser 1988	mammal
48. **Tamias striatus**	87	0.33	7	hibernation	Geiser 1988	mammal
49. **Thamnopsis sirtalis**	63.3	0.020	4	hibernation	Costanzo 1985	snake
50. **Ursus americanus**	110,000	0.35	34	denning hibernation	Singer et al. 1993	mammal
51. **Ursus maritimus**	200,000	0.42		denning hibernation	Watts et al. 1987	mammal
52. **Zapus hudsonicus**	22.6	0.24	6	hibernation	Geiser 1988	mammal
53. **Zapus princeps**	33.6	0.23	5.5	hibernation	Geiser 1988	mammal
54. **Amblyomma americanum**	0.0032	0.44	25	sit-and-wait strategist	Lighton & Fielden 1995	tick
55. **Amblyomma maculatum**	0.0045	0.35	25	sit-and-wait strategist	Lighton & Fielden 1995	tick
56. **Amblyomma cajenense**	0.0075	0.26	25	sit-and-wait strategist	Lighton & Fielden 1995	tick

57.	**Dermacentor andersoni**	0.0107	0.33	25	sit-and-wait strategist	Lighton & Fielden 1995	tick
58.	**Dermacentor variabilis**	0.0056	0.29	25	sit-and-wait strategist	Lighton & Fielden 1995	tick
59.	**Ornithodoros moubata**	0.0132	0.20	25	sit-and-wait strategist	Lighton & Fielden 1995	tick
60.	**Amblyomma marmoreum**	0.0702	0.14	25	sit-and-wait strategist	Lighton & Fielden 1995	tick
61.	**Amblyomma herbaeum**	0.0313	0.10	25	sit-and-wait strategist	Lighton & Fielden 1995	tick
62.	**Hadrurus arizonensis**	9	0.18	25	sit-and-wait strategist	Lighton et al. 2001	scorpion
63.	**Parurorctonus luteolus**	0.16	0.31	25	sit-and-wait strategist	Lighton et al. 2001	scorpion
64.	**Parurorctonus mesaensis**	2	0.25	25	sit-and-wait strategist	Lighton et al. 2001	scorpion
65.	**Parurorctonus marksi**	0.57	0.23	25	sit-and-wait strategist	Lighton et al. 2001	scorpion
66.	**Parurorctonus becki**	0.66	0.35	25	sit-and-wait strategist	Lighton et al. 2001	scorpion
67.	**Opisthophalmus flavescens**	5.3	0.25	25	sit-and-wait strategist	Lighton et al. 2001	Scorpion
68.	**Parabuthus villosus**	6.0	0.28	25	sit-and-wait strategist	Lighton et al. 2001	Scorpion
69.	**Pandinus imperator**	15.0	0.14	25	sit-and-wait strategist	Lighton et al. 2001	Scorpion
70.	**Urodactus armatus**	0.50	0.24	25	sit-and-wait strategist	Lighton et al. 2001	Scorpion
71.	**Caulophrynid sp.**	28	0.019	5	sit-and-wait strategist	Cowles & Childress 1995	Fish
72.	**Melanocetus johnsoni**	100	0.032	5	sit-and-wait strategist	Cowles & Childress 1995	Fish
73.	**Oneirodes sp.**	53	0.027	5	sit-and-wait strategist	Cowles & Childress 1995	Fish

* body mass estimated from body length given by Normant et al. 1998 using the length-weight relationship established for this species by Aljetlawi et al. 2004

