

SBML Model Report

Model name: “Aubert2002 - Coupling between Brain electrical activity, Metabolism and Hemodynamics”



May 6, 2016

1 General Overview

This is a document in SBML Level 2 Version 4 format. This model was created by the following two authors: Felix Winter¹ and Audald Lloret i Villas² at April ninth 2014 at 4:25 p. m. and last time modified at May twelveth 2015 at 11:18 a. m. Table 1 provides an overview of the quantities of all components of this model.

Table 1: Number of components in this model, which are described in the following sections.

Element	Quantity	Element	Quantity
compartment types	0	compartments	4
species types	0	species	20
events	3	constraints	0
reactions	18	function definitions	13
global parameters	69	unit definitions	2
rules	21	initial assignments	7

Model Notes

Aubert2002 - Coupling between Brainelectrical activity, Metabolism and HemodynamicsFelix Winter encoded this model in SBMLas part of his work at [ASD GmbH](#)

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This model is described in the article: [A model of the coupling between brain electrical activity, metabolism, and hemodynamics: application to the interpretation of functional neuroimaging](#). Aubert A, Costalat R. Neuroimage 2002 Nov; 17(3): 1162-1181

Abstract:

In order to improve the interpretation of functional neuroimaging data, we implemented a mathematical model of the coupling between membrane ionic currents, energy metabolism (i.e., ATP regeneration via phosphocreatine buffer effect, glycolysis, and mitochondrial respiration), blood-brain barrier exchanges, and hemodynamics. Various hypotheses were tested for the variation of the cerebral metabolic rate of oxygen (CMRO(2)): (H1) the CMRO(2) remains at its baseline level; (H2) the CMRO(2) is enhanced as soon as the cerebral blood flow (CBF) increases; (H3) the CMRO(2) increase depends on intracellular oxygen and pyruvate concentrations, and intracellular ATP/ADP ratio; (H4) in addition to hypothesis H3, the CMRO(2) progressively increases, due to the action of a second messenger. A good agreement with experimental data from magnetic resonance imaging and spectroscopy (MRI and MRS) was obtained when we simulated sustained and repetitive activation protocols using hypotheses (H3) or (H4), rather than hypotheses (H1) or (H2). Furthermore, by studying the effect of the variation of some physiologically important parameters on the time course of the modeled blood-oxygenation-level-dependent (BOLD) signal, we were able to formulate hypotheses about the physiological or biochemical significance of functional magnetic resonance data, especially the poststimulus undershoot and the baseline drift.

This model is hosted on [BioModels Database](#) and identified by: [BIOMD0000000570](#).

To cite BioModels Database, please use: [BioModels Database: An enhanced, curated and annotated resource for published quantitative kinetic models](#).

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2 Unit Definitions

This is an overview of five unit definitions of which three are predefined by SBML and not mentioned in the model.

2.1 Unit volume

Name volume

Definition ml

2.2 Unit substance

Name substance

Definition mmol

2.3 Unit area

Notes Square metre is the predefined SBML unit for area since SBML Level 2 Version 1.

Definition m^2

2.4 Unit length

Notes Metre is the predefined SBML unit for length since SBML Level 2 Version 1.

Definition m

2.5 Unit time

Notes Second is the predefined SBML unit for time.

Definition s

3 Compartments

This model contains four compartments.

Table 2: Properties of all compartments.

Id	Name	SBO	Spatial Dimensions	Size	Unit	Constant	Outside
compartment_1	Tissue		3	1	litre	<input checked="" type="checkbox"/>	
compartment_2	Arteries		3	1	litre	<input checked="" type="checkbox"/>	
compartment_3	Capillaries		3	1	litre	<input checked="" type="checkbox"/>	
compartment_4	Venous balloon		3	0.0237	ml	<input type="checkbox"/>	

3.1 Compartment `compartment_1`

This is a three dimensional compartment with a constant size of one ml.

Name Tissue

3.2 Compartment `compartment_2`

This is a three dimensional compartment with a constant size of one ml.

Name Arteries

3.3 Compartment `compartment_3`

This is a three dimensional compartment with a constant size of one ml.

Name Capillaries

3.4 Compartment compartment_4

This is a three dimensional compartment with a not constant size of 0.0237 ml.

Name Venous balloon

4 Species

This model contains 20 species. The boundary condition of seven of these species is set to true so that these species' amount cannot be changed by any reaction. Section 11 provides further details and the derived rates of change of each species.

Table 3: Properties of each species.

Id	Name	Compartment	Derived Unit	Constant	Boundary Condition
species_1	Na+	compartment_1	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_2	ATP	compartment_1	mmol	<input type="checkbox"/>	<input checked="" type="checkbox"/>
species_3	ADP	compartment_1	mmol	<input type="checkbox"/>	<input checked="" type="checkbox"/>
species_4	GLC	compartment_1	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_5	GAP	compartment_1	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_6	NAD+	compartment_1	mmol	<input type="checkbox"/>	<input checked="" type="checkbox"/>
species_7	NADH	compartment_1	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_8	PYR	compartment_1	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_9	PEP	compartment_1	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_10	LAC	compartment_1	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_11	PCr	compartment_1	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_12	Cr	compartment_1	mmol	<input type="checkbox"/>	<input checked="" type="checkbox"/>
species_13	O2	compartment_1	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_14	O2	compartment_2	mmol	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
species_15	GLC	compartment_2	mmol	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
species_16	LAC	compartment_2	mmol	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
species_17	GLC	compartment_3	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_18	LAC	compartment_3	mmol	<input type="checkbox"/>	<input type="checkbox"/>
species_19	O2	compartment_3	mmol	<input type="checkbox"/>	<input type="checkbox"/>
dHb	dHb	compartment_3	mmol	<input type="checkbox"/>	<input type="checkbox"/>

5 Parameters

This model contains 69 global parameters.

Table 4: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
parameter_1	S/V		90000.000		<input checked="" type="checkbox"/>
parameter_2	gNa		0.004		<input checked="" type="checkbox"/>
parameter_3	F		96500.000		<input checked="" type="checkbox"/>
parameter_4	RT/F		26.730		<input checked="" type="checkbox"/>
parameter_5	Vm		-70.000		<input checked="" type="checkbox"/>
parameter_6	Na_extracellular		150.000		<input checked="" type="checkbox"/>
parameter_7	ATP		2.200		<input type="checkbox"/>
parameter_8	k_pump		$2.9 \cdot 10^{-7}$		<input checked="" type="checkbox"/>
parameter_9	Km_pump		0.500		<input checked="" type="checkbox"/>
parameter_10	ADP		0.012		<input type="checkbox"/>
parameter_11	qAK		0.920		<input checked="" type="checkbox"/>
parameter_12	A		2.212		<input checked="" type="checkbox"/>
parameter_13	AMP		$7.03149141540894 \cdot 10^{-5}$		<input type="checkbox"/>
parameter_14	Tmax,GLC		0.048		<input checked="" type="checkbox"/>
parameter_15	Kt,GLC		9.000		<input checked="" type="checkbox"/>
parameter_16	kHK-PFK		0.120		<input checked="" type="checkbox"/>
parameter_17	KI,ATP		1.000		<input checked="" type="checkbox"/>
parameter_18	nH		4.000		<input checked="" type="checkbox"/>
parameter_19	Kg		0.050		<input checked="" type="checkbox"/>
parameter_20	kPGK		42.600		<input checked="" type="checkbox"/>
parameter_21	N		0.212		<input checked="" type="checkbox"/>
parameter_22	NAD+		0.186		<input type="checkbox"/>
parameter_23	kPK		86.700		<input checked="" type="checkbox"/>
parameter_24	k+LDH		2000.000		<input checked="" type="checkbox"/>
parameter_25	k-LDH		44.800		<input checked="" type="checkbox"/>
parameter_26	Tmax,LAC		0.006		<input checked="" type="checkbox"/>
parameter_27	Kt,LAC		0.500		<input checked="" type="checkbox"/>
parameter_28	vATPase		0.149		<input checked="" type="checkbox"/>
parameter_29	k+CK		3666.000		<input checked="" type="checkbox"/>
parameter_30	k-CK		20.000		<input checked="" type="checkbox"/>
parameter_31	C		10.000		<input checked="" type="checkbox"/>
parameter_32	PS/V		1.600		<input checked="" type="checkbox"/>
parameter_33	KO2		0.036		<input checked="" type="checkbox"/>
parameter_34	Hb*OP		8.600		<input checked="" type="checkbox"/>
parameter_35	nh		2.730		<input checked="" type="checkbox"/>
parameter_36	F0		0.012		<input checked="" type="checkbox"/>
parameter_37	F.in		0.012		<input type="checkbox"/>

