

## SBML Model Report

# Model name: “Schilling2009 - ERK distributive”



April 23, 2015

## 1 General Overview

This is a document in SBML Level 2 Version 4 format. This model was created by the following two authors: Lukas Endler<sup>1</sup> and Marcel Schilling<sup>2</sup> at October 27<sup>th</sup> 2010 at 4:50 p. m. and last time modified at April 23<sup>rd</sup> 2015 at 4:48 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	33
events	0	constraints	0
reactions	42	function definitions	0
global parameters	39	unit definitions	10
rules	9	initial assignments	0

## Model Notes

Schilling2009 - ERK distributive

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This model has been exported from [PottersWheel](#) on 2009-04-20 18:57:44. The PottersWheel Model Definition file can be obtained from the curation tab.

This model is described in the article: [Theoretical and experimental analysis links isoform-specific ERK signalling to cell fate decisions](#). Schilling M, Maiwald T, Hengl S, Winter D, Kreutz C, Kolch W, Lehmann WD, Timmer J, Klingmüller U. Mol. Syst. Biol. 2009; 5: 334

Abstract:

Cell fate decisions are regulated by the coordinated activation of signalling pathways such as the extracellular signal-regulated kinase (ERK) cascade, but contributions of individual kinase isoforms are mostly unknown. By combining quantitative data from erythropoietin-induced pathway activation in primary erythroid progenitor (colony-forming unit erythroid stage, CFU-E) cells with mathematical modelling, we predicted and experimentally confirmed a distributive ERK phosphorylation mechanism in CFU-E cells. Model analysis showed bow-tie-shaped signal processing and inherently transient signalling for cytokine-induced ERK signalling. Sensitivity analysis predicted that, through a feedback-mediated process, increasing one ERK isoform reduces activation of the other isoform, which was verified by protein over-expression. We calculated ERK activation for biochemically not addressable but physiologically relevant ligand concentrations showing that double-phosphorylated ERK1 attenuates proliferation beyond a certain activation level, whereas activated ERK2 enhances proliferation with saturation kinetics. Thus, we provide a quantitative link between earlier unobservable signalling dynamics and cell fate decisions.

This model is hosted on [BioModels Database](#) and identified by: [BIOMD0000000270](#).

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## 2 Unit Definitions

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

### 2.1 Unit substance

**Name** 10E4 molecules

**Definition**  $10^4 \cdot \text{item}$

### 2.2 Unit time

**Name** minutes

**Definition** 60 s

### 2.3 Unit volume

**Name** ml

**Definition** ml

### 2.4 Unit U

**Name** U

**Definition** dimensionless

### 2.5 Unit U\_per\_ml

**Name** U\_per\_ml

**Definition** dimensionless · ml<sup>-1</sup>

### 2.6 Unit ml\_per\_min\_per\_U

**Name** per min per (Uml)

**Definition** dimensionless<sup>-1</sup> · ml · (60 s)<sup>-1</sup>

### 2.7 Unit au

**Name** arb. units

**Definition** dimensionless

### 2.8 Unit au\_per\_molec

**Name** arb. unit. per 10000 molecules

**Definition** (10<sup>4</sup> · item)<sup>-1</sup> · ml · dimensionless

### 2.9 Unit per\_min

**Name** per minute

**Definition** (60 s)<sup>-1</sup>

### 2.10 Unit sec\_ord

**Name** second order rate constant

**Definition** (10<sup>4</sup> · item)<sup>-1</sup> · ml · (60 s)<sup>-1</sup>

## 2.11 Unit area

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

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

## 2.12 Unit length

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

**Definition** m

# 3 Compartment

This model contains one compartment.

Table 2: Properties of all compartments.

Id	Name	SBO	Spatial Dimensions	Size	Unit	Constant	Outside
cell	cell	0000290	3	1	litre	<input checked="" type="checkbox"/>	

## 3.1 Compartment cell

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

**Name** cell

**SBO:0000290** physical compartment

## 4 Species

This model contains 33 species. Section 8 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
JAK2		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
EpoR		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
SHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
SOS		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
Raf		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
MEK2		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
MEK1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
ERK1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
ERK2		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
pJAK2		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
pEpoR		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
mSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
actSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
mSOS		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
pRaf		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
ppMEK2		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
ppMEK1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
ppERK1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
ppERK2		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
pSOS		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
pMEK2		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$
pMEK1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	$\square$	$\square$

Id	Name	Compartment	Derived Unit	Constant	Boundary Condi- tion
pERK1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
pERK2		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Delay01_mSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Delay02_mSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Delay03_mSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Delay04_mSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Delay05_mSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Delay06_mSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Delay07_mSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Delay08_mSHP1		cell	$10^4 \cdot \text{item} \cdot \text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Epo		cell	dimensionless $\text{ml}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>

## 5 Parameters

This model contains 39 global parameters.

Table 4: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
JAK2- _phosphorylation- _by_Epo		0000036	0.012	$\text{dimensionless}^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
EpoR- _phosphorylation- _by_pJAK2		0000036	3.157	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
SHP1- _activation- _by_pEpoR		0000036	0.408	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
SHP1_delay		0000035	0.408	$(60 \text{ s})^{-1}$	✓
actSHP1- _deactivation		0000035	0.025	$(60 \text{ s})^{-1}$	✓
pEpoR- _dephosphorylation- _by_actSHP1		0000036	1.200	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
pJAK2- _dephosphorylation- _by_actSHP1		0000036	0.368	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
SOS- _recruitment- _by_pEpoR		0000036	0.103	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
mSOS- _release- _from- _membrane		0000035	15.596	$(60 \text{ s})^{-1}$	✓
mSOS- _induced_Raf- _phosphorylation		0000036	0.145	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
pRaf- _dephosphorylation		0000035	0.374	$(60 \text{ s})^{-1}$	✓
First_MEK2- _phosphorylation- _by_pRaf		0000036	3.119	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓

