SBML Model Report

Model name: "Markevich2004_MAPK-_phosphoRandomElementary"

May 6, 2016

1 General Overview

This is a document in SBML Level 2 Version 4 format. This model was created by Nicolas Le Novre[1] at May 23rd 2005 at 4:11 p. m. and last time modified at May 15th 2012 at 9:42 p. m. Table 1 gives 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	1
species types	0	species	16
events	0	constraints	0
reactions	17	function definitions	0
global parameters	27	unit definitions	1
rules	0	initial assignments	0

Model Notes

The model corresponds to the schema 3 of Markevich et al 2004, as described in the figure 2 and the supplementary table S2. Phosphorylations follow distributive random kinetics, while dephosphorylations follow an ordered mechanism. The phosphorylations are modeled with three elementary reactions:
E+S<=>ES->E+P

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The dephosphorylations are modeled with five elementary reactions:
E+S<=>ES->EP<=>E+P
The model reproduces figure 5 in the main article.

The model is further described in:

Signaling switches and bistability arising from multisite phosphorylation in protein kinase cascades. Markevich NI, Hoek JB, Kholodenko BN. J Cell Biol. 2004 Feb 2;164(3):353-9.
PMID: 14744999 ; DOI: 10.1083/jcb.200308060

Abstract:
Mitogen-activated protein kinase (MAPK) cascades can operate as bistable switches residing in either of two different stable states. MAPK cascades are often embedded in positive feedback loops, which are considered to be a prerequisite for bistable behavior. Here we demonstrate that in the absence of any imposed feedback regulation, bistability and hysteresis can arise solely from a distributive kinetic mechanism of the two-site MAPK phosphorylation and dephosphorylation. Importantly, the reported kinetic properties of the kinase (MEK) and phosphatase (MKP3) of extracellular signal-regulated kinase (ERK) fulfill the essential requirements for generating a bistable switch at a single MAPK cascade level. Likewise, a cycle where multisite phosphorylations are performed by different kinases, but dephosphorylation reactions are catalyzed by the same phosphatase, can also exhibit bistability and hysteresis. Hence, bistability induced by multisite covalent modification may be a widespread mechanism of the control of protein activity.

2 Unit Definitions

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

2.1 Unit `substance`

Name nanomole (default)

Definition nmol

2.2 Unit `volume`

Notes Litre is the predefined SBML unit for `volume`.

Definition l

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 Compartment

This model contains one compartment.

Table 2: Properties of all compartments.

Id	Name	SBO	Spatial Dimensions	Size	Unit	Constant	Outside
`cell`	cell		3	1	litre	☑	

3.1 Compartment `cell`

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

Name cell

4 Species

This model contains 16 species. Section 7 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
M	ERK	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
MpY	ERK-PY	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
MpT	ERK-PT	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
Mpp	ERK-PP	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
MEK	MEK	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
MKP3	MKP3	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
MpY_MEK	ERK-PY_MEK	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
MpT_MEK	ERK-PT_MEK	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
M_MEK_Y	ERK_MEK_Y	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
M_MEK_T	ERK_MEK_T	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
Mpp_MKP3	ERK-PP_MKP3	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
MpY_MKP3	ERK-PY_MKP3	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
MpT_MKP3_Y	ERK-PT_MKP3_Y	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
MpT_MKP3_T	ERK-PT_MKP3_T	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
M_MKP3_T	ERK_MKP3_T	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
M_MKP3_Y	ERK_MKP3_Y	cell	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟

5 Parameters

This model contains 27 global parameters.

Table 4: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
k1	k1		0.005		☑
k_1	k_1		1.000		☑
k2	k2		1.080		☑
k3	k3		0.025		☑
k_3	k_3		1.000		☑
k4	k4		0.007		☑
k5	k5		0.050		☑
k_5	k_5		1.000		☑
k6	k6		0.008		☑
k7	k7		0.005		☑
k_7	k_7		1.000		☑
k8	k8		0.450		☑
h1	h1		0.045		☑
h_1	h_1		1.000		☑
h2	h2		0.092		☑
h3	h3		1.000		☑
h_3	h_3		0.010		☑
h4	h4		0.010		☑
h_4	h_4		1.000		☑
h5	h5		0.500		☑
h6	h6		0.086		☑
h_6	h_6		0.001		☑
h7	h7		0.010		☑
h_7	h_7		1.000		☑
h8	h8		0.470		☑
h9	h9		0.140		☑
h_9	h_9		0.002		☑