Id	Name	SBO	Value	Unit	Constant
parameter_38	V_cap		0.006		<input checked="" type="checkbox"/>
parameter_47	v_Mito		0.019		<input checked="" type="checkbox"/>
dAMP_dATP	dAMP/dATP		-0.012		<input type="checkbox"/>
v_Mito_H3	v_Mito_H3		0.019		<input type="checkbox"/>
V_max_Mito	V_max_Mito		0.052		<input checked="" type="checkbox"/>
Km_Mito	Km,Mito		0.050		<input checked="" type="checkbox"/>
KI_Mito	KI,Mito		183.300		<input checked="" type="checkbox"/>
n_Mito	n_Mito		0.100		<input checked="" type="checkbox"/>
K_O2_Mito	K_O2_Mito		0.001		<input checked="" type="checkbox"/>
is_maximum	is_maximum		0.000		<input type="checkbox"/>
is_rising	is_rising		1.000		<input type="checkbox"/>
is_falling	is_falling		0.000		<input type="checkbox"/>
slope_up	slope_up		0.000		<input type="checkbox"/>
alpha_F_in	alpha_F_in		0.500		<input checked="" type="checkbox"/>
maximum	maximum		0.006		<input type="checkbox"/>
t_on	t_on		5.000		<input checked="" type="checkbox"/>
t_end	t_end		360.000		<input checked="" type="checkbox"/>
slope_down	slope_down		0.438		<input type="checkbox"/>
F_out	F_out		0.012		<input type="checkbox"/>
v_stim- _constant	v_stim_constant		0.230		<input type="checkbox"/>
rCBF	rCBF		1.000		<input type="checkbox"/>
rCMRO2	rCMRO2		0.000		<input type="checkbox"/>
rVv	rVv		1.000		<input type="checkbox"/>
O2c_bar	O2c_bar		5.680		<input type="checkbox"/>
ratioO2c_bar	ratioO2c_bar		1.000		<input type="checkbox"/>
Compartment- _7	Initial for Venous balloon		0.024		<input checked="" type="checkbox"/>
ModelValue- _35	Initial for F0		0.012		<input checked="" type="checkbox"/>
ModelValue- _60	Initial for O2c_bar		5.680		<input checked="" type="checkbox"/>
ModelValue- _50	Initial for alpha_F- _in		0.500		<input checked="" type="checkbox"/>
ModelValue- _51	Initial for maxi- mum		0.006		<input checked="" type="checkbox"/>
ModelValue- _53	Initial for t_end		360.000		<input checked="" type="checkbox"/>
ModelValue- _52	Initial for t_on		5.000		<input checked="" type="checkbox"/>

6 Initialassignments

This is an overview of seven initialassignments.

6.1 Initialassignment Compartment_7

Derived unit ml

Math $\text{vol}(\text{compartment_4})$

6.2 Initialassignment ModelValue_35

Derived unit contains undeclared units

Math parameter_36

6.3 Initialassignment ModelValue_60

Derived unit contains undeclared units

Math O2c_bar

6.4 Initialassignment ModelValue_50

Derived unit contains undeclared units

Math $\alpha_F\text{in}$

6.5 Initialassignment ModelValue_51

Derived unit contains undeclared units

Math maximum

6.6 Initialassignment ModelValue_53

Derived unit contains undeclared units

Math $t\text{end}$

6.7 Initialassignment ModelValue_52

Derived unit contains undeclared units

Math $t\text{on}$

7 Function definitions

This is an overview of 13 function definitions.

7.1 Function definition `Constant_flux_irreversible`

Name Constant flux (irreversible)

Argument `v`

Mathematical Expression

$$v \quad (1)$$

7.2 Function definition `v_pump`

Name `v_pump`

Arguments `S_V`, `k_pump`, `ATP`, `NA`, `Km_pump`

Mathematical Expression

$$\frac{S_V \cdot k_pump \cdot ATP \cdot NA}{1 + \frac{ATP}{Km_pump}} \quad (2)$$

7.3 Function definition `function_1`

Name `v_Leak-Na`

Arguments `S_V`, `gNA`, `F`, `RT_F`, `Na_e`, `Na`, `Vm`

Mathematical Expression

$$S_V \cdot \frac{gNA}{F} \cdot \left(RT_F \cdot \left(\frac{Na_e}{Na} \right) - Vm \right) \quad (3)$$

7.4 Function definition `v_GLC_m`

Name `v_GLC_m`

Arguments `Tmax`, `GLC_c`, `Kt_GLC`, `GLC_i`

Mathematical Expression

$$Tmax \cdot \left(\frac{GLC_c}{GLC_c + Kt_GLC} - \frac{GLC_i}{GLC_i + Kt_GLC} \right) \quad (4)$$

7.5 Function definition `function_2`

Name `v_HK-PFK`

Arguments `ATP`, `GLC_i`, `Kg`, `KI_ATP`, `nH`, `kHK_PFK`

Mathematical Expression

$$\frac{kHK_PFK \cdot ATP \cdot \frac{GLC_i}{GLC_i + Kg}}{1 + \left(\frac{ATP}{KI_ATP}\right)^{nH}} \quad (5)$$

7.6 Function definition `v_PGK`

Name `v_PGK`

Arguments `kPGK`, `GAP`, `ADP`, `NAD`, `NADH`

Mathematical Expression

$$kPGK \cdot GAP \cdot ADP \cdot \frac{NAD}{NADH} \quad (6)$$

7.7 Function definition `v_LAC_m`

Name `v_LAC_m`

Arguments `Tmax`, `LAC_i`, `Kt_LAC`, `LAC_c`

Mathematical Expression

$$Tmax \cdot \left(\frac{LAC_i}{LAC_i + Kt_LAC} - \frac{LAC_c}{LAC_c + Kt_LAC} \right) \quad (7)$$

7.8 Function definition `v_O2_m`

Name `v_O2_m`

Arguments `PS_V`, `KO2`, `HbOP`, `O2_c`, `nh`, `O2_i`

Mathematical Expression

$$PS_V \cdot \left(KO2 \cdot \left(\frac{HbOP}{O2_c} - 1 \right)^{\frac{1}{nh}} - O2_i \right) \quad (8)$$