Id	Name	SBO	Value	Unit	Constant
Second_MEK2- _phosphorylation- _by_pRaf		0000036	215.158	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
First_MEK1- _phosphorylation- _by_pRaf		0000036	0.687	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
Second_MEK1- _phosphorylation- _by_pRaf		0000036	667.957	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
First_MEK- _dephosphorylation		0000035	0.131	$(60 \text{ s})^{-1}$	✓
Second_MEK- _dephosphorylation		0000035	0.073	$(60 \text{ s})^{-1}$	✓
First_ERK1- _phosphorylation- _by_ppMEK		0000036	2.493	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
Second_ERK1- _phosphorylation- _by_ppMEK		0000036	59.525	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
First_ERK2- _phosphorylation- _by_ppMEK		0000036	2.444	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
Second_ERK2- _phosphorylation- _by_ppMEK		0000036	53.082	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
First_ERK- _dephosphorylation		0000035	39.089	$(60 \text{ s})^{-1}$	✓
Second_ERK- _dephosphorylation		0000035	3.005	$(60 \text{ s})^{-1}$	✓
ppERK_neg- _feedback_on- _mSOS		0000036	5122.680	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot (60 \text{ s})^{-1}$	✓
pSOS- _dephosphorylation		0000035	0.125	$(60 \text{ s})^{-1}$	✓
scale_pEpoR	scale_pEpoR	0000381	0.493	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot \text{dimensionless}$	✓
scale_pJAK2	scale_pJAK2	0000381	0.210	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot \text{dimensionless}$	✓
scale_ppERK	scale_ppERK	0000381	13.598	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot \text{dimensionless}$	✓



Id	Name	SBO	Value	Unit	Constant
scale_SOS	scale_SOS	0000381	1.102	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot \text{dimensionless}$	<input checked="" type="checkbox"/>
scale_ppMEK	scale_ppMEK	0000381	40.536	$(10^4 \cdot \text{item})^{-1} \cdot \text{ml} \cdot \text{dimensionless}$	<input checked="" type="checkbox"/>
rescaled-_pEpoR	rescaled_pEpoR	0000196	0.000	dimensionless	<input type="checkbox"/>
rescaled-_ppMEK1	rescaled_ppMEK1	0000196	0.000	dimensionless	<input type="checkbox"/>
rescaled-_ppMEK2	rescaled_ppMEK2	0000196	0.000	dimensionless	<input type="checkbox"/>
rescaled-_ppERK1	rescaled_ppERK1	0000196	0.000	dimensionless	<input type="checkbox"/>
rescaled-_ppERK2	rescaled_ppERK2	0000196	0.000	dimensionless	<input type="checkbox"/>
rescaled-_pJAK2	rescaled_pJAK2	0000196	0.000	dimensionless	<input type="checkbox"/>
rescaled-_pSOS	rescaled_pSOS	0000196	0.000	dimensionless	<input type="checkbox"/>
rescaled_SOS	rescaled_SOS	0000196	0.000	dimensionless	<input type="checkbox"/>
rescaled-_mSOS	rescaled_mSOS	0000196	0.000	dimensionless	<input type="checkbox"/>

## 6 Rules

This is an overview of nine rules.

### 6.1 Rule `rescaled_pEpoR`

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

$$\text{rescaled\_pEpoR} = \text{scale\_pEpoR} \cdot [\text{pEpoR}] \quad (1)$$

**Derived unit** dimensionless

### 6.2 Rule `rescaled_pJAK2`

Rule `rescaled_pJAK2` is an assignment rule for parameter `rescaled_pJAK2`:

$$\text{rescaled\_pJAK2} = \text{scale\_pJAK2} \cdot [\text{pJAK2}] \quad (2)$$

**Derived unit** dimensionless

### 6.3 Rule `rescaled_ppERK1`

Rule `rescaled_ppERK1` is an assignment rule for parameter `rescaled_ppERK1`:

$$\text{rescaled\_ppERK1} = \text{scale\_ppERK} \cdot [\text{ppERK1}] \quad (3)$$

**Derived unit** dimensionless

### 6.4 Rule `rescaled_ppERK2`

Rule `rescaled_ppERK2` is an assignment rule for parameter `rescaled_ppERK2`:

$$\text{rescaled\_ppERK2} = \text{scale\_ppERK} \cdot [\text{ppERK2}] \quad (4)$$

**Derived unit** dimensionless

### 6.5 Rule `rescaled_ppMEK1`

Rule `rescaled_ppMEK1` is an assignment rule for parameter `rescaled_ppMEK1`:

$$\text{rescaled\_ppMEK1} = \text{scale\_ppMEK} \cdot [\text{ppMEK1}] \quad (5)$$

**Derived unit** dimensionless

### 6.6 Rule `rescaled_ppMEK2`

Rule `rescaled_ppMEK2` is an assignment rule for parameter `rescaled_ppMEK2`:

$$\text{rescaled\_ppMEK2} = \text{scale\_ppMEK} \cdot [\text{ppMEK2}] \quad (6)$$

**Derived unit** dimensionless

### 6.7 Rule `rescaled_pSOS`

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

$$\text{rescaled\_pSOS} = \text{scale\_SOS} \cdot [\text{pSOS}] \quad (7)$$

**Derived unit** dimensionless

### 6.8 Rule `rescaled_SOS`

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

$$\text{rescaled\_SOS} = \text{scale\_SOS} \cdot [\text{SOS}] \quad (8)$$

**Derived unit** dimensionless

### 6.9 Rule `rescaled_mSOS`

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

$$\text{rescaled\_mSOS} = \text{scale\_SOS} \cdot [\text{mSOS}] \quad (9)$$

**Derived unit** dimensionless

## 7 Reactions

This model contains 42 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		$\text{JAK2} \xrightarrow{\text{Epo}} \text{pJAK2}$	0000216
2	reaction_2		$\text{EpoR} \xrightarrow{\text{pJAK2}} \text{pEpoR}$	0000216
3	reaction_3		$\text{SHP1} \xrightarrow{\text{pEpoR}} \text{mSHP1}$	0000177
4	reaction_4		$\text{mSHP1} \longrightarrow \text{Delay01\_mSHP1}$	0000397
5	reaction_5		$\text{Delay01\_mSHP1} \longrightarrow \text{Delay02\_mSHP1}$	0000397
6	reaction_6		$\text{Delay02\_mSHP1} \longrightarrow \text{Delay03\_mSHP1}$	0000397
7	reaction_7		$\text{Delay03\_mSHP1} \longrightarrow \text{Delay04\_mSHP1}$	0000397
8	reaction_8		$\text{Delay04\_mSHP1} \longrightarrow \text{Delay05\_mSHP1}$	0000397
9	reaction_9		$\text{Delay05\_mSHP1} \longrightarrow \text{Delay06\_mSHP1}$	0000397
10	reaction_10		$\text{Delay06\_mSHP1} \longrightarrow \text{Delay07\_mSHP1}$	0000397
11	reaction_11		$\text{Delay07\_mSHP1} \longrightarrow \text{Delay08\_mSHP1}$	0000397
12	reaction_12		$\text{Delay08\_mSHP1} \longrightarrow \text{actSHP1}$	0000396
13	reaction_13		$\text{actSHP1} \longrightarrow \text{SHP1}$	0000396
14	reaction_14		$\text{pEpoR} \xrightarrow{\text{actSHP1}} \text{EpoR}$	0000330
15	reaction_15		$\text{pJAK2} \xrightarrow{\text{actSHP1}} \text{JAK2}$	0000330
16	reaction_16		$\text{SOS} \xrightarrow{\text{pEpoR}} \text{mSOS}$	0000177
17	reaction_17		$\text{mSOS} \longrightarrow \text{SOS}$	0000180
18	reaction_18		$\text{Raf} \xrightarrow{\text{mSOS}} \text{pRaf}$	0000216
19	reaction_19		$\text{pRaf} \longrightarrow \text{Raf}$	0000330

