

## SBML Model Report

# Model name: “Schaber2006\_Pheromone-Starvation\_Crosstalk”



May 6, 2016

## 1 General Overview

This is a document in SBML Level 2 Version 4 format. This model was created by the following three authors: Lukas Endler<sup>1</sup>, Vijayalakshmi Chelliah<sup>2</sup> and Jorg Schaber<sup>3</sup> at August 20<sup>th</sup> 2009 at 5:18 p. m. and last time modified at April eighth 2016 at 4:03 p. m. Table 1 provides an overview of the quantities of all components of this model.

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

Element	Quantity	Element	Quantity
compartment types	0	compartments	1
species types	0	species	26
events	0	constraints	0
reactions	31	function definitions	0
global parameters	46	unit definitions	0
rules	2	initial assignments	0

## Model Notes

This a model from the article:

**A modelling approach to quantify dynamic crosstalk between the pheromone and the starvation pathway in baker’s yeast.**

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Schaber J, Kofahl B, Kowald A, Klipp E FEBS J.2006 Aug; 273(15):3520-33 [16884493](#),

**Abstract:**

Cells must be able to process multiple information in parallel and, moreover, they must also be able to combine this information in order to trigger the appropriate response. This is achieved by wiring signalling pathways such that they can interact with each other, a phenomenon often called crosstalk. In this study, we employ mathematical modelling techniques to analyse dynamic mechanisms and measures of crosstalk. We present a dynamic mathematical model that compiles current knowledge about the wiring of the pheromone pathway and the filamentous growth pathway in yeast. We consider the main dynamic features and the interconnections between the two pathways in order to study dynamic crosstalk between these two pathways in haploid cells. We introduce two new measures of dynamic crosstalk, the intrinsic specificity and the extrinsic specificity. These two measures incorporate the combined signal of several stimuli being present simultaneously and seem to be more stable than previous measures. When both pathways are responsive and stimulated, the model predicts that (a) the filamentous growth pathway amplifies the response of the pheromone pathway, and (b) the pheromone pathway inhibits the response of filamentous growth pathway in terms of mitogen activated protein kinase activity and transcriptional activity, respectively. Among several mechanisms we identified leakage of activated Ste11 as the most influential source of crosstalk. Moreover, we propose new experiments and predict their outcomes in order to test hypotheses about the mechanisms of crosstalk between the two pathways. Studying signals that are transmitted in parallel gives us new insights about how pathways and signals interact in a dynamical way, e.g., whether they amplify, inhibit, delay or accelerate each other.

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To cite BioModels Database, please use [Le Novre N., Bornstein B., Broicher A., Courtot M., Donizelli M., Dharuri H., Li L., Sauro H., Schilstra M., Shapiro B., Snoep J.L., Hucka M. \(2006\) BioModels Database: A Free, Centralized Database of Curated, Published, Quantitative Kinetic Models of Biochemical and Cellular Systems Nucleic Acids Res., 34: D689-D691.](#)

## 2 Unit Definitions

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

### 2.1 Unit substance

**Notes** Mole is the predefined SBML unit for substance.

**Definition** mol

### 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<sup>2</sup>

### 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
compartment	compartment	0000290	3	1	litre	<input checked="" type="checkbox"/>	

### 3.1 Compartment `compartment`

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

**Name** compartment

**SBO:0000290** physical compartment

## 4 Species

This model contains 26 species. The boundary condition of two of these species is set to true so that these species' amount cannot be changed by any reaction. 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
Ste5	Ste5	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste11	Ste11	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste5Ste11	Ste5Ste11	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Gbg	Gbg	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste5Ste11Gbg	Ste5Ste11Gbg	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Fus3	Fus3	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste5Ste11GbgFus3	Ste5Ste11GbgFus3	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste5Ste11GbgFus3P	Ste5Ste11GbgFus3P	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Fus3PP	Fus3PP	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste5Ste11GbgP	Ste5Ste11GbgP	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste11Ubi	Ste11Ubi	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
p	p	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Kss1	Kss1	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste5Ste11GbgKss1	Ste5Ste11GbgKss1	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste5Ste11GbgKss1P	Ste5Ste11GbgKss1P	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Kss1PP	Kss1PP	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste11P	Ste11P	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste12Kss1	Ste12Kss1	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste12	Ste12	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
Ste12P	Ste12P	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input type="checkbox"/>	<input type="checkbox"/>
s	s	compartment	$\text{mol} \cdot \text{l}^{-1}$	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

