Table 2
The rate of oxygen consumption by various cells in culture.

Cell line or tissue	Cell type	OCR (amol cell^{-1} s^{-1})	OCR, original units (as reported)	Comments, methods (cell growth conditions)	Ref.
HL-60	Human promyelocytic leukemia (SC)	7.5	0.40–0.50 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
HL-60	Human promyelocytic leukemia (SC)	11.5	11.46 ± 0.40[f] pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Oxygen monitor with Clark electrode (G1)[a]	[72]
HL-60ρ^0	Leukemia cells with knockout mitochondria (SC)	4.7	4.74 ± 0.16[f] pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Oxygen monitor with Clark electrode (G1)[a]	[72]
U937	Human histocytic leukemia (SC)	5.0	0.30 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
U937	Human histocytic leukemia (SC)	11.0	11.00 ± 0.83[f] pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Oxygen monitor with Clark electrode (G1)[a]	[72]
Jurkat	Human acute lymphoblastic leukemia (SC)	12	11.89 ± 0.50 pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Oxygen monitor with Clark electrode (G1)[a]	[72]
MDCK	Dog kidney (AC)	20.8	1.25 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
WEHI	Murine myelomonocytic leukemia cell line (SC)	7	0.4 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
WEHI213	Murine myelomonocytic leukemia cell line	9.4	9.44 ± 0.48[f] pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Clark electrode	[72]
MCL5	Lymphoblastoid (SC)	3.5	0.21 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
CH2	Lymphoblastoid (SC)	5.8	0.35 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
Ehrlich ascites tumor cells	Mouse carcinoma (SC)	27	27 amol cell^{-1} s^{-1}	Warburg apparatus	[43,45]
ALMA-16	Hybridoma (SC)	13	0.8 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
Hybridoma	Murine hybridoma (SC)	61	0.22 pmol cell^{-1} h^{-1}	Respirometer	[73]
C6	Rat glial tumor (on Cytodex beads)	12	0.7 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
C6	Rat glial tumor (SC)	12	0.7 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
WI-38	Human embryonic lung fibroblasts (on Cytodex beads)	2.5	0.15 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
WI-38	Human embryonic lung fibroblasts (on Cytodex beads)	1.7	0.10 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
A20	Mature murine B cell lymphoma (SC)	10	9.67 ± 0.50[f] pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Clark electrode (G1)[a]	[72]
EL4	Murine T cell lymphomas (SC)	7.7	7.69 ± 0.40[f] pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Clark electrode (G1)[a]	[72]
P815	Murine mastocytoma cell line (SC)	5.2	5.15 ± 0.37[f] pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Clark electrode (G1)[a]	[72]
BW1100	Murine mastocytoma cell line (SC)	8.1	8.11 ± 0.35[f] pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Clark electrode (G1)[a]	[72]
D2SC/1	Murine dendritic cell line (SC)	12.6	12.56 ± 0.83[f] pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Clark electrode (G1)[a]	[72]
MEF	Mouse embryonic fibroblasts	7	0.4 nmol min^{-1} (10^6 cells)$^{-1}$	Seahorse XF24 analyzer	[74]
MEF	Mouse embryonic fibroblasts	60	3.6 fmol min^{-1} cell^{-1}	Seahorse XF24 analyzer	[75]
Myocytes	Neonatal cardiomyocytes	100	300 pmol min^{-1} (50,000 cells)$^{-1}$	Seahorse XF24 analyzer	[76]
NRVM primary cell culture	Neonatal rat ventricular myocyte (AC)	40	180 pmol min^{-1} (75,000 cells)$^{-1}$	Seahorse XF24 analyzer	[52]
TIME cells	Tert-immortalized microvascular endothelial cells	28	50 pmol min^{-1} (30,000 cells)$^{-1}$	Seahorse XF24 analyzer	[77]
Podocytes	Primary mouse podocytes (a kidney epithelial cell)	83	100 pmol min^{-1} (20,000 cells)$^{-1}$	Seahorse XF24 analyzer	[78]
MC3T3 (on polysaccharide scaffolds)	Mouse myoblast (AC)	13	0.80 fmol min^{-1} cell^{-1}	Fick's law (G1)[a]	[71]
C2C12	Mouse myoblast (on HA-FN scaffold)	3.7	0.22 fmol min^{-1} cell^{-1}	Fick's law	[71]
Rat fibroblasts	Rat 1a spontaneously immortalized rat embryo fibroblasts	190	225 pmol min^{-1} (20,000 cells)$^{-1}$	Seahorse XF24 analyzer	[79]