Nº	Id	Name	Reaction Equation	SBO
20	reaction_20		$\text{MEK2} \xrightarrow{\text{pRaf}} \text{pMEK2}$	0000216
21	reaction_21		$\text{MEK1} \xrightarrow{\text{pRaf}} \text{pMEK1}$	0000216
22	reaction_22		$\text{pMEK2} \xrightarrow{\text{pRaf}} \text{ppMEK2}$	0000216
23	reaction_23		$\text{pMEK1} \xrightarrow{\text{pRaf}} \text{ppMEK1}$	0000216
24	reaction_24		$\text{ppMEK2} \longrightarrow \text{pMEK2}$	0000330
25	reaction_25		$\text{ppMEK1} \longrightarrow \text{pMEK1}$	0000330
26	reaction_26		$\text{pMEK2} \longrightarrow \text{MEK2}$	0000330
27	reaction_27		$\text{pMEK1} \longrightarrow \text{MEK1}$	0000330
28	reaction_28		$\text{ERK1} \xrightarrow{\text{ppMEK2}} \text{pERK1}$	0000216
29	reaction_29		$\text{ERK2} \xrightarrow{\text{ppMEK2}} \text{pERK2}$	0000216
30	reaction_30		$\text{ERK1} \xrightarrow{\text{ppMEK1}} \text{pERK1}$	0000216
31	reaction_31		$\text{ERK2} \xrightarrow{\text{ppMEK1}} \text{pERK2}$	0000216
32	reaction_32		$\text{pERK1} \xrightarrow{\text{ppMEK2}} \text{ppERK1}$	0000216
33	reaction_33		$\text{pERK2} \xrightarrow{\text{ppMEK2}} \text{ppERK2}$	0000216
34	reaction_34		$\text{pERK1} \xrightarrow{\text{ppMEK1}} \text{ppERK1}$	0000216
35	reaction_35		$\text{pERK2} \xrightarrow{\text{ppMEK1}} \text{ppERK2}$	0000216
36	reaction_36		$\text{ppERK1} \longrightarrow \text{pERK1}$	0000216
37	reaction_37		$\text{ppERK2} \longrightarrow \text{pERK2}$	0000216
38	reaction_38		$\text{pERK1} \longrightarrow \text{ERK1}$	0000216
39	reaction_39		$\text{pERK2} \longrightarrow \text{ERK2}$	0000216
40	reaction_40		$\text{mSOS} \xrightarrow{\text{ppERK1}} \text{pSOS}$	0000216
41	reaction_41		$\text{mSOS} \xrightarrow{\text{ppERK2}} \text{pSOS}$	0000216

Nº	Id	Name	Reaction Equation	SBO
42	reaction_42		$\text{pSOS} \longrightarrow \text{SOS}$	0000330

### 7.1 Reaction [reaction\\_1](#)

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

**SBO:0000216** phosphorylation

#### Reaction equation



#### Reactant

Table 6: Properties of each reactant.

Id	Name	SBO
JAK2		

#### Modifier

Table 7: Properties of each modifier.

Id	Name	SBO
Epo		0000461

#### Product

Table 8: Properties of each product.

Id	Name	SBO
pJAK2		

#### Kinetic Law

**Derived unit**  $(60 \text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_1 = \text{JAK2\_phosphorylation\_by\_Epo} \cdot [\text{JAK2}] \cdot [\text{Epo}] \cdot \text{vol}(\text{cell}) \quad (11)$$

### 7.2 Reaction [reaction\\_2](#)

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

**SBO:0000216** phosphorylation

Reaction equation



Reactant

Table 9: Properties of each reactant.

Id	Name	SBO
EpoR		

Modifier

Table 10: Properties of each modifier.

Id	Name	SBO
pJAK2		0000534

Product

Table 11: Properties of each product.

Id	Name	SBO
pEpoR		

Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_2 = \text{EpoR\_phosphorylation\_by\_pJAK2} \cdot [\text{EpoR}] \cdot [\text{pJAK2}] \cdot \text{vol}(\text{cell})$$

(13)

7.3 Reaction `reaction_3`

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

**SBO:0000177** non-covalent binding

Reaction equation



**Reactant**



Table 12: Properties of each reactant.

Id	Name	SBO
SHP1		

## Modifier

Table 13: Properties of each modifier.

Id	Name	SBO
pEpoR		0000463

## Product

Table 14: Properties of each product.

Id	Name	SBO
mSHP1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_3 = \text{SHP1\_activation\_by\_pEpoR} \cdot [\text{SHP1}] \cdot [\text{pEpoR}] \cdot \text{vol}(\text{cell}) \quad (15)$$

## 7.4 Reaction `reaction_4`

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

**SBO:0000397** omitted process

## Reaction equation



## Reactant

Table 15: Properties of each reactant.

Id	Name	SBO
mSHP1		

## Product

Table 16: Properties of each product.

Id	Name	SBO
Delay01_mSHP1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_4 = \text{SHP1\_delay} \cdot [\text{mSHP1}] \cdot \text{vol}(\text{cell}) \quad (17)$$

## 7.5 Reaction `reaction_5`

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

**SBO:0000397** omitted process

## Reaction equation



## Reactant

Table 17: Properties of each reactant.

Id	Name	SBO
Delay01_mSHP1		

## Product

Table 18: Properties of each product.

Id	Name	SBO
Delay02_mSHP1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_5 = \text{SHP1\_delay} \cdot [\text{Delay01\_mSHP1}] \cdot \text{vol}(\text{cell}) \quad (19)$$

## 7.6 Reaction `reaction_6`

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

**SBO:0000397** omitted process

### Reaction equation



### Reactant

Table 19: Properties of each reactant.