7.9 Function definition v_{O2_c}

Name v_{O2_c}

Arguments F_{in} , V_{cap} , $O2_a$, $O2_c$

Mathematical Expression

$$\frac{2 \cdot F_{in}}{V_{cap}} \cdot (O2_a - O2_c) \quad (9)$$

7.10 Function definition v_{GLC_c}

Name v_{GLC_c}

Arguments F_{in} , V_{cap} , GLC_a , GLC_c

Mathematical Expression

$$\frac{2 \cdot F_{in}}{V_{cap}} \cdot (GLC_a - GLC_c) \quad (10)$$

7.11 Function definition v_{LAC_c}

Name v_{LAC_c}

Arguments F_{in} , V_{cap} , LAC_a , LAC_c

Mathematical Expression

$$\frac{2 \cdot F_{in}}{V_{cap}} \cdot (LAC_a - LAC_c) \quad (11)$$

7.12 Function definition v_{dHb_in}

Name v_{dHb_in}

Arguments F_{in} , $O2_a$, $O2_c$

Mathematical Expression

$$F_{in} \cdot 2 \cdot (O2_a - O2_c) \quad (12)$$

7.13 Function definition v_{dHb_out}

Name v_{dHb_out}

Arguments F_{out} , dHb , V_v

Mathematical Expression

$$\frac{F_{out} \cdot dHb}{V_v} \quad (13)$$

8 Rules

This is an overview of 21 rules.

8.1 Rule `species_2`

Rule `species_2` is an assignment rule for species `species_2`:

$$[\text{species_2}] = \text{parameter_7} \cdot \text{vol}(\text{compartment_1}) \quad (14)$$

8.2 Rule `species_12`

Rule `species_12` is an assignment rule for species `species_12`:

$$[\text{species_12}] = \left(\text{parameter_31} - \frac{\text{species_11}}{\text{vol}(\text{compartment_1})} \right) \cdot \text{vol}(\text{compartment_1}) \quad (15)$$

8.3 Rule `parameter_10`

Rule `parameter_10` is an assignment rule for parameter `parameter_10`:

$$\begin{aligned} \text{parameter_10} = & \frac{\text{parameter_7}}{2} \cdot \left(\text{parameter_11} \right. \\ & \left. + \left(\text{parameter_11}^2 + 4 \cdot \text{parameter_11} \cdot \left(\frac{\text{parameter_12}}{\text{parameter_7}} - 1 \right) \right)^{0.5} \right) \end{aligned} \quad (16)$$

8.4 Rule `species_3`

Rule `species_3` is an assignment rule for species `species_3`:

$$[\text{species_3}] = \text{parameter_10} \cdot \text{vol}(\text{compartment_1}) \quad (17)$$

8.5 Rule `parameter_13`

Rule `parameter_13` is an assignment rule for parameter `parameter_13`:

$$\text{parameter_13} = \text{parameter_12} - \text{parameter_7} - \text{parameter_10} \quad (18)$$

8.6 Rule `parameter_22`

Rule `parameter_22` is an assignment rule for parameter `parameter_22`:

$$\text{parameter_22} = \text{parameter_21} - \frac{\text{species_7}}{\text{vol}(\text{compartment_1})} \quad (19)$$

8.7 Rule species_6

Rule species_6 is an assignment rule for species species_6:

$$[\text{species}_6] = \text{parameter_22} \cdot \text{vol}(\text{compartment_1}) \quad (20)$$

8.8 Rule dAMP_dATP

Rule dAMP_dATP is an assignment rule for parameter dAMP_dATP:

$$\begin{aligned} \text{dAMP_dATP} = & 1 + \frac{\text{parameter_11}}{2} - \frac{1}{2} \\ & \cdot \left(\text{parameter_11}^2 + 4 \cdot \text{parameter_11} \cdot \left(\frac{\text{parameter_12}}{\text{parameter_7}} - 1 \right) \right)^{\frac{1}{2}} \\ & + \frac{\text{parameter_11} \cdot \text{parameter_12}}{\text{parameter_7} \cdot \left(\text{parameter_11}^2 + 4 \cdot \text{parameter_11} \cdot \left(\frac{\text{parameter_12}}{\text{parameter_7}} - 1 \right) \right)^{\frac{1}{2}}} \end{aligned} \quad (21)$$

8.9 Rule v_Mito_H3

Rule v_Mito_H3 is an assignment rule for parameter v_Mito_H3:

$$\begin{aligned} \text{v_Mito_H3} = & \text{V_max_Mito} \cdot \frac{\frac{\text{species_8}}{\text{vol}(\text{compartment_1})}}{\text{Km_Mito} + \frac{\text{species_8}}{\text{vol}(\text{compartment_1})}} \\ & \cdot \frac{1}{1 + \left(\frac{\text{parameter_7}}{\text{parameter_10_KI_Mito}} \right)^{\text{n_Mito}}} \cdot \frac{\frac{\text{species_13}}{\text{vol}(\text{compartment_1})}}{\text{K_O2_Mito} + \frac{\text{species_13}}{\text{vol}(\text{compartment_1})}} \end{aligned} \quad (22)$$

8.10 Rule maximum

Rule maximum is an assignment rule for parameter maximum:

$$\text{maximum} = \text{ModelValue_35} \cdot \text{ModelValue_50} \quad (23)$$

8.11 Rule slope_up

Rule slope_up is an assignment rule for parameter slope_up:

$$\text{slope_up} = \frac{\text{ModelValue_51}}{\text{ModelValue_52}} \cdot \text{time} \quad (24)$$

8.12 Rule slope_down

Rule slope_down is an assignment rule for parameter slope_down:

$$\text{slope_down} = \frac{\text{maximum} \cdot (\text{t_on} + \text{t_end} - \text{time})}{\text{t_on}} \quad (25)$$

8.13 Rule parameter_37

Rule parameter_37 is an assignment rule for parameter parameter_37:

$$\begin{aligned} \text{parameter_37} = & \text{parameter_36} + \text{is_rising} \cdot \text{slope_up} + \text{is_maximum} \\ & \cdot \text{maximum} + \text{is_falling} \cdot \text{slope_down} \end{aligned} \quad (26)$$

8.14 Rule F_out

Rule F_out is an assignment rule for parameter F_out:

$$\begin{aligned} & \text{F_out} \quad (27) \\ = & \frac{\text{parameter_36} \cdot \left(\left(\frac{\text{vol}(\text{compartment_4})}{\text{Compartment_7}} \right)^2 + \left(\frac{\text{vol}(\text{compartment_4})}{\text{Compartment_7}} \right)^{0.5} \cdot 35 \cdot \frac{1}{\text{Compartment_7}} \cdot \text{parameter_37} \right)}{1 + \text{parameter_36} \cdot \left(\frac{\text{vol}(\text{compartment_4})}{\text{Compartment_7}} \right)^{0.5} \cdot 35 \cdot \frac{1}{\text{Compartment_7}}} \end{aligned}$$

8.15 Rule rCBF

Rule rCBF is an assignment rule for parameter rCBF:

$$\text{rCBF} = \frac{\text{parameter_37}}{\text{ModelValue_35}} \quad (28)$$

8.16 Rule rCMRO2

Rule rCMRO2 is an assignment rule for parameter rCMRO2:

$$\text{rCMRO2} = \frac{\text{mitochondrial_respiration}}{0.0192} \quad (29)$$

8.17 Rule rVv

Rule rVv is an assignment rule for parameter rVv:

$$\text{rVv} = \frac{\text{vol}(\text{compartment_4})}{\text{Compartment_7}} \quad (30)$$