6 Reactions

This model contains 17 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

№	Id	Name	Reaction Equation	SBO
1	reaction_0000001	binding ERK and MEK	$M + MEK \rightleftharpoons M\_MEK\_Y$	
2	reaction_0000002	tyr phosphorylation of ERK	$M\_MEK\_Y \longrightarrow MpY + MEK$	
3	reaction_0000003	binding ERK-PY and MEK	$MpY + MEK \rightleftharpoons MpY\_MEK$	
4	reaction_0000004	thr phosphorylation of ERK	$MpY\_MEK \longrightarrow Mpp + MEK$	
5	reaction_0000005	binding ERK and MEK	$M + MEK \rightleftharpoons M\_MEK\_T$	
6	reaction_0000006	thr phosphorylation of ERK	$M\_MEK\_T \longrightarrow MpT + MEK$	
7	reaction_0000007	binding ERK-PT and MEK	$MpT + MEK \rightleftharpoons MpT\_MEK$	
8	reaction_0000008	tyr phosphorylation of ERK	$MpT\_MEK \longrightarrow Mpp + MEK$	
9	reaction_0000009	binding ERK-PP and MKP3	$Mpp + MKP3 \rightleftharpoons Mpp\_MKP3$	
10	reaction_0000010	dephosphorylation of tyr on ERK-PP	$Mpp\_MKP3 \longrightarrow MpT\_MKP3\_Y$	
11	reaction_0000011	dissociation ERK-PT and MKP3	$MpT\_MKP3\_Y \rightleftharpoons MpT + MKP3$	

№	Id	Name	Reaction Equation	SBO
12	reaction_0000012	dephosphorylation of ERK-PT	$\mathrm{MpT\_MKP3\_T} \longrightarrow \mathrm{M\_MKP3\_T}$	
13	reaction_0000013	binding ERK-PT and MKP3	$\mathrm{MpT} + \mathrm{MKP3} \rightleftharpoons \mathrm{MpT\_MKP3\_T}$	
14	reaction_0000014	dephosphorylation of ERK-PY	$\mathrm{MpY\_MKP3} \longrightarrow \mathrm{M\_MKP3\_Y}$	
15	reaction_0000015	dissociation ERK and MKP3	$\mathrm{M\_MKP3\_T} \rightleftharpoons \mathrm{M} + \mathrm{MKP3}$	
16	reaction_0000017	binding ERK-PY and MKP3	$\mathrm{MpY} + \mathrm{MKP3} \rightleftharpoons \mathrm{MpY\_MKP3}$	
17	reaction_0000019	Dissociation ERK and MKP3	$\mathrm{M\_MKP3\_Y} \rightleftharpoons \mathrm{M} + \mathrm{MKP3}$	

6.1 Reaction reaction_0000001

This is a reversible reaction of two reactants forming one product.

Name binding ERK and MEK

Reaction equation

$$\mathrm{M} + \mathrm{MEK} \rightleftharpoons \mathrm{M\_MEK\_Y} \tag{1}$$

Reactants

Table 6: Properties of each reactant.

Id	Name	SBO
M	ERK	
MEK	MEK	

Product

Table 7: Properties of each product.

Id	Name	SBO
M_MEK_Y	ERK_MEK_Y	

Kinetic Law

Derived unit contains undeclared units

$$v_1 = \mathrm{vol}\,(\mathrm{cell}) \cdot (\mathrm{k1} \cdot [\mathrm{M}] \cdot [\mathrm{MEK}] - \mathrm{k\_1} \cdot [\mathrm{M\_MEK\_Y}]) \tag{2}$$

6.2 Reaction reaction_0000002

This is an irreversible reaction of one reactant forming two products.

Name tyr phosphorylation of ERK

Reaction equation

$$\mathrm{M\_MEK\_Y} \longrightarrow \mathrm{MpY} + \mathrm{MEK} \tag{3}$$

Reactant

Table 8: Properties of each reactant.

Id	Name	SBO
M_MEK_Y	ERK_MEK_Y	

Products

Table 9: Properties of each product.

Id	Name	SBO
MpY	ERK-PY	
MEK	MEK	

Kinetic Law

Derived unit contains undeclared units

$$v_2 = \mathrm{vol}\,(\mathrm{cell}) \cdot \mathrm{k2} \cdot [\mathrm{M\_MEK\_Y}] \tag{4}$$

6.3 Reaction reaction_0000003

This is a reversible reaction of two reactants forming one product.