Id	Name	SBO
Delay02_mSHP1		

### Product

Table 20: Properties of each product.

Id	Name	SBO
Delay03_mSHP1		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_6 = \text{SHP1\_delay} \cdot [\text{Delay02\_mSHP1}] \cdot \text{vol}(\text{cell}) \quad (21)$$

## 7.7 Reaction `reaction_7`

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

**SBO:0000397** omitted process

### Reaction equation



### Reactant

Table 21: Properties of each reactant.

Id	Name	SBO
Delay03_mSHP1		

## Product

Table 22: Properties of each product.

Id	Name	SBO
Delay04_mSHP1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_7 = \text{SHP1\_delay} \cdot [\text{Delay03\_mSHP1}] \cdot \text{vol}(\text{cell}) \quad (23)$$

## 7.8 Reaction `reaction_8`

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

**SBO:0000397** omitted process

## Reaction equation



## Reactant

Table 23: Properties of each reactant.

Id	Name	SBO
Delay04_mSHP1		

## Product

Table 24: Properties of each product.

Id	Name	SBO
Delay05_mSHP1		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_8 = \text{SHP1\_delay} \cdot [\text{Delay04\_mSHP1}] \cdot \text{vol}(\text{cell}) \quad (25)$$

### 7.9 Reaction `reaction_9`

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

**SBO:0000397** omitted process

### Reaction equation



### Reactant

Table 25: Properties of each reactant.

Id	Name	SBO
Delay05_mSHP1		

### Product

Table 26: Properties of each product.

Id	Name	SBO
Delay06_mSHP1		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

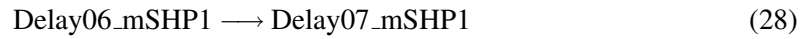
$$v_9 = \text{SHP1\_delay} \cdot [\text{Delay05\_mSHP1}] \cdot \text{vol}(\text{cell}) \quad (27)$$

### 7.10 Reaction `reaction_10`

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

**SBO:0000397** omitted process

### Reaction equation



### Reactant

Table 27: Properties of each reactant.

Id	Name	SBO
Delay06_mSHP1		

### Product

Table 28: Properties of each product.

Id	Name	SBO
Delay07_mSHP1		

### Kinetic Law

**Derived unit**  $(60 \text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{10} = \text{SHP1\_delay} \cdot [\text{Delay06\_mSHP1}] \cdot \text{vol}(\text{cell}) \quad (29)$$

## 7.11 Reaction `reaction_11`

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

**SBO:0000397** omitted process

### Reaction equation



### Reactant

Table 29: Properties of each reactant.

Id	Name	SBO
Delay07_mSHP1		

## Product

Table 30: Properties of each product.

Id	Name	SBO
Delay08_mSHP1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

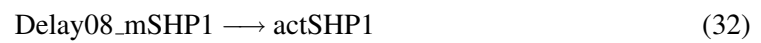
$$v_{11} = \text{SHP1\_delay} \cdot [\text{Delay07\_mSHP1}] \cdot \text{vol}(\text{cell}) \quad (31)$$

## 7.12 Reaction [reaction\\_12](#)

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

**SBO:0000396** uncertain process

## Reaction equation



## Reactant

Table 31: Properties of each reactant.

Id	Name	SBO
Delay08_mSHP1		

## Product

Table 32: Properties of each product.

Id	Name	SBO
actSHP1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{12} = \text{SHP1\_delay} \cdot [\text{Delay08\_mSHP1}] \cdot \text{vol}(\text{cell}) \quad (33)$$

### 7.13 Reaction [reaction\\_13](#)

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

**SBO:0000396** uncertain process

#### Reaction equation



#### Reactant

Table 33: Properties of each reactant.

Id	Name	SBO
actSHP1		

#### Product

Table 34: Properties of each product.

Id	Name	SBO
SHP1		

#### Kinetic Law

**Derived unit**  $(60 \text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{13} = \text{actSHP1\_deactivation} \cdot [\text{actSHP1}] \cdot \text{vol}(\text{cell}) \quad (35)$$

### 7.14 Reaction [reaction\\_14](#)

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

**SBO:0000330** dephosphorylation

#### Reaction equation



#### Reactant



Table 35: Properties of each reactant.

Id	Name	SBO
pEpoR		

## Modifier

Table 36: Properties of each modifier.

Id	Name	SBO
actSHP1		0000534

## Product

Table 37: Properties of each product.

Id	Name	SBO
EpoR		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{14} = \text{pEpoR\_dephosphorylation\_by\_actSHP1} \cdot [\text{pEpoR}] \cdot [\text{actSHP1}] \cdot \text{vol}(\text{cell}) \quad (37)$$

## 7.15 Reaction `reaction_15`

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

**SBO:0000330** dephosphorylation

## Reaction equation



## Reactant

Table 38: Properties of each reactant.

Id	Name	SBO
pJAK2		

## Modifier

Table 39: Properties of each modifier.

Id	Name	SBO
actSHP1		0000534

## Product

Table 40: Properties of each product.

Id	Name	SBO
JAK2		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{15} = \text{pJAK2\_dephosphorylation\_by\_actSHP1} \cdot [\text{pJAK2}] \cdot [\text{actSHP1}] \cdot \text{vol}(\text{cell}) \quad (39)$$

## 7.16 Reaction [reaction\\_16](#)

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

**SBO:0000177** non-covalent binding

## Reaction equation



## Reactant

Table 41: Properties of each reactant.

Id	Name	SBO
SOS		

## Modifier

Table 42: Properties of each modifier.

Id	Name	SBO
pEpoR		0000461

## Product

Table 43: Properties of each product.

Id	Name	SBO
mSOS		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{16} = \text{SOS\_recruitment\_by\_pEpoR} \cdot [\text{SOS}] \cdot [\text{pEpoR}] \cdot \text{vol}(\text{cell}) \quad (41)$$

## 7.17 Reaction [reaction\\_17](#)

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

**SBO:0000180** dissociation

## Reaction equation



## Reactant

Table 44: Properties of each reactant.

Id	Name	SBO
mSOS		

## Product

Table 45: Properties of each product.

Id	Name	SBO
SOS		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

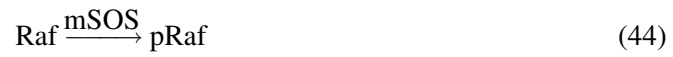
$$v_{17} = \text{mSOS\_release\_from\_membrane} \cdot [\text{mSOS}] \cdot \text{vol}(\text{cell}) \quad (43)$$

### 7.18 Reaction [reaction\\_18](#)

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

**SBO:0000216** phosphorylation

### Reaction equation



### Reactant

Table 46: Properties of each reactant.