8.18 Rule O2c_bar

Rule O2c_bar is an assignment rule for parameter O2c_bar:

$$\text{O2c_bar} = 2 \cdot \frac{\text{species_19}}{\text{vol}(\text{compartment_3})} - \frac{\text{species_14}}{\text{vol}(\text{compartment_2})} \quad (31)$$

8.19 Rule ratioO2c_bar

Rule ratioO2c_bar is an assignment rule for parameter ratioO2c_bar:

$$\text{ratioO2c_bar} = \frac{\text{O2c_bar}}{\text{ModelValue_60}} \quad (32)$$

8.20 Rule compartment_4

Rule compartment_4 is a rate rule for compartment compartment_4:

$$\frac{d}{dt}\text{vol}(\text{compartment_4}) = \text{parameter_37} - F_{\text{out}} \quad (33)$$

8.21 Rule parameter_7

Rule parameter_7 is a rate rule for parameter parameter_7:

$$\begin{aligned} \frac{d}{dt}\text{parameter_7} = & (2 \cdot \text{reaction_4} + \text{reaction_5} + \text{reaction_6} - \text{reaction_2} + 15 \\ & \cdot \text{mitochondrial_respiration} + \text{reaction_9} - \text{ATPases}) \cdot (1 - \text{dAMP_dATP})^1 \end{aligned} \quad (34)$$

9 Events

This is an overview of three events. Each event is initiated whenever its trigger condition switches from false to true. A delay function postpones the effects of an event to a later time point. At the time of execution, an event can assign values to species, parameters or compartments if these are not set to constant.

9.1 Event from_increase_to_stable

Name from increase to stable

Trigger condition

$$\text{time} = \text{ModelValue_52} \quad (35)$$

Assignments

$$\text{is_maximum} = 1 \quad (36)$$

$$\text{is_rising} = 0 \quad (37)$$

9.2 Event from_stable_to_decrease_end_of_stimulation

Name from stable to decrease (end of stimulation)

Trigger condition

$$\text{time} = \text{ModelValue_53} \quad (38)$$

Assignments

$$\text{is_maximum} = 0 \quad (39)$$

$$\text{is_falling} = 1 \quad (40)$$

$$\text{v_stim_constant} = 0 \quad (41)$$

9.3 Event `from_decrease_to_at_rest`

Name `from decrease to at_rest`

Trigger condition
$$\text{time} = \text{ModelValue_53} + \text{ModelValue_52} \quad (42)$$

Assignment
$$\text{is_falling} = 0 \quad (43)$$

10 Reactions

This model contains 18 reactions. All reactions are listed in the following table and are subsequently described in detail. If a reaction is affected by a modifier, the identifier of this species is written above the reaction arrow.

Table 5: Overview of all reactions

Nº	Id	Name	Reaction Equation	SBO
1	reaction_1	Sodium leak	$\emptyset \xrightarrow{\text{species_1}} \text{species_1}$	
2	reaction_2	Na/K - pump	$3 \text{ species_1} + \text{species_2} \xrightarrow{\text{species_2, species_1}} \text{species_3}$	
3	reaction_3	Blood-brain transport of glucose	$100 \text{ species_17} \xrightarrow{\text{species_17, species_4}} \text{species_4}$	
4	reaction_4	Hexokinase-phosphofructokinase system	$\text{species_4} + \text{species_2} \xrightarrow{\text{species_2, species_4}} 2 \text{ species_5} + \text{species_3}$	
5	reaction_5	Phosphoglycerate kinase	$\text{species_5} + \text{species_6} \xrightarrow{\text{species_3, species_5, species_3, species_6, species_7}} \text{species_7} + \text{species_9}$	
6	reaction_6	Pyruvate kinase	$\text{species_3} + \text{species_9} \xrightarrow{\text{species_3, species_9}} \text{species_2} + \text{species_8}$	
7	reaction_7	Lactate dehydrogenase	$\text{species_8} + \text{species_7} \xrightleftharpoons{\text{species_8, species_7, species_10, species_6}} \text{species_10} + \text{species_6}$	
8	reaction_8	Blood-brain transport of lactate	$\text{species_10} \xrightarrow{\text{species_10, species_18}} 100 \text{ species_18}$	
9	reaction_9	Creatine Kinase	$\text{species_11} + \text{species_3} \xrightleftharpoons{\text{species_11, species_3, species_12, species_2}} \text{species_12} + \text{species_2}$	
10	reaction_10	Blood-brain transport of oxygen	$100 \text{ species_19} \xrightarrow{\text{species_19, species_13}} \text{species_13}$	
11	reaction_11	Blood flow contribution to O2 variation	$\text{species_14} \xrightarrow{\text{species_14, species_19}} \text{species_19}$	
12	reaction_12	Blood flow contribution to GLC_c variation	$\text{species_15} \xrightarrow{\text{species_15, species_17}} \text{species_17}$	

Nº	Id	Name	Reaction Equation	SBO
13	reaction_13	Blood flow contribution to LAC_c variation	$\text{species_16} \xrightarrow{\text{species_16, species_18}} \text{species_18}$	
14	mitochondrial- _respiration	mitochondrial respiration	$\text{species_8} + \text{species_7} + 3 \text{ species_13} \longrightarrow \text{species_2}$	
15	ATPases	ATPases	$\text{species_2} \longrightarrow \emptyset$	
16	Na__inflow- _after- _stimulation	Na+ inflow after stimulation	$\emptyset \longrightarrow \text{species_1}$	
17	inflow_of_dHb	inflow of dHb	$\emptyset \xrightarrow{\text{species_14, species_19, species_14, species_19}} \text{dHb}$	
18	outflow_of_dHb	outflow of dHb	$\text{dHb} \xrightarrow{\text{dHb}} \emptyset$	

10.1 Reaction `reaction_1`

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name Sodium leak

Reaction equation



Modifier

Table 6: Properties of each modifier.

Id	Name	SBO
<code>species_1</code>	Na+	

Product

Table 7: Properties of each product.

Id	Name	SBO
<code>species_1</code>	Na+	

Kinetic Law

Derived unit contains undeclared units

$$v_1 = \text{vol}(\text{compartment_1}) \cdot \text{function_1} \left(\text{parameter_1}, \text{parameter_2}, \text{parameter_3}, \right. \\ \left. \text{parameter_4}, \text{parameter_6}, \frac{\text{species_1}}{\text{vol}(\text{compartment_1})}, \text{parameter_5} \right) \quad (45)$$

$$\text{function_1}(S_V, gNA, F, RT_F, Na_e, Na, Vm) = S_V \cdot \frac{gNA}{F} \cdot \left(RT_F \cdot \left(\frac{Na_e}{Na} \right) - Vm \right) \quad (46)$$

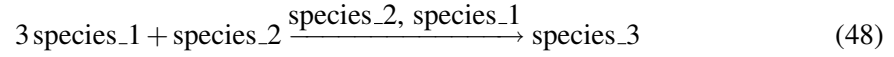
$$\text{function_1}(S_V, gNA, F, RT_F, Na_e, Na, Vm) = S_V \cdot \frac{gNA}{F} \cdot \left(RT_F \cdot \left(\frac{Na_e}{Na} \right) - Vm \right) \quad (47)$$

10.2 Reaction `reaction_2`

This is an irreversible reaction of two reactants forming one product influenced by two modifiers.