IV. RECORD MASS-SPECIFIC METABOLIC RATES R_{MAX} OF VARIOUS ORGANISMS DURING PEAKS OF ACTIVITY

Species	Body mass (g)	R_{MAX} (W kg^{-1})	Comment on R_{MAX} estimate	Reference	Taxon
1. **Meleagris gallopavo**	4780	1090*	Per unit pectoralis muscle mass during take-off flights	Askew et al. 2001	Bird
2. **Anas platyrhynchos**	1000	870*	Per unit pectoralis muscle mass during ascending flight	Williamson et al. 2001	Bird
3. **Parabuteo unicinctus**	920	1600*	Per unit pectoralis muscle mass during climbing flights shortly after take-off	Askew et al. 2001	Bird
4. **Phasanius colchicus**	783	985*	Per unit pectoralis muscle mass during take-off flights	Askew et al. 2001	Bird
5. **Alectoris chukar**	491.5	1433*	Per unit pectoralis muscle mass during take-off flights	Askew et al. 2001	Bird
6. **Columbia livia**	307	1031*	Per unit pectoralis muscle mass during take-off flights	Askew et al. 2001	Bird
7. **Galago senegalensis**	250	8900*	Per unit muscle mass during jumping take-off	Gorshkov 1983; Alexander 1968	Mammal
8. **Colinus virginianus**	199.5	1663*	Per unit pectoralis muscle mass during take-off flights	Askew et al. 2001	Bird
9. **Coturnis chinensis**	43.6	1950*	Per unit pectoralis muscle mass during take-off flights	Askew et al. 2001	Bird
10. **Osteopilus septendrionalis**	24.2	667*	Per unit muscle mass during jumping take-off	Marsh & John-Alder 1994	Frog
11. **Lampornis clemenciae**	8.4	1410*	Per unit muscle mass during flight under maximum loading	Chai & Millard 1997	Bird
12. **Eugenes fulgens**	7.4	1640*	Per unit muscle mass during flight under maximum loading	Chai & Millard 1997	Bird
13. **Selasphorus rufus**	4	700	Per unit flight muscle mass during hovering flight	Suarez et al. 1991	Bird
14. **Selasphorus rufus**	3.3	1095*	Per unit muscle mass during flight under maximum loading	Chai & Millard 1997	Bird
15. **Archilochus alexandri**	3.0	1150*	Per unit muscle mass during flight under maximum loading	Chai & Millard 1997	Bird
16. **Schistocerca gregaria**	2.5	5300*	Per unit muscle mass during jumping take-off	Gorshkov1983; Katz & Gosline 1993	Insect
17. **Schistocerca americana**	2.2	660	Metabolic rate of synchronous flight muscle in vitro	Josephson et al. 2001	Insect
18. **Cotinus mutabilis**	1.2	930	Metabolic rate of asynchronous flight muscle in vitro	Josephson et al. 2001	Insect
19. **Pseudacris crucifer**	0.85	920*	Per unit muscle mass during jumping take-off	Marsh & John-Alder 1994	Frog
20. **Acris gryllus**	0.65	1100*	Per unit muscle mass during jumping take-off	Marsh & John-Alder 1994	Frog
21. **Erythemis simplicicollis**	0.195	1152	Per unit flight muscle mass during hovering flight	Harrison & Lighton 1998	Insect
22. **Euglossa imperialis**	0.161	3340	Per unit flight muscle mass during hovering flight assuming flight muscle constitutes 27% of body mass as in honeybees (Suarez et al. 1996)	Borrell & Medeiros 2004	Insect
23. **Galleria mellonella**	0.084	870	Per unit thorax mass during flight	Schmolz et al. 1999	Insect
24. **Apis mellifera**	0.078	1800	Per unit flight muscle mass during hovering flight	Suarez et al. 1996	Insect
25. **Spilopsyllus cuniculus**	0.00045	6500*	Per unit muscle mass during jumping take-off	Gorshkov 1983; Alexander 1968	Insect
26. **Escherichia coli**	1.2×10^{-12}	5800	Metabolic rate during fastest recorded growth, doubling time $\tau = 20$ min	At growth efficiency of 0.5 and caloric value of biomass of around $K \approx 7$ kJ g^{-1} $R_{\mathrm{MAX}} = K/\tau \sim 5.8\times10^3$ W kg^{-1}	Bacterium

* Calculated from mechanical power output

Notes: mechanical power outputs P_{MAX} were converted to metabolic rates $R_{\mathrm{MAX}} = P/\eta$ using efficiency of $\eta = 0.2$ for bird flight (Rayner, 1999) and a conservative estimate of $\eta = 0.5$ for jumps of various animals (Gorshkov, 1983).