Id	Name	SBO
Raf		

### Modifier

Table 47: Properties of each modifier.

Id	Name	SBO
mSOS		0000461

### Product

Table 48: Properties of each product.

Id	Name	SBO
pRaf		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{18} = \text{mSOS\_induced\_Raf\_phosphorylation} \cdot [\text{Raf}] \cdot [\text{mSOS}] \cdot \text{vol}(\text{cell}) \quad (45)$$

### 7.19 Reaction [reaction\\_19](#)

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

**SBO:0000330** dephosphorylation

#### Reaction equation



#### Reactant

Table 49: Properties of each reactant.

Id	Name	SBO
pRaf		

#### Product

Table 50: Properties of each product.

Id	Name	SBO
Raf		

#### Kinetic Law

**Derived unit**  $(60 \text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{19} = \text{pRaf\_dephosphorylation} \cdot [\text{pRaf}] \cdot \text{vol}(\text{cell}) \quad (47)$$

### 7.20 Reaction [reaction\\_20](#)

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

**SBO:0000216** phosphorylation

#### Reaction equation



#### Reactant

Table 51: Properties of each reactant.

Id	Name	SBO
MEK2		

## Modifier

Table 52: Properties of each modifier.

Id	Name	SBO
pRaf		0000534

## Product

Table 53: Properties of each product.

Id	Name	SBO
pMEK2		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{20} = \text{First\_MEK2\_phosphorylation\_by\_pRaf} \cdot [\text{MEK2}] \cdot [\text{pRaf}] \cdot \text{vol}(\text{cell}) \quad (49)$$

## 7.21 Reaction `reaction_21`

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

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 54: Properties of each reactant.

Id	Name	SBO
MEK1		

## Modifier

Table 55: Properties of each modifier.

Id	Name	SBO
pRaf		0000534

## Product

Table 56: Properties of each product.

Id	Name	SBO
pMEK1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{21} = \text{First\_MEK1\_phosphorylation\_by\_pRaf} \cdot [\text{MEK1}] \cdot [\text{pRaf}] \cdot \text{vol}(\text{cell}) \quad (51)$$

## 7.22 Reaction [reaction\\_22](#)

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

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 57: Properties of each reactant.

Id	Name	SBO
pMEK2		

## Modifier

Table 58: Properties of each modifier.

Id	Name	SBO
pRaf		0000534

## Product

Table 59: Properties of each product.

Id	Name	SBO
ppMEK2		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{22} = \text{Second\_MEK2\_phosphorylation\_by\_pRaf} \cdot [\text{pMEK2}] \cdot [\text{pRaf}] \cdot \text{vol}(\text{cell}) \quad (53)$$

## 7.23 Reaction [reaction\\_23](#)

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

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 60: Properties of each reactant.

Id	Name	SBO
pMEK1		

## Modifier

Table 61: Properties of each modifier.

Id	Name	SBO
pRaf		0000534



## Product

Table 62: Properties of each product.

Id	Name	SBO
ppMEK1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{23} = \text{Second\_MEK1\_phosphorylation\_by\_pRaf} \cdot [\text{pMEK1}] \cdot [\text{pRaf}] \cdot \text{vol}(\text{cell}) \quad (55)$$

## 7.24 Reaction [reaction\\_24](#)

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

**SBO:0000330** dephosphorylation

## Reaction equation



## Reactant

Table 63: Properties of each reactant.

Id	Name	SBO
ppMEK2		

## Product

Table 64: Properties of each product.

Id	Name	SBO
pMEK2		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{24} = \text{First\_MEK\_dephosphorylation} \cdot [\text{ppMEK2}] \cdot \text{vol}(\text{cell}) \quad (57)$$

### 7.25 Reaction [reaction\\_25](#)

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

**SBO:0000330** dephosphorylation

#### Reaction equation



#### Reactant

Table 65: Properties of each reactant.

Id	Name	SBO
ppMEK1		

#### Product

Table 66: Properties of each product.

Id	Name	SBO
pMEK1		

#### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{25} = \text{First\_MEK\_dephosphorylation} \cdot [\text{ppMEK1}] \cdot \text{vol}(\text{cell}) \quad (59)$$

### 7.26 Reaction [reaction\\_26](#)

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

**SBO:0000330** dephosphorylation

#### Reaction equation



#### Reactant

Table 67: Properties of each reactant.

Id	Name	SBO
pMEK2		

## Product

Table 68: Properties of each product.

Id	Name	SBO
MEK2		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{26} = \text{Second\_MEK\_dephosphorylation} \cdot [\text{pMEK2}] \cdot \text{vol}(\text{cell}) \quad (61)$$

## 7.27 Reaction [reaction\\_27](#)

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

**SBO:0000330** dephosphorylation

## Reaction equation



## Reactant

Table 69: Properties of each reactant.

Id	Name	SBO
pMEK1		

## Product

Table 70: Properties of each product.

Id	Name	SBO
MEK1		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{27} = \text{Second\_MEK\_dephosphorylation} \cdot [\text{pMEK1}] \cdot \text{vol}(\text{cell}) \quad (63)$$

### 7.28 Reaction [reaction\\_28](#)

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

**SBO:0000216** phosphorylation

### Reaction equation



### Reactant

Table 71: Properties of each reactant.

Id	Name	SBO
ERK1		

### Modifier

Table 72: Properties of each modifier.

Id	Name	SBO
ppMEK2		0000534

### Product

Table 73: Properties of each product.

Id	Name	SBO
pERK1		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{28} = \text{First\_ERK1\_phosphorylation\_by\_ppMEK} \cdot [\text{ERK1}] \cdot [\text{ppMEK2}] \cdot \text{vol}(\text{cell}) \quad (65)$$

### 7.29 Reaction [reaction\\_29](#)

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

**SBO:0000216** phosphorylation

#### Reaction equation



#### Reactant

Table 74: Properties of each reactant.

Id	Name	SBO
ERK2		

#### Modifier

Table 75: Properties of each modifier.

Id	Name	SBO
ppMEK2		0000534

#### Product

Table 76: Properties of each product.

Id	Name	SBO
pERK2		

#### Kinetic Law

**Derived unit**  $(60 \text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{29} = \text{First\_ERK2\_phosphorylation\_by\_ppMEK} \cdot [\text{ERK2}] \cdot [\text{ppMEK2}] \cdot \text{vol}(\text{cell}) \quad (67)$$

### 7.30 Reaction [reaction\\_30](#)

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

**SBO:0000216** phosphorylation

### Reaction equation



### Reactant

Table 77: Properties of each reactant.