Name Na/K - pump

Reaction equation



Reactants

Table 8: Properties of each reactant.

Id	Name	SBO
species_1	Na+	
species_2	ATP	

Modifiers

Table 9: Properties of each modifier.

Id	Name	SBO
species_2	ATP	
species_1	Na+	

Product

Table 10: Properties of each product.

Id	Name	SBO
species_3	ADP	

Kinetic Law

Derived unit contains undeclared units

$$v_2 = \text{vol}(\text{compartment_1}) \cdot v_{\text{pump}} \left(\text{parameter_1}, \text{parameter_8}, \frac{\text{species_2}}{\text{vol}(\text{compartment_1})}, \frac{\text{species_1}}{\text{vol}(\text{compartment_1})}, \text{parameter_9} \right) \quad (49)$$

$$v_{\text{pump}}(\text{S_V}, k_{\text{pump}}, \text{ATP}, \text{NA}, \text{Km_pump}) = \frac{\text{S_V} \cdot k_{\text{pump}} \cdot \text{ATP} \cdot \text{NA}}{1 + \frac{\text{ATP}}{\text{Km_pump}}} \quad (50)$$

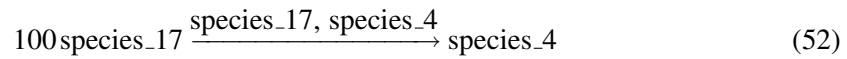
$$v_{\text{pump}}(\text{S_V}, k_{\text{pump}}, \text{ATP}, \text{NA}, \text{Km_pump}) = \frac{\text{S_V} \cdot k_{\text{pump}} \cdot \text{ATP} \cdot \text{NA}}{1 + \frac{\text{ATP}}{\text{Km_pump}}} \quad (51)$$

10.3 Reaction `reaction_3`

This is an irreversible reaction of one reactant forming one product influenced by two modifiers.

Name Blood-brain transport of glucose

Reaction equation



Reactant

Table 11: Properties of each reactant.

Id	Name	SBO
species_17	GLC	

Modifiers

Table 12: Properties of each modifier.

Id	Name	SBO
species_17	GLC	
species_4	GLC	

Product

Table 13: Properties of each product.

Id	Name	SBO
species_4	GLC	

Kinetic Law

Derived unit contains undeclared units

$$v_3 = v_GLC.m \left(\text{parameter_14}, \frac{\text{species_17}}{\text{vol}(\text{compartment_3})}, \text{parameter_15}, \frac{\text{species_4}}{\text{vol}(\text{compartment_1})} \right) \quad (53)$$

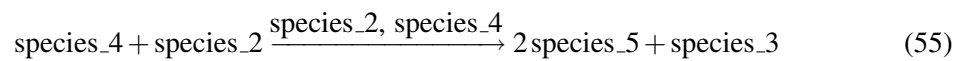
$$\begin{aligned}
 & v_GLC_m(Tmax, GLC_c, Kt_GLC, GLC_i) \\
 &= Tmax \cdot \left(\frac{GLC_c}{GLC_c + Kt_GLC} - \frac{GLC_i}{GLC_i + Kt_GLC} \right)
 \end{aligned}
 \tag{54}$$

10.4 Reaction `reaction_4`

This is an irreversible reaction of two reactants forming two products influenced by two modifiers.

Name Hexokinase-phosphofructokinase system

Reaction equation



Reactants

Table 14: Properties of each reactant.

Id	Name	SBO
<code>species_4</code>	GLC	
<code>species_2</code>	ATP	

Modifiers

Table 15: Properties of each modifier.

Id	Name	SBO
<code>species_2</code>	ATP	
<code>species_4</code>	GLC	

Products

Table 16: Properties of each product.

Id	Name	SBO
<code>species_5</code>	GAP	
<code>species_3</code>	ADP	

Kinetic Law

Derived unit contains undeclared units

$$v_4 = \text{vol}(\text{compartment}_1) \cdot \text{function}_2 \left(\frac{\text{species}_2}{\text{vol}(\text{compartment}_1)}, \frac{\text{species}_4}{\text{vol}(\text{compartment}_1)}, \text{parameter}_19, \text{parameter}_17, \text{parameter}_18, \text{parameter}_16 \right) \quad (56)$$

$$\text{function}_2(\text{ATP}, \text{GLC}_i, \text{Kg}, \text{KI_ATP}, nH, \text{kHK_PFK}) = \frac{\text{kHK_PFK} \cdot \text{ATP} \cdot \frac{\text{GLC}_i}{\text{GLC}_i + \text{Kg}}}{1 + \left(\frac{\text{ATP}}{\text{KI_ATP}} \right)^{nH}} \quad (57)$$

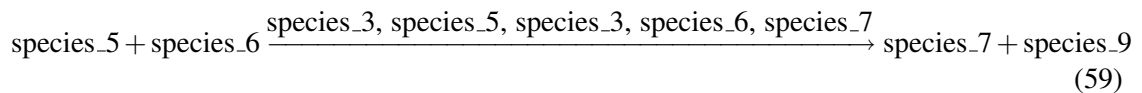
$$\text{function}_2(\text{ATP}, \text{GLC}_i, \text{Kg}, \text{KI_ATP}, nH, \text{kHK_PFK}) = \frac{\text{kHK_PFK} \cdot \text{ATP} \cdot \frac{\text{GLC}_i}{\text{GLC}_i + \text{Kg}}}{1 + \left(\frac{\text{ATP}}{\text{KI_ATP}} \right)^{nH}} \quad (58)$$

10.5 Reaction `reaction_5`

This is an irreversible reaction of two reactants forming two products influenced by five modifiers.

Name Phosphoglycerate kinase

Reaction equation



Reactants

Table 17: Properties of each reactant.

Id	Name	SBO
<code>species_5</code>	GAP	
<code>species_6</code>	NAD+	

Modifiers

Table 18: Properties of each modifier.

Id	Name	SBO
species_3	ADP	
species_5	GAP	
species_3	ADP	
species_6	NAD+	
species_7	NADH	

Products

Table 19: Properties of each product.

Id	Name	SBO
species_7	NADH	
species_9	PEP	

Kinetic Law

Derived unit contains undeclared units

$$v_5 = \text{vol}(\text{compartment_1}) \cdot v_PGK \left(\text{parameter_20}, \frac{\text{species_5}}{\text{vol}(\text{compartment_1})}, \frac{\text{species_3}}{\text{vol}(\text{compartment_1})}, \frac{\text{species_6}}{\text{vol}(\text{compartment_1})}, \frac{\text{species_7}}{\text{vol}(\text{compartment_1})} \right) \quad (60)$$

$$v_PGK(kPGK, \text{GAP}, \text{ADP}, \text{NAD}, \text{NADH}) = kPGK \cdot \text{GAP} \cdot \text{ADP} \cdot \frac{\text{NAD}}{\text{NADH}} \quad (61)$$

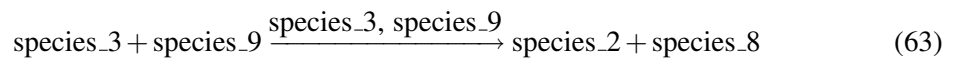
$$v_PGK(kPGK, \text{GAP}, \text{ADP}, \text{NAD}, \text{NADH}) = kPGK \cdot \text{GAP} \cdot \text{ADP} \cdot \frac{\text{NAD}}{\text{NADH}} \quad (62)$$

10.6 Reaction `reaction_6`

This is an irreversible reaction of two reactants forming two products influenced by two modifiers.

