

## SBML Model Report

**Model name: “Markevich2004\_MAPK-  
\_phosphoRandomElementary”**



May 6, 2016

### 1 General Overview

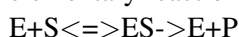
This is a document in SBML Level 2 Version 4 format. This model was created by Nicolas Le Novre<sup>1</sup> at May 23<sup>rd</sup> 2005 at 4:11 p. m. and last time modified at May 15<sup>th</sup> 2012 at 9:42 p. m. Table 1 gives an overview of the quantities of all components of this model.

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

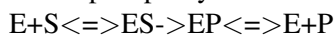
The model corresponds to the schema 3 of Markevich et al 2004, as described in the figure 2 and the supplementary table S2. Phosphorylations follow distributive random kinetics, while dephosphorylations follow an ordered mechanism. The phosphorylations are modeled with three elementary reactions:



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The dephosphorylations are modeled with five elementary reactions:



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.

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To cite BioModels Database, please use: Li C, Donizelli M, Rodriguez N, Dharuri H, Endler L, Chelliah V, Li L, He E, Henry A, Stefan MI, Snoep JL, Hucka M, Le Novre N, Laibe C (2010) BioModels Database: An enhanced, curated and annotated resource for published quantitative kinetic models. BMC Syst Biol., 4:92.

## 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** 1

### 2.3 Unit `area`

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

**Definition**  $\text{m}^2$

### 2.4 Unit `length`

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

**Definition**  $\text{m}$

### 2.5 Unit `time`

**Notes** Second is the predefined SBML unit for time.

**Definition**  $\text{s}$

## 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	<input checked="" type="checkbox"/>	

### 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	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
MpY	ERK-PY	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
MpT	ERK-PT	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
Mpp	ERK-PP	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
MEK	MEK	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
MKP3	MKP3	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
MpY_MEK	ERK-PY_MEK	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
MpT_MEK	ERK-PT_MEK	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
M_MEK_Y	ERK_MEK_Y	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
M_MEK_T	ERK_MEK_T	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
Mpp_MKP3	ERK-PP_MKP3	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
MpY_MKP3	ERK-PY_MKP3	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
MpT_MKP3_Y	ERK-PT_MKP3_Y	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
MpT_MKP3_T	ERK-PT_MKP3_T	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
M_MKP3_T	ERK_MKP3_T	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$
M_MKP3_Y	ERK_MKP3_Y	cell	$\text{nmol} \cdot \text{l}^{-1}$	$\square$	$\square$

## 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

Nº	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	$MpT\_MKP3\_Y \rightleftharpoons MpT + MKP3$	

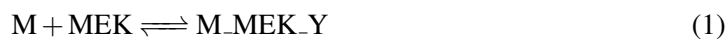
Nº	Id	Name	Reaction Equation	SBO
12	reaction- _0000012	dephosphorylation of ERK-PT	$\text{MpT\_MKP3\_T} \longrightarrow \text{M\_MKP3\_T}$	
13	reaction- _0000013	binding ERK-PT and MKP3	$\text{MpT} + \text{MKP3} \rightleftharpoons \text{MpT\_MKP3\_T}$	
14	reaction- _0000014	dephosphorylation of ERK-PY	$\text{MpY\_MKP3} \longrightarrow \text{M\_MKP3\_Y}$	
15	reaction- _0000015	dissociation ERK and MKP3	$\text{M\_MKP3\_T} \rightleftharpoons \text{M} + \text{MKP3}$	
16	reaction- _0000017	binding ERK-PY and MKP3	$\text{MpY} + \text{MKP3} \rightleftharpoons \text{MpY\_MKP3}$	
17	reaction- _0000019	Dissociation ERK and MKP3	$\text{M\_MKP3\_Y} \rightleftharpoons \text{M} + \text{MKP3}$	

## 6.1 Reaction [reaction\\_0000001](#)

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

**Name** binding ERK and MEK

### Reaction equation



### 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

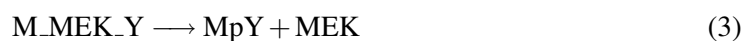
$$v_1 = \text{vol}(\text{cell}) \cdot (k_1 \cdot [M] \cdot [MEK] - k_{-1} \cdot [M\_MEK\_Y]) \quad (2)$$