(*continued on next page*)

Table 2 (*continued*)

Cell line or tissue	Cell type	OCR (amol $cell^{-1}$ s^{-1})	OCR, original units (as reported)	Comments, methods (cell growth conditions)	Ref.
Rat hepatocytes (fresh)	Primary, rat (SC)	200	12 fmol min^{-1} $cell^{-1}$	Fick's law	[71]
Rat hepatocytes (fresh)	Primary, rat (on scaffold)	200	12 fmol min^{-1} $cell^{-1}$	Fick's law	[71]
Rat hepatocytes	Rat hepatocytes	350	0.35 nmol s^{-1} (10^6 cells)$^{-1}$	Clark electrode with real-time numerical averaging	[49]
Rat hepatocytes	Rat hepatocytes	430	0.43 nmol s^{-1} (10^6 cells)$^{-1}$	Clark electrode	[51]
Porcine hepatocytes	Day 4 after seeding Day 15 after seeding	900 300	0.9 nmol s^{-1} (10^6 cells)$^{-1}$ 0.3 nmol s^{-1} (10^6 cells)$^{-1}$	Clark electrode with real-time numerical averaging	[49]
Synaptosomes	Rat brain, no treatment	(65 amol s^{-1} ng-protein^{-1})	3.92 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode	[80]
Sf9 insect cells	*Spodoptera frugiperda*, ovarian	33	2.0 fmol min^{-1} $cell^{-1}$	Fick's law (G2)[b]	[71]
Hi-5 insect cells	*Trichoplusia ni*, ovarian	105	6.3 fmol min^{-1} $cell^{-1}$	Fick's law (G2)[b]	[71]
FS-4	Human diploid foreskin cells (SC)	14	0.05 mmol h^{-1} (10^9 cells)$^{-1}$	Based on oxygen demand by cells and mass transfer coefficient (G3)[c]	[48]
HLM	Liver (AC)	102	0.37 mmol h^{-1} (10^9 cells)$^{-1}$	Use modified Cartesian diver	[48,81]
LIR	Liver (AC)	83	0.30 mmol h^{-1} (10^9 cells)$^{-1}$	Use modified Cartesian diver	[48,81]
Skin fibroblast	Human (AC)	18	0.064 mmol h^{-1} (10^9 cells)$^{-1}$	Use modified Cartesian diver	[48,81]
143B	Human osteosarcoma (AC)	16.3	16.32 ± 0.53^{f} pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Oxygen monitor with Clark electrode	[72]
143Bρ0	Human osteosarcoma with knockout mitochondria (AC)	5.6	5.62 ± 0.40^{f} pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Oxygen monitor with Clark electrode	[72]
Detroit 6	From bone marrow of lung cancer patients (AC)	120	0.43 mmol h^{-1} (10^9 cells)$^{-1}$		[82]
MCN	Leukemia (AC)	61	0.22 mmol h^{-1} (10^9 cells)$^{-1}$	Based on oxygen demand by cells and mass transfer coefficient	[82]
Conjunctiva	Human eye cells (AC)	78	0.28 mmol h^{-1} (10^9 cells)$^{-1}$	Based on oxygen demand by cells and mass transfer coefficient	[82]