Id	Name	Compartment	Derived Unit	Constant	Boundary Condi- tion
PREP	PREP	compartment	$\text{mol} \cdot \text{l}^{-1}$	$\square$	$\square$
Ste12TeSte5Kss1	Ste12TeSte5Kss1	compartment	$\text{mol} \cdot \text{l}^{-1}$	$\square$	$\square$
Ste12TeSte5	Ste12TeSte5	compartment	$\text{mol} \cdot \text{l}^{-1}$	$\square$	$\square$
Ste12TeSte5P	Ste12TeSte5P	compartment	$\text{mol} \cdot \text{l}^{-1}$	$\square$	$\square$
FREP	FREP	compartment	$\text{mol} \cdot \text{l}^{-1}$	$\square$	$\square$

## 5 Parameters

This model contains 46 global parameters.

Table 4: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
alpha			0.00		<input type="checkbox"/>
beta			0.00		<input type="checkbox"/>
alphaA	alphaA		1.00		<input checked="" type="checkbox"/>
betaA	betaA		1.00		<input checked="" type="checkbox"/>
alphat	alphat		0.00		<input checked="" type="checkbox"/>
betat	betat		0.00		<input checked="" type="checkbox"/>
alphas	alphas		2.00		<input checked="" type="checkbox"/>
betas	betas		20.00		<input checked="" type="checkbox"/>
alphae	alphae		10.00		<input checked="" type="checkbox"/>
betae	betae		360.00		<input checked="" type="checkbox"/>
k3	k3		1.00		<input checked="" type="checkbox"/>
k4	k4		1.00		<input checked="" type="checkbox"/>
k5	k5		1.00		<input checked="" type="checkbox"/>
k6	k6		1.00		<input checked="" type="checkbox"/>
k9	k9		1.00		<input checked="" type="checkbox"/>
k10	k10		1.00		<input checked="" type="checkbox"/>
k11	k11		1.00		<input checked="" type="checkbox"/>
k12	k12		1.00		<input checked="" type="checkbox"/>
k13	k13		1.00		<input checked="" type="checkbox"/>
k17	k17		1.00		<input checked="" type="checkbox"/>
k19	k19		1.00		<input checked="" type="checkbox"/>
k20	k20		1.00		<input checked="" type="checkbox"/>
k21	k21		1.00		<input checked="" type="checkbox"/>
k22	k22		1.00		<input checked="" type="checkbox"/>
k23	k23		1.00		<input checked="" type="checkbox"/>
k25	k25		1.00		<input checked="" type="checkbox"/>
k27	k27		1.00		<input checked="" type="checkbox"/>
k31	k31		1.00		<input checked="" type="checkbox"/>
k32	k32		1.00		<input checked="" type="checkbox"/>
k33	k33		1.00		<input checked="" type="checkbox"/>
k34	k34		1.00		<input checked="" type="checkbox"/>
k8	k8		0.10		<input checked="" type="checkbox"/>
k14	k14		0.10		<input checked="" type="checkbox"/>
k15	k15		0.10		<input checked="" type="checkbox"/>
k16	k16		0.10		<input checked="" type="checkbox"/>
k26	k26		0.10		<input checked="" type="checkbox"/>
k30	k30		0.10		<input checked="" type="checkbox"/>

Id	Name	SBO	Value	Unit	Constant
k7	k7		10.00		✓
k18	k18		10.00		✓
k1	k1		0.01		✓
k2	k2		0.01		✓
k24	k24		0.01		✓
k28	k28		0.01		✓
k29	k29		0.01		✓
alphastim	alphastim		1.00		✓
betastim	betastim		1.00		✓

## 6 Rules

This is an overview of two rules.