Name Pyruvate kinase

Reaction equation



Reactants

Table 20: Properties of each reactant.

Id	Name	SBO
species_3	ADP	
species_9	PEP	

Modifiers

Table 21: Properties of each modifier.

Id	Name	SBO
species_3	ADP	
species_9	PEP	

Products

Table 22: Properties of each product.

Id	Name	SBO
species_2	ATP	
species_8	PYR	

Kinetic Law

Derived unit contains undeclared units

$$v_6 = \text{parameter_23} \cdot \text{species_3} \cdot \frac{\text{species_9}}{\text{vol}(\text{compartment_1})} \quad (64)$$

10.7 Reaction `reaction_7`

This is a reversible reaction of two reactants forming two products influenced by four modifiers.

Name Lactate dehydrogenase

Reaction equation



Reactants

Table 23: Properties of each reactant.

Id	Name	SBO
species_8	PYR	
species_7	NADH	

Modifiers

Table 24: Properties of each modifier.

Id	Name	SBO
species_8	PYR	
species_7	NADH	
species_10	LAC	
species_6	NAD+	

Products

Table 25: Properties of each product.

Id	Name	SBO
species_10	LAC	
species_6	NAD+	

Kinetic Law

Derived unit contains undeclared units

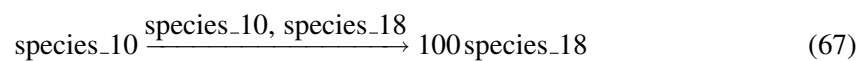
$$v_7 = \text{vol}(\text{compartment}_1) \cdot \left(\text{parameter}_{24} \cdot \frac{\text{species}_8}{\text{vol}(\text{compartment}_1)} \cdot \frac{\text{species}_7}{\text{vol}(\text{compartment}_1)} - \text{parameter}_{25} \cdot \frac{\text{species}_{10}}{\text{vol}(\text{compartment}_1)} \cdot \frac{\text{species}_6}{\text{vol}(\text{compartment}_1)} \right) \quad (66)$$

10.8 Reaction [reaction_8](#)

This is an irreversible reaction of one reactant forming one product influenced by two modifiers.

Name Blood-brain transport of lactate

Reaction equation



Reactant

Table 26: Properties of each reactant.

Id	Name	SBO
species_10	LAC	

Modifiers

Table 27: Properties of each modifier.

Id	Name	SBO
species_10	LAC	
species_18	LAC	

Product

Table 28: Properties of each product.

Id	Name	SBO
species_18	LAC	

Kinetic Law

Derived unit contains undeclared units

$$v_8 = v_LAC_m \left(parameter_26, \frac{species_10}{vol(compartment_1)}, parameter_27, \frac{species_18}{vol(compartment_3)} \right) \quad (68)$$

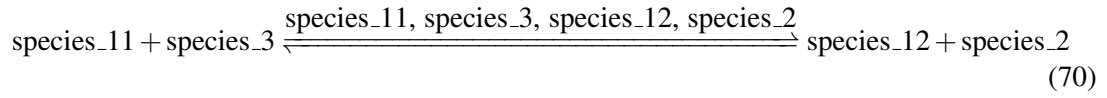
$$v_LAC_m(Tmax, LAC_i, Kt_LAC, LAC_c) = Tmax \cdot \left(\frac{LAC_i}{LAC_i + Kt_LAC} - \frac{LAC_c}{LAC_c + Kt_LAC} \right) \quad (69)$$

10.9 Reaction `reaction_9`

This is a reversible reaction of two reactants forming two products influenced by four modifiers.

Name Creatine Kinase

Reaction equation



Reactants

Table 29: Properties of each reactant.

Id	Name	SBO
species_11	PCr	
species_3	ADP	

Modifiers

Table 30: Properties of each modifier.

Id	Name	SBO
species_11	PCr	
species_3	ADP	
species_12	Cr	
species_2	ATP	

Products

Table 31: Properties of each product.

Id	Name	SBO
species_12	Cr	
species_2	ATP	

Kinetic Law

Derived unit contains undeclared units

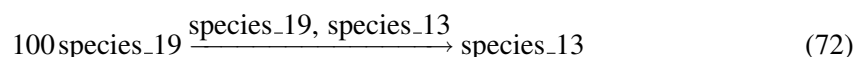
$$v_9 = \text{vol}(\text{compartment_1}) \cdot \left(\text{parameter_29} \cdot \frac{\text{species_11}}{\text{vol}(\text{compartment_1})} \cdot \frac{\text{species_3}}{\text{vol}(\text{compartment_1})} - \text{parameter_30} \cdot \frac{\text{species_12}}{\text{vol}(\text{compartment_1})} \cdot \frac{\text{species_2}}{\text{vol}(\text{compartment_1})} \right) \quad (71)$$

10.10 Reaction `reaction_10`

This is an irreversible reaction of one reactant forming one product influenced by two modifiers.

Name Blood-brain transport of oxygen

Reaction equation



Reactant

Table 32: Properties of each reactant.

Id	Name	SBO
species_19	O2	

Modifiers

Table 33: Properties of each modifier.

Id	Name	SBO
species_19	O2	
species_13	O2	

Product

Table 34: Properties of each product.

Id	Name	SBO
species_13	O2	

Kinetic Law

Derived unit contains undeclared units

$$v_{10} = v_O2_m \left(\text{parameter_32}, \text{parameter_33}, \text{parameter_34}, \frac{\text{species_19}}{\text{vol}(\text{compartment_3})}, \right. \\ \left. \text{parameter_35}, \frac{\text{species_13}}{\text{vol}(\text{compartment_1})} \right) \quad (73)$$

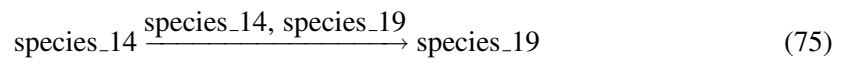
$$v_{O2_m}(PS_V, KO2, HbOP, O2_c, nh, O2_i) = PS_V \cdot \left(KO2 \cdot \left(\frac{HbOP}{O2_c} - 1 \right)^{\frac{1}{nh}} - O2_i \right) \quad (74)$$

10.11 Reaction `reaction_11`

This is an irreversible reaction of one reactant forming one product influenced by two modifiers.

Name Blood flow contribution to O2 variation

Reaction equation



Reactant

Table 35: Properties of each reactant.

Id	Name	SBO
species_14	O2	

Modifiers

Table 36: Properties of each modifier.

Id	Name	SBO
species_14	O2	
species_19	O2	

Product

Table 37: Properties of each product.

Id	Name	SBO
species_19	O2	

Kinetic Law

Derived unit contains undeclared units

$$v_{11} = v_{O2_c} \left(\text{parameter_37, parameter_38, } \frac{\text{species_14}}{\text{vol}(\text{compartment_2})}, \frac{\text{species_19}}{\text{vol}(\text{compartment_3})} \right) \quad (76)$$

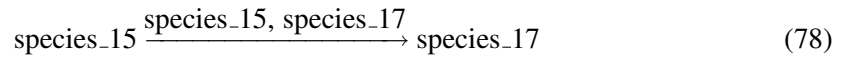
$$v_{O2_c}(F_{in}, V_{cap}, O2_a, O2_c) = \frac{2 \cdot F_{in}}{V_{cap}} \cdot (O2_a - O2_c) \quad (77)$$

10.12 Reaction [reaction_12](#)

This is an irreversible reaction of one reactant forming one product influenced by two modifiers.