Id	Name	SBO
ERK1		

### Modifier

Table 78: Properties of each modifier.

Id	Name	SBO
ppMEK1		0000534

### Product

Table 79: Properties of each product.

Id	Name	SBO
pERK1		

### Kinetic Law

**Derived unit**  $(60 \text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{30} = \text{First\_ERK1\_phosphorylation\_by\_ppMEK} \cdot [\text{ERK1}] \cdot [\text{ppMEK1}] \cdot \text{vol}(\text{cell}) \quad (69)$$

### 7.31 Reaction [reaction\\_31](#)

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

**SBO:0000216** phosphorylation

### Reaction equation



**Reactant**

Table 80: Properties of each reactant.

Id	Name	SBO
ERK2		

## Modifier

Table 81: Properties of each modifier.

Id	Name	SBO
ppMEK1		0000534

## Product

Table 82: Properties of each product.

Id	Name	SBO
pERK2		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{31} = \text{First\_ERK2\_phosphorylation\_by\_ppMEK} \cdot [\text{ERK2}] \cdot [\text{ppMEK1}] \cdot \text{vol}(\text{cell}) \quad (71)$$

## 7.32 Reaction [reaction\\_32](#)

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

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 83: Properties of each reactant.

Id	Name	SBO
pERK1		



## Modifier

Table 84: Properties of each modifier.

Id	Name	SBO
ppMEK2		0000534

## Product

Table 85: Properties of each product.

Id	Name	SBO
ppERK1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{32} = \text{Second\_ERK1\_phosphorylation\_by\_ppMEK} \cdot [\text{pERK1}] \cdot [\text{ppMEK2}] \cdot \text{vol}(\text{cell}) \quad (73)$$

### 7.33 Reaction [reaction\\_33](#)

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

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 86: Properties of each reactant.

Id	Name	SBO
pERK2		

## Modifier

Table 87: Properties of each modifier.

Id	Name	SBO
ppMEK2		0000534

## Product

Table 88: Properties of each product.

Id	Name	SBO
ppERK2		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{33} = \text{Second\_ERK2\_phosphorylation\_by\_ppMEK} \cdot [\text{pERK2}] \cdot [\text{ppMEK2}] \cdot \text{vol}(\text{cell}) \quad (75)$$

## 7.34 Reaction [reaction\\_34](#)

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

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 89: Properties of each reactant.

Id	Name	SBO
pERK1		

## Modifier

Table 90: Properties of each modifier.

Id	Name	SBO
ppMEK1		0000534

## Product

Table 91: Properties of each product.

Id	Name	SBO
ppERK1		

## Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{34} = \text{Second\_ERK1\_phosphorylation\_by\_ppMEK} \cdot [\text{pERK1}] \cdot [\text{ppMEK1}] \cdot \text{vol}(\text{cell}) \quad (77)$$

## 7.35 Reaction [reaction\\_35](#)

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

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 92: Properties of each reactant.

Id	Name	SBO
pERK2		

## Modifier

Table 93: Properties of each modifier.

Id	Name	SBO
ppMEK1		0000534

## Product

Table 94: Properties of each product.

Id	Name	SBO
ppERK2		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{35} = \text{Second\_ERK2\_phosphorylation\_by\_ppMEK} \cdot [\text{pERK2}] \cdot [\text{ppMEK1}] \cdot \text{vol}(\text{cell}) \quad (79)$$

### 7.36 Reaction [reaction\\_36](#)

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

**SBO:0000216** phosphorylation

### Reaction equation



### Reactant

Table 95: Properties of each reactant.

Id	Name	SBO
ppERK1		

### Product

Table 96: Properties of each product.

Id	Name	SBO
pERK1		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{36} = \text{First\_ERK\_dephosphorylation} \cdot [\text{ppERK1}] \cdot \text{vol}(\text{cell}) \quad (81)$$

7.37 Reaction `reaction_37`

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

**SBO:0000216** phosphorylation

Reaction equation



Reactant

Table 97: Properties of each reactant.

Id	Name	SBO
ppERK2		

Product

Table 98: Properties of each product.

Id	Name	SBO
pERK2		

Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{37} = \text{First\_ERK\_dephosphorylation} \cdot [\text{ppERK2}] \cdot \text{vol}(\text{cell}) \tag{83}$$

7.38 Reaction `reaction_38`

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

**SBO:0000216** phosphorylation

Reaction equation



Reactant

Table 99: Properties of each reactant.

Id	Name	SBO
pERK1		

## Product

Table 100: Properties of each product.

Id	Name	SBO
ERK1		

## Kinetic Law

**Derived unit**  $(60 \text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

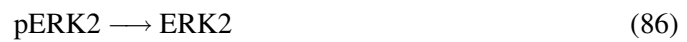
$$v_{38} = \text{Second\_ERK\_dephosphorylation} \cdot [\text{pERK1}] \cdot \text{vol}(\text{cell}) \quad (85)$$

## 7.39 Reaction [reaction\\_39](#)

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

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 101: Properties of each reactant.

Id	Name	SBO
pERK2		

## Product

Table 102: Properties of each product.

Id	Name	SBO
ERK2		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{39} = \text{Second\_ERK\_dephosphorylation} \cdot [\text{pERK2}] \cdot \text{vol}(\text{cell}) \quad (87)$$

### 7.40 Reaction `reaction_40`

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

**SBO:0000216** phosphorylation

### Reaction equation



### Reactant

Table 103: Properties of each reactant.

Id	Name	SBO
mSOS		

### Modifier

Table 104: Properties of each modifier.

Id	Name	SBO
ppERK1		0000534

### Product

Table 105: Properties of each product.

Id	Name	SBO
pSOS		

### Kinetic Law

**Derived unit**  $(60\text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{40} = \text{ppERK\_neg\_feedback\_on\_mSOS} \cdot [\text{mSOS}] \cdot [\text{ppERK1}] \cdot \text{vol}(\text{cell}) \quad (89)$$

### 7.41 Reaction [reaction\\_41](#)

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

**SBO:0000216** phosphorylation

#### Reaction equation



#### Reactant

Table 106: Properties of each reactant.

Id	Name	SBO
mSOS		

#### Modifier

Table 107: Properties of each modifier.

Id	Name	SBO
ppERK2		0000534

#### Product

Table 108: Properties of each product.