### 6.1 Rule $\alpha$

Rule  $\alpha$  is an assignment rule for parameter  $\alpha$ :

$$\alpha = \alpha_{\text{stim}} \quad (1)$$

$$\cdot \begin{cases} \alpha_A \cdot \left(1 - \exp\left(\frac{(\text{time} - \alpha_{\text{phat}})}{\alpha_{\text{phas}}}\right)\right) & \text{if } (\text{time} \geq \alpha_{\text{phat}}) \wedge (\text{time} \leq \alpha_{\text{phae}}) \\ \alpha_A \cdot \exp\left(\frac{(\text{time} - \alpha_{\text{phat}})}{\alpha_{\text{phas}}}\right) & \text{if } \text{time} \geq \alpha_{\text{phae}} \\ 0 & \text{otherwise} \end{cases}$$

### 6.2 Rule $\beta$

Rule  $\beta$  is an assignment rule for parameter  $\beta$ :

$$\beta = \beta_{\text{stim}} \cdot \beta_A$$

$$\cdot \begin{cases} 1 - \exp\left(\frac{(\text{time} - \beta_{\text{tat}})}{\beta_{\text{tas}}}\right) & \text{if } (\text{time} \geq \beta_{\text{tat}}) \wedge (\text{time} \leq \beta_{\text{tae}}) \\ \exp\left(\frac{(\text{time} - \beta_{\text{tae}})}{\beta_{\text{tas}}}\right) & \text{if } \text{time} > \beta_{\text{tae}} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

## 7 Reactions

This model contains 31 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	v1	v1	$\text{Ste5} + \text{Ste11} \rightleftharpoons \text{Ste5Ste11}$	0000177
2	v2	v2	$\text{Ste5Ste11} + \text{Gbg} \rightleftharpoons \text{Ste5Ste11Gbg}$	0000177
3	v3	v3	$\text{Ste5Ste11Gbg} + \text{Fus3} \rightleftharpoons \text{Ste5Ste11GbgFus3}$	0000177
4	v4	v4	$\text{Ste5Ste11GbgFus3} \rightleftharpoons \text{Ste5Ste11GbgFus3P}$	0000216
5	v5	v5	$\text{Ste5Ste11GbgFus3P} \rightleftharpoons \text{Fus3PP} + \text{Ste5Ste11GbgP}$	0000216
6	v6	v6	$\text{Fus3} + \text{Ste5Ste11GbgP} \rightleftharpoons \text{Ste5Ste11GbgFus3P}$	0000177
7	v7	v7	$\text{Ste5} + \text{Ste5Ste11GbgP} \rightleftharpoons \text{Gbg} + \text{Ste11Ubi}$	0000180
8	v8	v8	$\text{Ste11Ubi} \rightleftharpoons \text{p}$	0000179
9	v9	v9	$\text{Ste5Ste11Gbg} + \text{Kss1} \rightleftharpoons \text{Ste5Ste11GbgKss1}$	0000177
10	v10	v10	$\text{Ste5Ste11GbgKss1} \rightleftharpoons \text{Ste5Ste11GbgKss1P}$	0000216
11	v11	v11	$\text{Ste5Ste11GbgKss1P} \rightleftharpoons \text{Ste5Ste11GbgP} + \text{Kss1PP}$	0000216
12	v12	v12	$\text{Ste5Ste11GbgP} + \text{Kss1} \rightleftharpoons \text{Ste5Ste11GbgKss1P}$	0000177
13	v13	v13	$\text{Ste11} \rightleftharpoons \text{Ste11P}$	0000216
14	v14	v14	$\text{Ste11P} \rightleftharpoons \text{Ste11}$	0000330
15	v15	v15	$\text{Kss1} \xrightleftharpoons[\text{Ste11P, Ste11Ubi}]{} \text{Kss1PP}$	0000216
16	v16	v16	$\text{Kss1PP} \xrightleftharpoons[\text{Fus3PP}]{} \text{Kss1}$	0000330
17	v17	v17	$\text{Ste12Kss1} \rightleftharpoons 2 \text{Kss1} + \text{Ste12}$	0000180
18	v18	v18	$2 \text{Kss1} + \text{Ste12} \rightleftharpoons \text{Ste12Kss1}$	0000177
19	v19	v19	$\text{Ste12} \xrightleftharpoons[\text{Fus3PP, Kss1PP}]{} \text{Ste12P}$	0000216