Name binding ERK-PY and MEK

Reaction equation

$$\mathrm{MpY} + \mathrm{MEK} \rightleftharpoons \mathrm{MpY\_MEK} \tag{5}$$

Reactants

Table 10: Properties of each reactant.

Id	Name	SBO
MpY	ERK-PY	
MEK	MEK	

Product

Table 11: Properties of each product.

Id	Name	SBO
MpY_MEK	ERK-PY_MEK	

Kinetic Law

Derived unit contains undeclared units

$$v_3 = \mathrm{vol}(\mathrm{cell}) \cdot (\mathrm{k3} \cdot [\mathrm{MpY}] \cdot [\mathrm{MEK}] - \mathrm{k\_3} \cdot [\mathrm{MpY\_MEK}]) \tag{6}$$

6.4 Reaction reaction_0000004

This is an irreversible reaction of one reactant forming two products.

Name thr phosphorylation of ERK

Reaction equation

$$\mathrm{MpY\_MEK} \longrightarrow \mathrm{Mpp} + \mathrm{MEK} \tag{7}$$

Reactant

Table 12: Properties of each reactant.

Id	Name	SBO
MpY_MEK	ERK-PY_MEK	

Products

Table 13: Properties of each product.

Id	Name	SBO
Mpp	ERK-PP	
MEK	MEK	

Kinetic Law

Derived unit contains undeclared units

$$v_4 = \mathrm{vol}(\mathrm{cell}) \cdot \mathrm{k4} \cdot [\mathrm{MpY\_MEK}] \tag{8}$$

6.5 Reaction reaction_0000005

This is a reversible reaction of two reactants forming one product.

Name binding ERK and MEK

Reaction equation

$$\mathrm{M} + \mathrm{MEK} \rightleftharpoons \mathrm{M\_MEK\_T} \tag{9}$$

Reactants

Table 14: Properties of each reactant.

Id	Name	SBO
M	ERK	
MEK	MEK	

Product

Table 15: Properties of each product.

Id	Name	SBO
M_MEK_T	ERK_MEK_T	

Kinetic Law

Derived unit contains undeclared units

$$v_5 = \mathrm{vol}\,(\mathrm{cell}) \cdot (\mathrm{k5} \cdot [\mathrm{M}] \cdot [\mathrm{MEK}] - \mathrm{k\_5} \cdot [\mathrm{M\_MEK\_T}]) \tag{10}$$

6.6 Reaction reaction_0000006

This is an irreversible reaction of one reactant forming two products.

Name thr phosphorylation of ERK

Reaction equation

$$\mathrm{M\_MEK\_T} \longrightarrow \mathrm{MpT} + \mathrm{MEK} \tag{11}$$

Reactant

Table 16: Properties of each reactant.

Id	Name	SBO
M_MEK_T	ERK_MEK_T	

Products

Table 17: Properties of each product.

Id	Name	SBO
MpT	ERK-PT	
MEK	MEK	

Kinetic Law

Derived unit contains undeclared units

$$v_6 = \mathrm{vol}\,(\mathrm{cell}) \cdot \mathrm{k6} \cdot [\mathrm{M\_MEK\_T}] \tag{12}$$

6.7 Reaction reaction_0000007

This is a reversible reaction of two reactants forming one product.

Name binding ERK-PT and MEK

Reaction equation

$$\mathrm{MpT} + \mathrm{MEK} \rightleftharpoons \mathrm{MpT\_MEK} \tag{13}$$

Reactants

Table 18: Properties of each reactant.

Id	Name	SBO
MpT	ERK-PT	
MEK	MEK	

Product

Table 19: Properties of each product.

Id	Name	SBO
MpT_MEK	ERK-PT_MEK	

Kinetic Law

Derived unit contains undeclared units

$$v_7 = \mathrm{vol}\,(\mathrm{cell}) \cdot (\mathrm{k7} \cdot [\mathrm{MpT}] \cdot [\mathrm{MEK}] - \mathrm{k\_7} \cdot [\mathrm{MpT\_MEK}]) \tag{14}$$

6.8 Reaction reaction_0000008

This is an irreversible reaction of one reactant forming two products.