Lung To	Human embryonic lung cells (AC)	67	0.24 mmol h^{-1} (10^9 cells)$^{-1}$	Based on oxygen demand by cells and mass transfer coefficient	[82]
Intestine 407	Human (AC)	111	0.40 mmol h^{-1} (10^9 cells)$^{-1}$	Based on oxygen demand by cells and mass transfer coefficient	[82]
MAF-E	Adult Fallopian tube (AC)	106	0.38 mmol h^{-1} (10^9 cells)$^{-1}$	Based on oxygen demand by cells and mass transfer coefficient	[82]
Red blood cells	Human (adult)	4×10^{-5}	Contribution estimated from the rate of autoxidation of oxyhemoglobin to form superoxide; H_2O_2 is generated at a rate of 3.9 ± 0.6 nmol·h^{-1}·gHb^{-1}	This corresponds to about 50 superoxide radicals being produced each second in an RBC.	[83]
Red blood cells	Rabbit	0.02	$(1.5\pm0.2)\times10^{-15}$ L RBC^{-1} h^{-1}	Gilson differential recording respirometer, 38 °C	[84]
Lymphoblastoid (Namalioa)	Human (AC)	15	0.053 mmol h^{-1} (10^9 cells)$^{-1}$	Based on oxygen demand by cells and mass transfer coefficient	[85]
J774A.1	Murine macrophages (AC)	31	1.87 nmol min^{-1} (10^6 cells)$^{-1}$	EPR oximetry	[86]
J774A.1	Murine macrophages (AC)	6.2	6.18 ± 0.33^{f} pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Oxygen monitor with Clark electrode	[72]
CHO	Chinese hamster ovary cells (SC)	74	4.43 nmol min^{-1} (10^6 cells)$^{-1}$	EPR oximetry (G4)[d]	[86]
CHO	Chinese hamster ovary cells (SC)	88	3.2×10^{-13} mol $cell^{-1}$ h^{-1} (5.3 nmol min^{-1} (10^6 cells)$^{-1}$)	Microtiter plate with oxygen sensor	[87]
CHO	Chinese hamster ovary cells (SC)	86	0.31 pmol $cell^{-1}$ h^{-1}	Using a respirometer	[73]
CHO	Chinese hamster ovary cells (SC)	8.0	0.50 fmol min^{-1} $cell^{-1}$	Fick's law (G1)[a]	[71]
CHO	Chinese hamster ovary cells (SC)	63	3.8×10^7 molecules of O_2 s^{-1} $cell^{-1}$	EPR oximetry	[47]
CCD	Kidney cortex collecting duct cells	25	1.48 nmol min^{-1} (10^6 cells)$^{-1}$	EPR oximetry	[86]
AG08472	Vascular endothelial cells of the pig thoracic aorta (AC)	17	1 ± 0.15 nmol min^{-1} (10^6 cells)$^{-1}$ (when measured at 22 °C), 0.64 (at 4 °C)	Optical method using oxygen quenchers	[88]
AG08473	SMC of cells of the pig thoracic aorta (AC)	44	2.64 ± 0.14 nmol min^{-1} (10^6 cells)$^{-1}$	Optical method using oxygen quenchers	[88]