Id	Name	SBO
pSOS		

#### Kinetic Law

**Derived unit**  $(60 \text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{41} = \text{ppERK\_neg\_feedback\_on\_mSOS} \cdot [\text{mSOS}] \cdot [\text{ppERK2}] \cdot \text{vol}(\text{cell}) \quad (91)$$

### 7.42 Reaction [reaction\\_42](#)

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

**SBO:0000330** dephosphorylation



## Reaction equation



## Reactant

Table 109: Properties of each reactant.

Id	Name	SBO
pSOS		

## Product

Table 110: Properties of each product.

Id	Name	SBO
SOS		

## Kinetic Law

**Derived unit**  $(60 \text{ s})^{-1} \cdot 10^4 \cdot \text{item}$

$$v_{42} = \text{pSOS\_dephosphorylation} \cdot [\text{pSOS}] \cdot \text{vol}(\text{cell}) \quad (93)$$

## 8 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.

### 8.1 Species JAK2

**SBO:0000252** polypeptide chain

**Initial concentration**  $2 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_1](#) and as a product in [reaction\\_15](#)).

$$\frac{d}{dt} \text{JAK2} = v_{15} - v_1 \quad (94)$$

## 8.2 Species `EpoR`

**SBO:0000252** polypeptide chain

**Initial concentration**  $1 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_2](#) and as a product in [reaction\\_14](#)).

$$\frac{d}{dt}\text{EpoR} = v_{14} - v_2 \quad (95)$$

## 8.3 Species `SHP1`

**SBO:0000252** polypeptide chain

**Initial concentration**  $10.7991 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_3](#) and as a product in [reaction\\_13](#)).

$$\frac{d}{dt}\text{SHP1} = v_{13} - v_3 \quad (96)$$

## 8.4 Species `SOS`

**SBO:0000252** polypeptide chain

**Initial concentration**  $2.5101 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in three reactions (as a reactant in [reaction\\_16](#) and as a product in [reaction\\_17](#), [reaction\\_42](#)).

$$\frac{d}{dt}\text{SOS} = v_{17} + v_{42} - v_{16} \quad (97)$$

## 8.5 Species `Raf`

**SBO:0000252** polypeptide chain

**Initial concentration**  $3.7719 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_18](#) and as a product in [reaction\\_19](#)).

$$\frac{d}{dt}\text{Raf} = v_{19} - v_{18} \quad (98)$$

## 8.6 Species MEK2

**SBO:0000252** polypeptide chain

**Initial concentration**  $11 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_20](#) and as a product in [reaction\\_26](#)).

$$\frac{d}{dt}\text{MEK2} = v_{26} - v_{20} \quad (99)$$

## 8.7 Species MEK1

**SBO:0000252** polypeptide chain

**Initial concentration**  $24 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_21](#) and as a product in [reaction\\_27](#)).

$$\frac{d}{dt}\text{MEK1} = v_{27} - v_{21} \quad (100)$$

## 8.8 Species ERK1

**SBO:0000252** polypeptide chain

**Initial concentration**  $7 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in three reactions (as a reactant in [reaction\\_28](#), [reaction\\_30](#) and as a product in [reaction\\_38](#)).

$$\frac{d}{dt}\text{ERK1} = v_{38} - v_{28} - v_{30} \quad (101)$$

## 8.9 Species ERK2

**SBO:0000252** polypeptide chain

**Initial concentration**  $21 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in three reactions (as a reactant in [reaction\\_29](#), [reaction\\_31](#) and as a product in [reaction\\_39](#)).

$$\frac{d}{dt}\text{ERK2} = v_{39} - v_{29} - v_{31} \quad (102)$$

### 8.10 Species pJAK2

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in three reactions (as a reactant in [reaction\\_15](#) and as a product in [reaction\\_1](#) and as a modifier in [reaction\\_2](#)).

$$\frac{d}{dt} \text{pJAK2} = v_1 - v_{15} \quad (103)$$

### 8.11 Species pEpoR

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in four reactions (as a reactant in [reaction\\_14](#) and as a product in [reaction\\_2](#) and as a modifier in [reaction\\_3](#), [reaction\\_16](#)).

$$\frac{d}{dt} \text{pEpoR} = v_2 - v_{14} \quad (104)$$

### 8.12 Species mSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_4](#) and as a product in [reaction\\_3](#)).

$$\frac{d}{dt} \text{mSHP1} = v_3 - v_4 \quad (105)$$

### 8.13 Species actSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in four reactions (as a reactant in [reaction\\_13](#) and as a product in [reaction\\_12](#) and as a modifier in [reaction\\_14](#), [reaction\\_15](#)).

$$\frac{d}{dt} \text{actSHP1} = v_{12} - v_{13} \quad (106)$$

### 8.14 Species mSOS

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in five reactions (as a reactant in [reaction\\_17](#), [reaction\\_40](#), [reaction\\_41](#) and as a product in [reaction\\_16](#) and as a modifier in [reaction\\_18](#)).

$$\frac{d}{dt} \text{mSOS} = v_{16} - v_{17} - v_{40} - v_{41} \quad (107)$$

### 8.15 Species pRaf

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in six reactions (as a reactant in [reaction\\_19](#) and as a product in [reaction\\_18](#) and as a modifier in [reaction\\_20](#), [reaction\\_21](#), [reaction\\_22](#), [reaction\\_23](#)).

$$\frac{d}{dt} \text{pRaf} = v_{18} - v_{19} \quad (108)$$

### 8.16 Species ppMEK2

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in six reactions (as a reactant in [reaction\\_24](#) and as a product in [reaction\\_22](#) and as a modifier in [reaction\\_28](#), [reaction\\_29](#), [reaction\\_32](#), [reaction\\_33](#)).

$$\frac{d}{dt} \text{ppMEK2} = v_{22} - v_{24} \quad (109)$$

### 8.17 Species ppMEK1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in six reactions (as a reactant in [reaction\\_25](#) and as a product in [reaction\\_23](#) and as a modifier in [reaction\\_30](#), [reaction\\_31](#), [reaction\\_34](#), [reaction\\_35](#)).

$$\frac{d}{dt} \text{ppMEK1} = v_{23} - v_{25} \quad (110)$$

### 8.18 Species ppERK1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in four reactions (as a reactant in [reaction\\_36](#) and as a product in [reaction\\_32](#), [reaction\\_34](#) and as a modifier in [reaction\\_40](#)).

$$\frac{d}{dt} \text{ppERK1} = v_{32} + v_{34} - v_{36} \quad (111)$$

### 8.19 Species ppERK2

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in four reactions (as a reactant in [reaction\\_37](#) and as a product in [reaction\\_33](#), [reaction\\_35](#) and as a modifier in [reaction\\_41](#)).