## 6.2 Reaction [reaction\\_0000002](#)

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

**Name** tyr phosphorylation of ERK

### Reaction equation



### 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

$$v_2 = \text{vol}(\text{cell}) \cdot k_2 \cdot [\text{M\_MEK\_Y}] \quad (4)$$

## 6.3 Reaction `reaction_0000003`

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

**Name** binding ERK-PY and MEK

## Reaction equation



## 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

$$v_3 = \text{vol}(\text{cell}) \cdot (k_3 \cdot [\text{MpY}] \cdot [\text{MEK}] - k_{-3} \cdot [\text{MpY\_MEK}]) \quad (6)$$

## 6.4 Reaction `reaction_00000004`

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

**Name** thr phosphorylation of ERK

### Reaction equation



### 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

$$v_4 = \text{vol}(\text{cell}) \cdot k_4 \cdot [\text{MpY\_MEK}] \quad (8)$$

## 6.5 Reaction [reaction\\_0000005](#)

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

**Name** binding ERK and MEK

### Reaction equation



### 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

$$v_5 = \text{vol}(\text{cell}) \cdot (k_5 \cdot [M] \cdot [MEK] - k_{-5} \cdot [M\_MEK\_T]) \quad (10)$$

## 6.6 Reaction [reaction\\_0000006](#)

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

**Name** thr phosphorylation of ERK

### Reaction equation



### 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

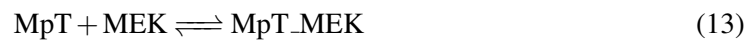
$$v_6 = \text{vol}(\text{cell}) \cdot k_6 \cdot [\text{M\_MEK\_T}] \quad (12)$$

## 6.7 Reaction `reaction_0000007`

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

**Name** binding ERK-PT and MEK

## Reaction equation



## 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

$$v_7 = \text{vol}(\text{cell}) \cdot (k_7 \cdot [\text{MpT}] \cdot [\text{MEK}] - k_{-7} \cdot [\text{MpT\_MEK}]) \quad (14)$$

**6.8 Reaction** reaction\_0000008

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

**Name** tyr phosphorylation of ERK**Reaction equation****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

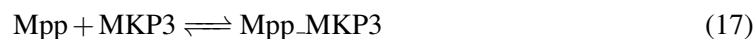
$$v_8 = \text{vol}(\text{cell}) \cdot k_8 \cdot [\text{MpT\_MEK}] \quad (16)$$

## 6.9 Reaction [reaction\\_0000009](#)

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

**Name** binding ERK-PP and MKP3

### Reaction equation



### 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

$$v_9 = \text{vol}(\text{cell}) \cdot (h_1 \cdot [\text{Mpp}] \cdot [\text{MKP3}] - h_{-1} \cdot [\text{Mpp\_MKP3}]) \quad (18)$$

## 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



### 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

$$v_{10} = \text{vol}(\text{cell}) \cdot h_2 \cdot [\text{Mpp\_MKP3}] \quad (20)$$

## 6.11 Reaction `reaction_0000011`

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

**Name** dissociation ERK-PT and MKP3

## Reaction equation



## 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
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### Kinetic Law

**Derived unit** contains undeclared units

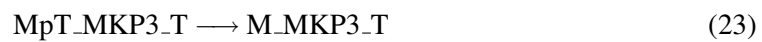
$$v_{11} = \text{vol}(\text{cell}) \cdot (h_3 \cdot [\text{MpT\_MKP3\_Y}] - h_{-3} \cdot [\text{MpT}] \cdot [\text{MKP3}]) \quad (22)$$

### 6.12 Reaction [reaction\\_0000012](#)

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

**Name** dephosphorylation of ERK-PT

### Reaction equation



### 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

$$v_{12} = \text{vol}(\text{cell}) \cdot h_5 \cdot [\text{MpT\_MKP3\_T}] \quad (24)$$