Table 2 (*continued*)

Cell line or tissue	Cell type	OCR (amol $cell^{-1}$ s^{-1})	OCR, original units (as reported)	Comments, methods (cell growth conditions)	Ref.
HeLa cells	Human cervical carcinoma cells (AC)	(200 amol s^{-1} ng-protein^{-1})	11.7 ± 1.3 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[89]
HeLa cells	Human cervical carcinoma (AC)	12.5	12.50 ± 0.5^{f} pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Clark electrode (G1)[a]	[72]
A549	Human adenocarcinoma alveolar epithelial	27	1.6 nmol min^{-1} (10^6 cells)$^{-1}$	Seahorse XF24 analyzer	[90]
NIH-H460	Human large cell lung cancer, epithelial	30	1.8 nmol min^{-1} (10^6 cells)$^{-1}$	Seahorse XF24 analyzer	[90]
L-6 myoblasts	Human muscle (AC)	(200 amol s^{-1} ng-protein^{-1})	12 ± 1.3 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[89]
Beating cardiac myocytes	New born rats	(680 amol s^{-1} ng-protein^{-1})	40.5 ± 1.3 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode with Lucite attachment (G1)[a]	[89]
Beating cardiac myocytes	Old rats	(1200 amol s^{-1} ng-protein^{-1})	69.5 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode with Lucite attachment (G1)[a]	[91]
Heart nonmuscle	Newborn rat	(200 amol s^{-1} ng-protein^{-1})	11.8 ± 0.7 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[89]
Bovine endothelial	From aortae of cattle (AC)	(67 amol s^{-1} ng-protein^{-1})	4.0 ± 0.7 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[92]
Renal mesangial	Rat cells (AC)	(150 amol s^{-1} ng-protein^{-1})	9.0 ± 0.3 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[92]
LLC-PK	Renal epithelial cells from pig kidney (AC)	(320 amol s^{-1} ng-protein^{-1})	19.0 ± 0.9 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[92]
LLC-MK	Rhesus monkey kidney (AC)	(470 amol s^{-1} ng-protein^{-1})	28.2 ± 0.7 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[92]
HepG2	Human hepatoma cells (AC)	(110 amol s^{-1} ng-protein^{-1})	6.7 ± 1.2 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[92]
Hep3B	Human hepatoma cells (AC)	(160 amol s^{-1} ng-protein^{-1})	9.6 ± 1.4 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[92]
AFP-27	Murine hybridoma cell line	6.0	2.15×10^{-8} μmol $cell^{-1}$ h^{-1}	Tissue oxygen probe system, 37 °C (G1)[a]	[93]
Human mesenchymal preadipocytes	Undifferentiated (AC)	25	0.591 ± 0.302 nmol min^{-1} (0.4×10^6 cells)$^{-1}$	Clark electrode (G1)[a]	[94]
Human mesenchymal preadipocytes	Differentiated (AC)	120	2.865 ± 0.219 nmol min^{-1} (0.4×10^6 cells)$^{-1}$	Clark electrode (G1)[a]	[94]
RAW264.7	Transformed mouse macrophages (AC)	8.9	8.89 ± 0.23^{f} pmol O_2 s^{-1} (10^6 cells)$^{-1}$	Clark electrode (G1)[a]	[72]
BHK	Baby hamster kidney	83	0.3 pmol $cell^{-1}$ h^{-1}	Respirometer (G5)[e]	[73]
TM4	Murine testicular cells	(10 amol s^{-1} ng-protein^{-1})	37 nmol h^{-1} (mg protein)$^{-1}$	Polarography at 34 °C	[95]
MCF-7	Breast cancer cell line (AC)	(1300 amol s^{-1} ng-protein^{-1})	77.5 nmol min^{-1} (mg protein)$^{-1}$	Clark electrode (G1)[a]	[96]

(*continued on next page*)

Table 2 (*continued*)