$$\frac{d}{dt} \text{ppERK2} = v_{33} + v_{35} - v_{37} \quad (112)$$

### 8.20 Species pSOS

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in three reactions (as a reactant in [reaction\\_42](#) and as a product in [reaction\\_40](#), [reaction\\_41](#)).

$$\frac{d}{dt} \text{pSOS} = v_{40} + v_{41} - v_{42} \quad (113)$$

### 8.21 Species pMEK2

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in four reactions (as a reactant in [reaction\\_22](#), [reaction\\_26](#) and as a product in [reaction\\_20](#), [reaction\\_24](#)).

$$\frac{d}{dt} \text{pMEK2} = v_{20} + v_{24} - v_{22} - v_{26} \quad (114)$$

## 8.22 Species pMEK1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in four reactions (as a reactant in [reaction\\_23](#), [reaction\\_27](#) and as a product in [reaction\\_21](#), [reaction\\_25](#)).

$$\frac{d}{dt} \text{pMEK1} = v_{21} + v_{25} - v_{23} - v_{27} \quad (115)$$

## 8.23 Species pERK1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in six reactions (as a reactant in [reaction\\_32](#), [reaction\\_34](#), [reaction\\_38](#) and as a product in [reaction\\_28](#), [reaction\\_30](#), [reaction\\_36](#)).

$$\frac{d}{dt} \text{pERK1} = v_{28} + v_{30} + v_{36} - v_{32} - v_{34} - v_{38} \quad (116)$$

## 8.24 Species pERK2

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in six reactions (as a reactant in [reaction\\_33](#), [reaction\\_35](#), [reaction\\_39](#) and as a product in [reaction\\_29](#), [reaction\\_31](#), [reaction\\_37](#)).

$$\frac{d}{dt} \text{pERK2} = v_{29} + v_{31} + v_{37} - v_{33} - v_{35} - v_{39} \quad (117)$$

## 8.25 Species Delay01\_mSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_5](#) and as a product in [reaction\\_4](#)).

$$\frac{d}{dt} \text{Delay01\_mSHP1} = v_4 - v_5 \quad (118)$$

### 8.26 Species Delay02\_mSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_6](#) and as a product in [reaction\\_5](#)).

$$\frac{d}{dt}\text{Delay02\_mSHP1} = v_5 - v_6 \quad (119)$$

### 8.27 Species Delay03\_mSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_7](#) and as a product in [reaction\\_6](#)).

$$\frac{d}{dt}\text{Delay03\_mSHP1} = v_6 - v_7 \quad (120)$$

### 8.28 Species Delay04\_mSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_8](#) and as a product in [reaction\\_7](#)).

$$\frac{d}{dt}\text{Delay04\_mSHP1} = v_7 - v_8 \quad (121)$$

### 8.29 Species Delay05\_mSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_9](#) and as a product in [reaction\\_8](#)).

$$\frac{d}{dt}\text{Delay05\_mSHP1} = v_8 - v_9 \quad (122)$$



### 8.30 Species Delay06\_mSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_10](#) and as a product in [reaction\\_9](#)).

$$\frac{d}{dt}\text{Delay06\_mSHP1} = v_9 - v_{10} \quad (123)$$

### 8.31 Species Delay07\_mSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_11](#) and as a product in [reaction\\_10](#)).

$$\frac{d}{dt}\text{Delay07\_mSHP1} = v_{10} - v_{11} \quad (124)$$

### 8.32 Species Delay08\_mSHP1

**SBO:0000252** polypeptide chain

**Initial concentration**  $0 \cdot 10^4 \cdot \text{item} \cdot \text{ml}^{-1}$

This species takes part in two reactions (as a reactant in [reaction\\_12](#) and as a product in [reaction\\_11](#)).

$$\frac{d}{dt}\text{Delay08\_mSHP1} = v_{11} - v_{12} \quad (125)$$

### 8.33 Species Epo

**SBO:0000252** polypeptide chain

**Initial concentration**  $50 \text{ dimensionless} \cdot \text{ml}^{-1}$

This species takes part in one reaction (as a modifier in [reaction\\_1](#)).

$$\frac{d}{dt}\text{Epo} = 0 \quad (126)$$

## A Glossary of Systems Biology Ontology Terms

**SBO:0000035 forward unimolecular rate constant, continuous case:** Numerical parameter that quantifies the forward velocity of a chemical reaction involving only one reactant. This parameter encompasses all the contributions to the velocity except the quantity of the reactant. It is to be used in a reaction modelled using a continuous framework

**SBO:0000036 forward bimolecular rate constant, continuous case:** Numerical parameter that quantifies the forward velocity of a chemical reaction involving two reactants. This parameter encompasses all the contributions to the velocity except the quantity of the reactants. It is to be used in a reaction modelled using a continuous framework

**SBO:0000177 non-covalent binding:** Interaction between several biochemical entities that results in the formation of a non-covalent complex

**SBO:0000180 dissociation:** Transformation of a non-covalent complex that results in the formation of several independent biochemical entities

**SBO:0000196 concentration of an entity pool:** The amount of an entity per unit of volume.

**SBO:0000216 phosphorylation:** Addition of a phosphate group ( $\text{-H}_2\text{PO}_4$ ) to a chemical entity

**SBO:0000252 polypeptide chain:** Naturally occurring macromolecule formed by the repetition of amino-acid residues linked by peptidic bonds. A polypeptide chain is synthesized by the ribosome. CHEBI:1654

**SBO:0000290 physical compartment:** Specific location of space, that can be bounded or not. A physical compartment can have 1, 2 or 3 dimensions

**SBO:0000330 dephosphorylation:** Removal of a phosphate group ( $\text{-H}_2\text{PO}_4$ ) from a chemical entity.

**SBO:0000381 biochemical proportionality coefficient:** A multiplicative factor for quantities, expressions or functions

**SBO:0000396 uncertain process:** An equivocal or conjectural process, whose existence is assumed but not proven

**SBO:0000397 omitted process:** One or more processes that are not represented in certain representations or interpretations of a model

**SBO:0000461 essential activator:** A substance that is absolutely required for occurrence and stimulation of a reaction

**SBO:0000463 standard biochemical potential:** The biochemical potential of a substance measured at standard concentrations and under standard conditions

**SBO:0000534 catalytic activator:** An essential activator that affects the apparent value of the catalytic constant

SBML<sup>2</sup>LaTeX 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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