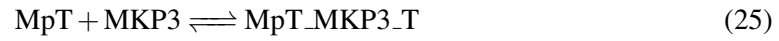
### 6.13 Reaction [reaction\\_0000013](#)

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

**Name** binding ERK-PT and MKP3



### Reaction equation



### 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

$$v_{13} = \text{vol}(\text{cell}) \cdot (h_4 \cdot [\text{MpT}] \cdot [\text{MKP3}] - h_{-4} \cdot [\text{MpT\_MKP3\_T}]) \quad (26)$$

### 6.14 Reaction [reaction\\_0000014](#)

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

**Name** dephosphorylation of ERK-PY

### Reaction equation



### 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

$$v_{14} = \text{vol}(\text{cell}) \cdot h_8 \cdot [\text{MpY\_MKP3}] \quad (28)$$

## 6.15 Reaction `reaction_0000015`

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

**Name** dissociation ERK and MKP3

## Reaction equation



## 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

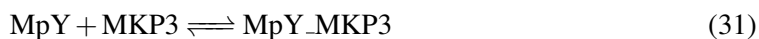
$$v_{15} = \text{vol}(\text{cell}) \cdot (h_6 \cdot [\text{M\_MKP3\_T}] - h_6 \cdot [\text{M}] \cdot [\text{MKP3}]) \quad (30)$$

## 6.16 Reaction [reaction\\_0000017](#)

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

**Name** binding ERK-PY and MKP3

### Reaction equation



### 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

$$v_{16} = \text{vol}(\text{cell}) \cdot (h_7 \cdot [\text{MpY}] \cdot [\text{MKP3}] - h_{-7} \cdot [\text{MpY\_MKP3}]) \quad (32)$$

## 6.17 Reaction [reaction\\_0000019](#)

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

**Name** Dissociation ERK and MKP3

### Reaction equation



### 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

$$v_{17} = \text{vol}(\text{cell}) \cdot (h_9 \cdot [\text{M\_MKP3\_Y}] - h_{-9} \cdot [\text{M}] \cdot [\text{MKP3}]) \quad (34)$$

## 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**  $800 \text{ nmol} \cdot \text{l}^{-1}$

This species takes part in four reactions (as a reactant in [reaction\\_0000001](#), [reaction\\_0000005](#) and as a product in [reaction\\_0000015](#), [reaction\\_0000019](#)).

$$\frac{d}{dt}M = v_{15} + v_{17} - v_1 - v_5 \quad (35)$$

## 7.2 Species $\text{MpY}$

**Name** ERK-PY

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

This species takes part in three reactions (as a reactant in [reaction\\_0000003](#), [reaction\\_0000017](#) and as a product in [reaction\\_0000002](#)).

$$\frac{d}{dt}\text{MpY} = v_2 - v_3 - v_{16} \quad (36)$$

## 7.3 Species $\text{MpT}$

**Name** ERK-PT

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

This species takes part in four reactions (as a reactant in [reaction\\_0000007](#), [reaction\\_0000013](#) and as a product in [reaction\\_0000006](#), [reaction\\_0000011](#)).

$$\frac{d}{dt}\text{MpT} = v_6 + v_{11} - v_7 - v_{13} \quad (37)$$

## 7.4 Species $\text{Mpp}$

**Name** ERK-PP

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

This species takes part in three reactions (as a reactant in [reaction\\_0000009](#) and as a product in [reaction\\_0000004](#), [reaction\\_0000008](#)).

$$\frac{d}{dt}\text{Mpp} = v_4 + v_8 - v_9 \quad (38)$$

## 7.5 Species $\text{MEK}$

**Name** MEK

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

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](#)).

$$\frac{d}{dt}\text{MEK} = v_2 + v_4 + v_6 + v_8 - v_1 - v_3 - v_5 - v_7 \quad (39)$$

## 7.6 Species MKP3

**Name** MKP3

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

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](#)).

$$\frac{d}{dt}\text{MKP3} = v_{11} + v_{15} + v_{17} - v_9 - v_{13} - v_{16} \quad (40)$$