Cell line or tissue	Cell type	OCR (amol cell^{-1} s^{-1})	OCR, original units (as reported)	Comments, methods (cell growth conditions)	Ref.
Molt-4 cells	Human leukemia cell line (AC)	12	0.7 nmol min^{-1} (10^6 cells)$^{-1}$	EPR with ^{15}N-PDT, 37 °C (G1)[a]	[97]
Molt-4 ρ^0 cells	Human leukemia cell line with knockout mitochondria (AC)	1.3	0.08 nmol min^{-1} (10^6 cells)$^{-1}$	EPR with ^{15}N-PDT, 37 °C	[97]
LNCAP	Prostate cancer (AC)	63	3.75 ± 1.12 nmol min^{-1} (10^6 cells)$^{-1}$	EPR with ^{15}N-PDT, 37 °C	[97]
AGS	Human gastric cancer cell line (AC)	27	1.6 nmol min^{-1} (10^6 cells)$^{-1}$	Clark electrode, 25 °C	[98]
BM MNCs	Human bone marrow mononuclear cells Cultured for 14 days	10.6 6.9	0.038 (adherent) μmol h^{-1} (10^6 cells)$^{-1}$ 0.025 (nonadherent) μmol h^{-1} (10^6 cells)$^{-1}$	Hermetically sealed tissue culture well inserts equipped with oxygen electrodes, 37 °C	[99]
Escherichia coli	Bacteria	0.13	0.008 fmol min^{-1} cell^{-1}	Fick's law (G3)[c]	[71]
Salmonella typhimurium	Bacteria	0.017	0.001 fmol min^{-1} cell^{-1}	Fick's law (G3)[c]	[71]
Saccharomyces cerevisiae	Brewer's yeast (Edme)	2	0.12 fmol min^{-1} cell^{-1}	Fick's law (G2)[b]	[71]
Candida albicans	Yeast (fungus)	25 (per cfu)	1.5 fmol min^{-1} cfu^{-1}	Fick's law (G2)[b]	[71]
Embryonic stem cells	Murine (AC)	40	4×10^{-17} mol s^{-1} cell^{-1}	Using oxygen probe (Phoenix Electrode Co., Houston, TX, USA)	[100]
Neural stem cells	Murine (AC)	31	3.06×10^{-17} mol s^{-1} cell^{-1}	Using oxygen probe (Phoenix Electrode Co., Houston, TX, USA)	[101]
Human, adult neutrophils	Preincubated with chemotactic factor (FMLP) and activated with OPZ (opsonized zymosan)	86	5.16 nmol min^{-1} (10^6 neutrophils)$^{-1}$	Clark electrode, 37 °C	[102]
Human neutrophils	Polymorphonuclear neutrophils (PMN)	15	4.38 nmol min^{-1} (5×10^7 neutrophils)$^{-1}$	Clark electrode, 37 °C	[103]
Human neutrophils	PMN activated with LPS	16	4.87 nmol min^{-1} (5×10^7 neutrophils)$^{-1}$	Clark electrode, 37 °C	[103]
Human neutrophils	PMN when phagocytizing *E. coli*	16	48.6 nmol min^{-1} (5×10^7 neutrophils)$^{-1}$	Clark electrode, 37 °C	[103]
Human neutrophils	PMN when phagocytizing *Staphylococcus aureus*	34	102 nmol min^{-1} (5×10^7 neutrophils)$^{-1}$	Clark electrode, 37 °C	[103]
Human neutrophils	PMN when phagocytizing zymosan	25	73.9 nmol min^{-1} (5×10^7 neutrophils)$^{-1}$	Clark electrode, 37 °C	[103]
Rat neutrophils	Untreated	8.3	299.3 nmol h^{-1} (10^7 cells)$^{-1}$	Clark electrode, 37 °C	[104]
Rat neutrophils	Treated with glucose (5 mM)	9.1	328.2 nmol h^{-1} (10^7 cells)$^{-1}$	Clark electrode, 37 °C	[104]

AC, adherent cells; cfu, colony-forming units; EPR, electron paramagnetic resonance; OCR, rate of oxygen consumption; SC, suspension cells; ^{15}N-PDT, 4-oxo-2, 2, 6, 6-tetramethylpiperidine-d^{16}-1-^{15}N-oxyl.

[a] G1, cells grown at 37 °C, with 5% CO_2, 95% humidity.

[b] G2, cells grown at 27 °C, in a humidity chamber.

[c] G3, cells grown at 37 °C.

[d] G4, cells grown in spinner flasks, 37 °C, 12% CO_2, 88% humidity.

[e] G5, cells grown at 36.5 °C.

[f] Contributions from cell surface, basal, and mitochondrial O_2 consumption are given in Table 4.