Name tyr phosphorylation of ERK

Reaction equation

$$\mathrm{MpT\_MEK} \longrightarrow \mathrm{Mpp} + \mathrm{MEK} \tag{15}$$

Reactant

Table 20: Properties of each reactant.

Id	Name	SBO
MpT_MEK	ERK-PT_MEK	

Products

Table 21: Properties of each product.

Id	Name	SBO
Mpp	ERK-PP	
MEK	MEK	

Kinetic Law

Derived unit contains undeclared units

$$v_8 = \mathrm{vol}\,(\mathrm{cell}) \cdot \mathrm{k8} \cdot [\mathrm{MpT\_MEK}] \tag{16}$$

6.9 Reaction reaction_0000009

This is a reversible reaction of two reactants forming one product.

Name binding ERK-PP and MKP3

Reaction equation

$$\mathrm{Mpp} + \mathrm{MKP3} \rightleftharpoons \mathrm{Mpp\_MKP3} \tag{17}$$

Reactants

Table 22: Properties of each reactant.

Id	Name	SBO
Mpp	ERK-PP	
MKP3	MKP3	

Product

Table 23: Properties of each product.

Id	Name	SBO
Mpp_MKP3	ERK-PP_MKP3	

Kinetic Law

Derived unit contains undeclared units

$$v_9 = \mathrm{vol}\,(\mathrm{cell}) \cdot (\mathrm{h1} \cdot [\mathrm{Mpp}] \cdot [\mathrm{MKP3}] - \mathrm{h\_1} \cdot [\mathrm{Mpp\_MKP3}]) \tag{18}$$

6.10 Reaction reaction_0000010

This is an irreversible reaction of one reactant forming one product.

Name dephosphorylation of tyr on ERK-PP

Reaction equation

$$\mathrm{Mpp\_MKP3} \longrightarrow \mathrm{MpT\_MKP3\_Y} \tag{19}$$

Reactant

Table 24: Properties of each reactant.

Id	Name	SBO
Mpp_MKP3	ERK-PP_MKP3	

Product

Table 25: Properties of each product.

Id	Name	SBO
MpT_MKP3_Y	ERK-PT_MKP3_Y	

Kinetic Law

Derived unit contains undeclared units

$$v_{10} = \mathrm{vol}\,(\mathrm{cell}) \cdot \mathrm{h2} \cdot [\mathrm{Mpp\_MKP3}] \tag{20}$$

6.11 Reaction reaction_0000011

This is a reversible reaction of one reactant forming two products.

Name dissociation ERK-PT and MKP3

Reaction equation

$$\mathrm{MpT\_MKP3\_Y} \rightleftharpoons \mathrm{MpT} + \mathrm{MKP3} \tag{21}$$

Reactant

Table 26: Properties of each reactant.

Id	Name	SBO
MpT_MKP3_Y	ERK-PT_MKP3_Y	

Products

Table 27: Properties of each product.

Id	Name	SBO
MpT	ERK-PT	
MKP3	MKP3	

Id	Name	SBO

Kinetic Law

Derived unit contains undeclared units

$$v_{11} = \mathrm{vol}(\mathrm{cell}) \cdot (\mathrm{h3} \cdot [\mathrm{MpT\_MKP3\_Y}] - \mathrm{h\_3} \cdot [\mathrm{MpT}] \cdot [\mathrm{MKP3}]) \tag{22}$$

6.12 Reaction `reaction_0000012`

This is an irreversible reaction of one reactant forming one product.

Name dephosphorylation of ERK-PT

Reaction equation

$$\mathrm{MpT\_MKP3\_T} \longrightarrow \mathrm{M\_MKP3\_T} \tag{23}$$

Reactant

Table 28: Properties of each reactant.

Id	Name	SBO
`MpT_MKP3_T`	ERK-PT_MKP3_T	

Product

Table 29: Properties of each product.

Id	Name	SBO
`M_MKP3_T`	ERK_MKP3_T	

Kinetic Law

Derived unit contains undeclared units

$$v_{12} = \mathrm{vol}(\mathrm{cell}) \cdot \mathrm{h5} \cdot [\mathrm{MpT\_MKP3\_T}] \tag{24}$$

6.13 Reaction `reaction_0000013`

This is a reversible reaction of two reactants forming one product.

Name binding ERK-PT and MKP3

Reaction equation

$$\mathrm{MpT} + \mathrm{MKP3} \rightleftharpoons \mathrm{MpT\_MKP3\_T} \tag{25}$$

Reactants

Table 30: Properties of each reactant.