## 7.7 Species MpY\_MEK

**Name** ERK-PY\_MEK

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

This species takes part in two reactions (as a reactant in [reaction\\_0000004](#) and as a product in [reaction\\_0000003](#)).

$$\frac{d}{dt}\text{MpY\_MEK} = v_3 - v_4 \quad (41)$$

## 7.8 Species MpT\_MEK

**Name** ERK-PT\_MEK

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

This species takes part in two reactions (as a reactant in [reaction\\_0000008](#) and as a product in [reaction\\_0000007](#)).

$$\frac{d}{dt}\text{MpT\_MEK} = v_7 - v_8 \quad (42)$$

## 7.9 Species M\_MEK\_Y

**Name** ERK\_MEK\_Y

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

This species takes part in two reactions (as a reactant in [reaction\\_0000002](#) and as a product in [reaction\\_0000001](#)).

$$\frac{d}{dt}\text{M\_MEK\_Y} = v_1 - v_2 \quad (43)$$

### 7.10 Species `M_MEK_T`

**Name** `ERK_MEK_T`

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

This species takes part in two reactions (as a reactant in [reaction\\_0000006](#) and as a product in [reaction\\_0000005](#)).

$$\frac{d}{dt} \text{M\_MEK\_T} = v_5 - v_6 \quad (44)$$

### 7.11 Species `Mpp_MKP3`

**Name** `ERK-PP_MKP3`

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

This species takes part in two reactions (as a reactant in [reaction\\_0000010](#) and as a product in [reaction\\_0000009](#)).

$$\frac{d}{dt} \text{Mpp\_MKP3} = v_9 - v_{10} \quad (45)$$

### 7.12 Species `MpY_MKP3`

**Name** `ERK-PY_MKP3`

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

This species takes part in two reactions (as a reactant in [reaction\\_0000014](#) and as a product in [reaction\\_0000017](#)).

$$\frac{d}{dt} \text{MpY\_MKP3} = v_{16} - v_{14} \quad (46)$$

### 7.13 Species `MpT_MKP3_Y`

**Name** `ERK-PT_MKP3_Y`

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

This species takes part in two reactions (as a reactant in [reaction\\_0000011](#) and as a product in [reaction\\_0000010](#)).

$$\frac{d}{dt} \text{MpT\_MKP3\_Y} = v_{10} - v_{11} \quad (47)$$

### 7.14 Species MpT\_MKP3\_T

**Name** ERK-PT\_MKP3\_T

**Initial concentration** 0 nmol · l<sup>-1</sup>

This species takes part in two reactions (as a reactant in [reaction\\_0000012](#) and as a product in [reaction\\_0000013](#)).

$$\frac{d}{dt}\text{MpT\_MKP3\_T} = v_{13} - v_{12} \quad (48)$$

### 7.15 Species M\_MKP3\_T

**Name** ERK\_MKP3\_T

**Initial concentration** 0 nmol · l<sup>-1</sup>

This species takes part in two reactions (as a reactant in [reaction\\_0000015](#) and as a product in [reaction\\_0000012](#)).

$$\frac{d}{dt}\text{M\_MKP3\_T} = v_{12} - v_{15} \quad (49)$$

### 7.16 Species M\_MKP3\_Y

**Name** ERK\_MKP3\_Y

**Initial concentration** 0 nmol · l<sup>-1</sup>

This species takes part in two reactions (as a reactant in [reaction\\_0000019](#) and as a product in [reaction\\_0000014](#)).

$$\frac{d}{dt}\text{M\_MKP3\_Y} = v_{14} - v_{17} \quad (50)$$

SBML<sup>2</sup>TeX was developed by Andreas Dräger<sup>a</sup>, Hannes Planatscher<sup>a</sup>, Dieudonné M Wouamba<sup>a</sup>, Adrian Schröder<sup>a</sup>, Michael Hucka<sup>b</sup>, Lukas Endler<sup>c</sup>, Martin Golebiewski<sup>d</sup> and Andreas Zell<sup>a</sup>. Please see <http://www.ra.cs.uni-tuebingen.de/software/SBML2LaTeX> for more information.

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