MINIMUM AND MAXIMUM METABOLIC RATE REFERENCES

Aljetlawi A.A., Sparrevik E., Leonardsson K. (2004) Prey-predator size-dependent functional response: derivation and rescaling to the real world. J Animal Ecology 73: 239-252.

Askew G.N., Marsh R.L., Ellington C. P. (2001) The mechanical power output of the flight muscles of blue-breasted quail (Coturnix chinensis) during take-off. J. Exp. Biol. 204: 3601-3619.

Borrell B.J., Medeiros M.J. (2004) Thermal stability and muscle efficiency in hovering orchid bees (Apidae: Euglossini). J. exp. Biol. 207: 2925-2933.

Chai P., Millard D. (1997) Flight and size constraints: hovering performance of large hummingbirds under maximal loading. J. Exp. Biol. 200: 2757-2763.

Costanzo J.P. (1985) The bioenergetics of hibernation in the eastern garter snake Thamnopsis sirtalis sirtalis. Physiol. Zool. 58: 682-692.

Cowles D.L., Childress J.J. (1995) Aerobic metabolism of the anglerfish Melanocetus johnsoni, a deep-pelagic marine sit-and-wait predator. Deep-Sea Research I 42: 1631-1638.

De Zwaan A., Cortesi P., van der Thillart G., Roos J., Storey K.B. (1991) Differential sensitivities to hypoxia by two anoxia-tolerant marine molluscs: A biochemical analysis. Mar. Biol. 111: 343-351.

Famme P., Knudsen J. 1984 Total heat balance study of anaerobiosis in Tubifex tubifex (Müller). J. Comp. Physiol. B 154: 587-591.

Geiser F. (1988) Reduction of metabolism during hibernation and daily torpor in mammals and birds: Temperature effect or physiological inhibition? J. Comp. Physiol. B 158: 25-37.

Geiser R., Brigham R.F. (2000) Torpor, thermal biology, and energetics in Australian long-eared bats (Nyctophilus). J. Comp. Physiol. B 170: 153-162.

Gnaiger E., Staudigl I. (1987) Aerobic metabolism and physiological responses of aquatic oligochaetes to environmental anoxia: heat dissipation, oxygen consumption, feeding, and defecation. Physiol. Zool. 60: 659-677.

Gorshkov V.G. (1983) Power and rate of locomotion in animals of different sizes. J. of General Biology 44: 661-678 (in Russian).

Hardewig I., Addink A.D.F., Grieshaber M.K., Pörtner H.O., van den Thillart G. 1991 Metabolic rates at different oxygen levels determined by direct and indirect calorimetry in the oxyconformer Sipunculus nudus. J. exp. Biol. 157: 143-160.

Harrison J.F., Lighton J.R.B. (1998) Oxygen-sensitive flight metabolism in the dragonfly Erythemis simplicicollis J. Exp. Biol. 201:1739-1744.

Herbert C.V., Jackson D.C. (1985) Temperature effects on the responses to prolonged submergence in the turtle Chrysemis picta bellii. II. Metabolic rate, blood acid-base and ionic changes, and cardiovascular function in aerated and anoxic water. Physiol. Zool. 58: 670-681.

Josephson R.K., Malamud J.G., Stokes D.R. (2001) The efficiency of an asynchronous flight muscle from a beetle. J. exp. Biol. 204: 4125-4139.

Kölsch G., Jakobi K., Wegener G., Braune H.J. (2002) Energy metabolism and metabolic rate of the alder leaf beetle *Agelastica alni* (L.) (Coleoptera, Chrysomelidae) under aerobic and anaerobic conditions: a microcalorimetric study. Journal of Insect Physiology 48: 143-151.