Name Blood flow contribution to GLC_c variation

Reaction equation



Reactant

Table 38: Properties of each reactant.

Id	Name	SBO
species_15	GLC	

Modifiers

Table 39: Properties of each modifier.

Id	Name	SBO
species_15	GLC	
species_17	GLC	

Product

Table 40: Properties of each product.

Id	Name	SBO
species_17	GLC	

Kinetic Law

Derived unit contains undeclared units

$$v_{12} = v_{GLC_c} \left(\text{parameter_37}, \text{parameter_38}, \frac{\text{species_15}}{\text{vol}(\text{compartment_2})}, \frac{\text{species_17}}{\text{vol}(\text{compartment_3})} \right) \quad (79)$$

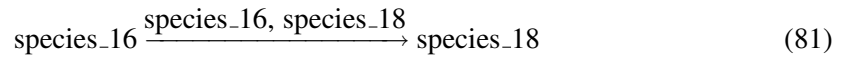
$$v_GLC_c(F_in, V_cap, GLC_a, GLC_c) = \frac{2 \cdot F_in}{V_cap} \cdot (GLC_a - GLC_c) \quad (80)$$

10.13 Reaction [reaction_13](#)

This is an irreversible reaction of one reactant forming one product influenced by two modifiers.

Name Blood flow contribution to LAC_c variation

Reaction equation



Reactant

Table 41: Properties of each reactant.

Id	Name	SBO
species_16	LAC	

Modifiers

Table 42: Properties of each modifier.

Id	Name	SBO
species_16	LAC	
species_18	LAC	

Product

Table 43: Properties of each product.

Id	Name	SBO
species_18	LAC	

Kinetic Law

Derived unit contains undeclared units

$$v_{13} = v_LAC_c \left(\text{parameter_37}, \text{parameter_38}, \frac{\text{species_16}}{\text{vol}(\text{compartment_2})}, \frac{\text{species_18}}{\text{vol}(\text{compartment_3})} \right) \quad (82)$$

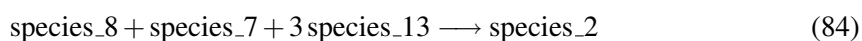
$$v_{\text{LAC}_c}(F_{\text{in}}, V_{\text{cap}}, \text{LAC}_a, \text{LAC}_c) = \frac{2 \cdot F_{\text{in}}}{V_{\text{cap}}} \cdot (\text{LAC}_a - \text{LAC}_c) \quad (83)$$

10.14 Reaction `mitochondrial_respiration`

This is an irreversible reaction of three reactants forming one product.

Name mitochondrial respiration

Reaction equation



Reactants

Table 44: Properties of each reactant.

Id	Name	SBO
<code>species_8</code>	PYR	
<code>species_7</code>	NADH	
<code>species_{13}</code>	O2	

Product

Table 45: Properties of each product.

Id	Name	SBO
<code>species_2</code>	ATP	

Kinetic Law

Derived unit contains undeclared units

$$v_{14} = \text{vol}(\text{compartment}_1) \cdot \text{Constant_flux_irreversible}(v_{\text{Mito.H3}}) \quad (85)$$

$$\text{Constant_flux_irreversible}(v) = v \quad (86)$$

$$\text{Constant_flux_irreversible}(v) = v \quad (87)$$

10.15 Reaction `ATPases`

This is an irreversible reaction of one reactant forming no product.

Name ATPases

Reaction equation



Reactant

Table 46: Properties of each reactant.

Id	Name	SBO
species_2	ATP	

Kinetic Law

Derived unit contains undeclared units

$$v_{15} = \text{vol}(\text{compartment_1}) \cdot \text{Constant_flux_irreversible}(v) \quad (89)$$

$$\text{Constant_flux_irreversible}(v) = v \quad (90)$$

$$\text{Constant_flux_irreversible}(v) = v \quad (91)$$

Table 47: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
v	v		0.149		<input checked="" type="checkbox"/>

10.16 Reaction [Na_inflow_after_stimulation](#)

This is an irreversible reaction of no reactant forming one product.

Name Na+ inflow after stimulation

Reaction equation



Product

Table 48: Properties of each product.

Id	Name	SBO
species_1	Na+	

Kinetic Law

Derived unit contains undeclared units

$$v_{16} = \text{vol}(\text{compartment}_1) \cdot \text{Constant_flux_irreversible}(v_stim_constant) \quad (93)$$

$$\text{Constant_flux_irreversible}(v) = v \quad (94)$$

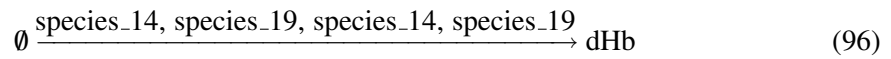
$$\text{Constant_flux_irreversible}(v) = v \quad (95)$$

10.17 Reaction `inflow_of_dHb`

This is an irreversible reaction of no reactant forming one product influenced by four modifiers.

Name inflow of dHb

Reaction equation



Modifiers

Table 49: Properties of each modifier.

Id	Name	SBO
species_14	O2	
species_19	O2	
species_14	O2	
species_19	O2	

Product

Table 50: Properties of each product.

Id	Name	SBO
dHb	dHb	

Kinetic Law

Derived unit contains undeclared units

$$v_{17} = \text{vol}(\text{compartment_3}) \cdot v_{\text{dHb_in}} \left(\text{parameter_37}, \frac{\text{species_14}}{\text{vol}(\text{compartment_2})}, \frac{\text{species_19}}{\text{vol}(\text{compartment_3})} \right) \quad (97)$$

$$v_{\text{dHb_in}}(F_{\text{in}}, O2_{\text{a}}, O2_{\text{c}}) = F_{\text{in}} \cdot 2 \cdot (O2_{\text{a}} - O2_{\text{c}}) \quad (98)$$

$$v_{\text{dHb_in}}(F_{\text{in}}, O2_{\text{a}}, O2_{\text{c}}) = F_{\text{in}} \cdot 2 \cdot (O2_{\text{a}} - O2_{\text{c}}) \quad (99)$$

10.18 Reaction outflow_of_dHb

This is an irreversible reaction of one reactant forming no product influenced by one modifier.

Name outflow of dHb

Reaction equation



Reactant

Table 51: Properties of each reactant.

Id	Name	SBO
dHb	dHb	

Modifier

Table 52: Properties of each modifier.

Id	Name	SBO
dHb	dHb	

Kinetic Law

Derived unit contains undeclared units

$$v_{18} = \text{vol}(\text{compartment_3}) \cdot v_{\text{dHb_out}} \left(F_{\text{out}}, \frac{\text{dHb}}{\text{vol}(\text{compartment_3})}, \text{vol}(\text{compartment_4}) \right) \quad (101)$$

$$v_dHb_out(F_out, dHb, V_v) = \frac{F_out \cdot dHb}{V_v} \quad (102)$$

$$v_dHb_out(F_out, dHb, V_v) = \frac{F_out \cdot dHb}{V_v} \quad (103)$$

11 Derived Rate Equations

When interpreted as an ordinary differential equation framework, this model implies the following set of equations for the rates of change of each species.