Id	Name	SBO
MpT	ERK-PT	
MKP3	MKP3	

Product

Table 31: Properties of each product.

Id	Name	SBO
MpT_MKP3_T	ERK-PT_MKP3_T	

Kinetic Law

Derived unit contains undeclared units

$$v_{13} = \mathrm{vol}\,(\mathrm{cell}) \cdot (\mathrm{h4} \cdot [\mathrm{MpT}] \cdot [\mathrm{MKP3}] - \mathrm{h\_4} \cdot [\mathrm{MpT\_MKP3\_T}]) \tag{26}$$

6.14 Reaction reaction_0000014

This is an irreversible reaction of one reactant forming one product.

Name dephosphorylation of ERK-PY

Reaction equation

$$\mathrm{MpY\_MKP3} \longrightarrow \mathrm{M\_MKP3\_Y} \tag{27}$$

Reactant

Table 32: Properties of each reactant.

Id	Name	SBO
MpY_MKP3	ERK-PY_MKP3	

Product

Table 33: Properties of each product.

Id	Name	SBO
M_MKP3_Y	ERK_MKP3_Y	

Kinetic Law

Derived unit contains undeclared units

$$v_{14} = \mathrm{vol}\,(\mathrm{cell}) \cdot \mathrm{h8} \cdot [\mathrm{MpY\_MKP3}] \tag{28}$$

6.15 Reaction reaction_0000015

This is a reversible reaction of one reactant forming two products.

Name dissociation ERK and MKP3

Reaction equation

$$\mathrm{M\_MKP3\_T} \rightleftharpoons \mathrm{M} + \mathrm{MKP3} \tag{29}$$

Reactant

Table 34: Properties of each reactant.

Id	Name	SBO
M_MKP3_T	ERK_MKP3_T	

Products

Table 35: Properties of each product.

Id	Name	SBO
M	ERK	
MKP3	MKP3	

Kinetic Law

Derived unit contains undeclared units

$$v_{15} = \mathrm{vol}\,(\mathrm{cell}) \cdot (\mathrm{h6} \cdot [\mathrm{M\_MKP3\_T}] - \mathrm{h\_6} \cdot [\mathrm{M}] \cdot [\mathrm{MKP3}]) \tag{30}$$

6.16 Reaction reaction_0000017

This is a reversible reaction of two reactants forming one product.

Name binding ERK-PY and MKP3

Reaction equation

$$\mathrm{MpY} + \mathrm{MKP3} \rightleftharpoons \mathrm{MpY\_MKP3} \tag{31}$$

Reactants

Table 36: Properties of each reactant.

Id	Name	SBO
MpY	ERK-PY	
MKP3	MKP3	

Product

Table 37: Properties of each product.

Id	Name	SBO
MpY_MKP3	ERK-PY_MKP3	

Kinetic Law

Derived unit contains undeclared units

$$v_{16} = \mathrm{vol}\,(\mathrm{cell}) \cdot (\mathrm{h7} \cdot [\mathrm{MpY}] \cdot [\mathrm{MKP3}] - \mathrm{h\_7} \cdot [\mathrm{MpY\_MKP3}]) \tag{32}$$

6.17 Reaction reaction_0000019

This is a reversible reaction of one reactant forming two products.

Name Dissociation ERK and MKP3

Reaction equation

$$\mathrm{M\_MKP3\_Y} \rightleftharpoons \mathrm{M} + \mathrm{MKP3} \tag{33}$$

Reactant

Table 38: Properties of each reactant.

Id	Name	SBO
M_MKP3_Y	ERK_MKP3_Y	

Products

Table 39: Properties of each product.

Id	Name	SBO
M	ERK	
MKP3	MKP3	

Kinetic Law

Derived unit contains undeclared units

$$v_{17} = \mathrm{vol}\,(\mathrm{cell}) \cdot (\mathrm{h9} \cdot [\mathrm{M\_MKP3\_Y}] - \mathrm{h\_9} \cdot [\mathrm{M}] \cdot [\mathrm{MKP3}]) \tag{34}$$

7 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.