Lighton J.R.B., Brownell P.H., Joos B., Turner R.J. (2001) Low metabolic rate in scorpions: implications for population biomass and cannibalism. J. exp. Biol. 204: 607-613.

Lighton J.R.B., Fielden L.J. (1995) Mass scaling of standard metabolism in ticks: A valid case of low metabolic rates in sit-and-wait strategists. Physiol. Zool. 68: 43-62.

Lovegrove B.G., Raman J., Perrin M.R. (2001) Heterothermy in elephant shrews, Elephantulus spp. (Macroscelidea): daily torpor or hibernation? J Comp Physiol B 171: 1-10.

Moratzky T., Burkhardt G., Weyel W., Wegener G. (1993) Metabolic rate and tolerance of anoxia: microcalorimetric and biochemical studies on vertebrates and insects. Thermochimica Acta 229: 193-204.

Normant M., Graf G., Szaniawska A. 1998 Heat production in Saduria entomon (Isopoda) from the Gulf of Gdańsk during an experimental exposure to anoxic conditions. Mar. Biol. 131: 269-273.

Oeschger R., Peper H., Gerhard G., Theede H. (1992) Metabolic responses of Halicryptus spinulosus (Priapulida) to reduced oxygen levels and anoxia. J. exp. Mar. Biol. Ecol. 162: 229-241.

Rayner J.M. (1999) Estimating power curves of flying vertebrates. J. exp. Biol. 202: 3449-3461.

Schmolz E., Geisenheyner S., Schricker B., Lamprecht I. (1999) Heat dissipation of flying wax moths (Galleria mellonilla) measured by means of direct calorimetry. J. Thermal Analysis and Calorimetry 56: 1185-1190.

Singer D., Bach F., Bretschneider H. J., Kuhn H.-J. (2002) Metabolic size allometry and the limits to beneficial metabolic reduction: Hypothesis of a uniform specific minimal metabolic rate. In *Surviving Hypoxia. Mechanisms of Control and Adaptation* (eds. P. W. Hochachka, P. L. Lutz, T. Sick, M. Rosenthal, G. van den Thillart), pp. 447-458. CRC, Boca Raton.

Sobral P., Widdows J. (1997) Influence of hypoxia and anoxia on the physiological responses of the clam Ruditapes decussatusfrom southern Portugal. Mar. Biol. 127: 455-461.

Suarez R.K., Lighton J.R.B., Brown G.S., Mathieu-Costello O. (1991) Mitochondrial respiration in hummingbird flight muscles. Proc. Natl. Acad. Sci. USA 88: 4870-4873.

Van Ginneken V.J.T., Onderwater M., Olivar O.L., van den Thillart G.E.E.J.M. (2001) Metabolic depression and investigation of glucose/ethanol conversion in the European eel (Anguilla anguilla Linnaeus 1758) during anaerobiosis. Thermochimica Acta 373: 23-30.

Van Waversveld, J., Addink, A.D.F., van den Thillart G. (1989) The anaerobic energy metabolism of goldfish determined by simultaneous direct and indirect calorimetry during anoxia and hypoxia. Journal of Comparative Physiology B 159: 263-268.

Wang W.X., Widdows J. (1993) Calorimetric studies on the energy metabolism of an infaunal bivalve, *Abra tenui*s, under normoxia, hypoxia and anoxia. Mar. Biol. 116: 73-79.

Watts P.D., Øristland N.A., Hurst R.J. (1987) Standard metabolic rate of polar bears under simulated denning conditions. Physiol. Zool. 60: 687-691.

Williamson M.R., Dial K.P., Biewener A.A. (2001) Pectoralis muscle performance during ascending and slow level flight in mallards *(Anas platyrhyncho*s). J. exp. Biol. 204: 495-507.