Identifiers for kinetic laws highlighted in gray cannot be verified to evaluate to units of SBML substance per time. As a result, some SBML interpreters may not be able to verify the consistency of the units on quantities in the model. Please check if

- parameters without an unit definition are involved or
- volume correction is necessary because the `hasOnlySubstanceUnits` flag may be set to `false` and `spacialDimensions` > 0 for certain species.

11.1 Species `species_1`

Name Na⁺

Initial amount 15 mmol

This species takes part in five reactions (as a reactant in [reaction_2](#) and as a product in [reaction_1](#), [Na_inflow_after_stimulation](#) and as a modifier in [reaction_1](#), [reaction_2](#)).

$$\frac{d}{dt} \text{species}_1 = v_1 + v_{16} - 3 v_2 \quad (104)$$

11.2 Species `species_2`

Name ATP

Initial amount 2.2 mmol

Involved in rule [species_2](#)

This species takes part in nine reactions (as a reactant in [reaction_2](#), [reaction_4](#), [ATPases](#) and as a product in [reaction_6](#), [reaction_9](#), [mitochondrial_respiration](#) and as a modifier in [reaction_2](#), [reaction_4](#), [reaction_9](#)). Not these but one rule determines the species' quantity because this species is on the boundary of the reaction system.

11.3 Species `species_3`

Name ADP

Initial amount 0.0119296850858459 mmol

Involved in rule `species_3`

This species takes part in eight reactions (as a reactant in `reaction_6`, `reaction_9` and as a product in `reaction_2`, `reaction_4` and as a modifier in `reaction_5`, `reaction_5`, `reaction_6`, `reaction_9`). Not these but one rule determines the species' quantity because this species is on the boundary of the reaction system.

11.4 Species `species_4`

Name GLC

Initial amount 1.2 mmol

This species takes part in four reactions (as a reactant in `reaction_4` and as a product in `reaction_3` and as a modifier in `reaction_3`, `reaction_4`).

$$\frac{d}{dt}\text{species}_4 = v_3 - v_4 \quad (105)$$

11.5 Species `species_5`

Name GAP

Initial amount 0.0057 mmol

This species takes part in three reactions (as a reactant in `reaction_5` and as a product in `reaction_4` and as a modifier in `reaction_5`).

$$\frac{d}{dt}\text{species}_5 = 2 v_4 - v_5 \quad (106)$$

11.6 Species `species_6`

Name NAD+

Initial amount 0.186 mmol

Involved in rule `species_6`

This species takes part in four reactions (as a reactant in `reaction_5` and as a product in `reaction_7` and as a modifier in `reaction_5`, `reaction_7`). Not these but one rule determines the species' quantity because this species is on the boundary of the reaction system.

11.7 Species `species_7`

Name NADH

Initial amount 0.026 mmol

This species takes part in five reactions (as a reactant in [reaction_7](#), [mitochondrial_respiration](#) and as a product in [reaction_5](#) and as a modifier in [reaction_5](#), [reaction_7](#)).

$$\frac{d}{dt}\text{species_7} = v_5 - v_7 - v_{14} \quad (107)$$

11.8 Species `species_8`

Name PYR

Initial amount 0.16 mmol

This species takes part in four reactions (as a reactant in [reaction_7](#), [mitochondrial_respiration](#) and as a product in [reaction_6](#) and as a modifier in [reaction_7](#)).

$$\frac{d}{dt}\text{species_8} = v_6 - v_7 - v_{14} \quad (108)$$

11.9 Species `species_9`

Name PEP

Initial amount 0.02 mmol

This species takes part in three reactions (as a reactant in [reaction_6](#) and as a product in [reaction_5](#) and as a modifier in [reaction_6](#)).

$$\frac{d}{dt}\text{species_9} = v_5 - v_6 \quad (109)$$

11.10 Species `species_10`

Name LAC

Initial amount 1 mmol

This species takes part in four reactions (as a reactant in [reaction_8](#) and as a product in [reaction_7](#) and as a modifier in [reaction_7](#), [reaction_8](#)).

$$\frac{d}{dt}\text{species_10} = v_7 - v_8 \quad (110)$$

11.11 Species `species_11`

Name PCr

Initial amount 5 mmol

This species takes part in two reactions (as a reactant in [reaction_9](#) and as a modifier in [reaction_9](#)).

$$\frac{d}{dt}\text{species_11} = -v_9 \quad (111)$$

11.12 Species `species_12`

Name Cr

Initial amount 5 mmol

Involved in rule [species_12](#)

This species takes part in two reactions (as a product in [reaction_9](#) and as a modifier in [reaction_9](#)). Not these but one rule determines the species' quantity because this species is on the boundary of the reaction system.

11.13 Species `species_13`

Name O2

Initial amount 0.0262 mmol

This species takes part in three reactions (as a reactant in [mitochondrial_respiration](#) and as a product in [reaction_10](#) and as a modifier in [reaction_10](#)).

$$\frac{d}{dt}\text{species_13} = v_{10} - 3 v_{14} \quad (112)$$

11.14 Species `species_14`

Name O2

Initial amount 8.34 mmol

This species takes part in four reactions (as a reactant in [reaction_11](#) and as a modifier in [reaction_11](#), [inflow_of_dHb](#), [inflow_of_dHb](#)), which do not influence its rate of change because this constant species is on the boundary of the reaction system:

$$\frac{d}{dt}\text{species_14} = 0 \quad (113)$$

11.15 Species `species_15`

Name GLC

Initial amount 4.8 mmol

This species takes part in two reactions (as a reactant in [reaction_12](#) and as a modifier in [reaction_12](#)), which do not influence its rate of change because this constant species is on the boundary of the reaction system:

$$\frac{d}{dt}\text{species_15} = 0 \quad (114)$$

11.16 Species `species_16`

Name LAC

Initial amount 0.313 mmol

This species takes part in two reactions (as a reactant in [reaction_13](#) and as a modifier in [reaction_13](#)), which do not influence its rate of change because this constant species is on the boundary of the reaction system:

$$\frac{d}{dt}\text{species_16} = 0 \quad (115)$$

11.17 Species `species_17`

Name GLC

Initial amount 4.56 mmol

This species takes part in four reactions (as a reactant in [reaction_3](#) and as a product in [reaction_12](#) and as a modifier in [reaction_3](#), [reaction_12](#)).

$$\frac{d}{dt}\text{species_17} = v_{12} - 100 v_3 \quad (116)$$

11.18 Species `species_18`

Name LAC

Initial amount 0.35 mmol

This species takes part in four reactions (as a product in [reaction_8](#), [reaction_13](#) and as a modifier in [reaction_8](#), [reaction_13](#)).

$$\frac{d}{dt}\text{species_18} = 100 v_8 + v_{13} \quad (117)$$

11.19 Species species_19

Name O2

Initial amount 7.01 mmol

This species takes part in six reactions (as a reactant in [reaction_10](#) and as a product in [reaction_11](#) and as a modifier in [reaction_10](#), [reaction_11](#), [inflow_of_dHb](#), [inflow_of_dHb](#)).

$$\frac{d}{dt} \text{species_19} = v_{11} - 100 v_{10} \quad (118)$$

11.20 Species dHb

Name dHb

Initial amount 0.0630000000000001 mmol

This species takes part in three reactions (as a reactant in [outflow_of_dHb](#) and as a product in [inflow_of_dHb](#) and as a modifier in [outflow_of_dHb](#)).

$$\frac{d}{dt} \text{dHb} = v_{17} - v_{18} \quad (119)$$

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