7.1 Species M

Name ERK

Initial concentration $800\ \mathrm{nmol} \cdot \mathrm{l}^{-1}$

This species takes part in four reactions (as a reactant in reaction_0000001, reaction_0000005 and as a product in reaction_0000015, reaction_0000019).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{M} = v_{15} + v_{17} - v_1 - v_5 \tag{35}$$

7.2 Species MpY

Name ERK-PY

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in reaction_0000003, reaction_0000017 and as a product in reaction_0000002).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{MpY} = v_2 - v_3 - v_{16} \tag{36}$$

7.3 Species MpT

Name ERK-PT

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in four reactions (as a reactant in reaction_0000007, reaction_0000013 and as a product in reaction_0000006, reaction_0000011).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{MpT} = v_6 + v_{11} - v_7 - v_{13} \tag{37}$$

7.4 Species Mpp

Name ERK-PP

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in reaction_0000009 and as a product in reaction_0000004, reaction_0000008).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{Mpp} = v_4 + v_8 - v_9 \tag{38}$$

7.5 Species MEK

Name MEK

Initial concentration $180\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in eight reactions (as a reactant in reaction_0000001, reaction_0000003, reaction_0000005, reaction_0000007 and as a product in reaction_0000002, reaction_0000004, reaction_0000006, reaction_0000008).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{MEK} = v_2 + v_4 + v_6 + v_8 - v_1 - v_3 - v_5 - v_7 \tag{39}$$

7.6 Species MKP3

Name MKP3

Initial concentration $100\ \mathrm{nmol} \cdot \mathrm{l}^{-1}$

This species takes part in six reactions (as a reactant in reaction_0000009, reaction_0000013, reaction_0000017 and as a product in reaction_0000011, reaction_0000015, reaction_0000019).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{MKP3} = v_{11} + v_{15} + v_{17} - v_{9} - v_{13} - v_{16} \tag{40}$$

7.7 Species MpY_MEK

Name ERK-PY_MEK

Initial concentration $0\ \mathrm{nmol} \cdot \mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000004 and as a product in reaction_0000003).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{MpY\_MEK} = v_{3} - v_{4} \tag{41}$$

7.8 Species MpT_MEK

Name ERK-PT_MEK

Initial concentration $0\ \mathrm{nmol} \cdot \mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000008 and as a product in reaction_0000007).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{MpT\_MEK} = v_{7} - v_{8} \tag{42}$$

7.9 Species M_MEK_Y

Name ERK_MEK_Y

Initial concentration $0\ \mathrm{nmol} \cdot \mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000002 and as a product in reaction_0000001).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{M\_MEK\_Y} = v_{1} - v_{2} \tag{43}$$

7.10 Species M_MEK_T

Name ERK_MEK_T

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000006 and as a product in reaction_0000005).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{M\_MEK\_T} = v_5 - v_6 \tag{44}$$

7.11 Species Mpp_MKP3

Name ERK-PP_MKP3

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000010 and as a product in reaction_0000009).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{Mpp\_MKP3} = v_9 - v_{10} \tag{45}$$

7.12 Species MpY_MKP3

Name ERK-PY_MKP3

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000014 and as a product in reaction_0000017).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{MpY\_MKP3} = v_{16} - v_{14} \tag{46}$$

7.13 Species MpT_MKP3_Y

Name ERK-PT_MKP3_Y

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000011 and as a product in reaction_0000010).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{MpT\_MKP3\_Y} = v_{10} - v_{11} \tag{47}$$

7.14 Species MpT_MKP3_T

Name ERK-PT_MKP3_T

Initial concentration $0\ \mathrm{nmol} \cdot \mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000012 and as a product in reaction_0000013).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{MpT\_MKP3\_T} = v_{13} - v_{12} \tag{48}$$

7.15 Species M_MKP3_T

Name ERK_MKP3_T

Initial concentration $0\ \mathrm{nmol} \cdot \mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000015 and as a product in reaction_0000012).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{M\_MKP3\_T} = v_{12} - v_{15} \tag{49}$$

7.16 Species M_MKP3_Y

Name ERK_MKP3_Y

Initial concentration $0\ \mathrm{nmol} \cdot \mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_0000019 and as a product in reaction_0000014).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{M\_MKP3\_Y} = v_{14} - v_{17} \tag{50}$$

SBML2LaTeX was developed by Andreas Dräger[a], Hannes Planatscher[a], Dieudonné M Wouamba[a], Adrian Schröder[a], Michael Hucka[b], Lukas Endler[c], Martin Golebiewski[d] and Andreas Zell[a]. Please see http://www.ra.cs.uni-tuebingen.de/software/SBML2LaTeX for more information.

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