Nº	Id	Name	Reaction Equation	SBO
20	v20	v20	$s \xrightarrow{\text{Ste12P}} \text{PREP}$	0000205
21	v21	v21	$\text{Ste12TeSte5Kss1} \rightleftharpoons \text{Kss1} + \text{Ste12TeSte5}$	0000180
22	v22	v22	$\text{Kss1} + \text{Ste12TeSte5} \rightleftharpoons \text{Ste12TeSte5Kss1}$	0000177
23	v23	v23	$\text{Ste12TeSte5} \xrightarrow{\text{Kss1PP}} \text{Ste12TeSte5P}$	0000216
24	v24	v24	$\text{Ste12TeSte5} \xrightarrow{\text{Fus3PP}} \text{p}$	0000179
25	v25	v25	$s \xrightarrow{\text{Ste12TeSte5P}} \text{FREP}$	0000205
26	v26	v26	$\text{Fus3PP} \rightleftharpoons \text{Fus3}$	0000330
27	v27	v27	$\text{Ste5Ste11} \rightleftharpoons \text{Ste5} + \text{Ste11}$	0000180
28	v28	v28	$\text{Ste12P} \rightleftharpoons \text{Ste12}$	0000330
29	v29	v29	$\text{PREP} \rightleftharpoons \text{p}$	0000179
30	v30	v30	$\text{Ste12TeSte5P} \rightleftharpoons \text{Ste12TeSte5}$	0000330
31	v31	v31	$\text{FREP} \rightleftharpoons \text{p}$	0000179

## 7.1 Reaction v1

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

**Name** v1

**SBO:0000177** non-covalent binding

### Reaction equation



### Reactants

Table 6: Properties of each reactant.

Id	Name	SBO
Ste5	Ste5	
Ste11	Ste11	

### Product

Table 7: Properties of each product.

Id	Name	SBO
Ste5Ste11	Ste5Ste11	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_1 = \text{vol}(\text{compartment}) \cdot k_1 \cdot [\text{Ste5}] \cdot [\text{Ste11}] \quad (4)$$

## 7.2 Reaction v2

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

**Name** v2

**SBO:0000177** non-covalent binding

### Reaction equation



## Reactants

Table 8: Properties of each reactant.

Id	Name	SBO
Ste5Ste11	Ste5Ste11	
Gbg	Gbg	

## Product

Table 9: Properties of each product.

Id	Name	SBO
Ste5Ste11Gbg	Ste5Ste11Gbg	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_2 = \text{vol}(\text{compartment}) \cdot k_2 \cdot [\text{Ste5Ste11}] \cdot [\text{Gbg}] \cdot \alpha \quad (6)$$

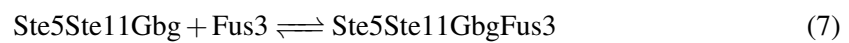
## 7.3 Reaction v3

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

**Name** v3

**SBO:0000177** non-covalent binding

## Reaction equation



## Reactants

Table 10: Properties of each reactant.

Id	Name	SBO
Ste5Ste11Gbg	Ste5Ste11Gbg	
Fus3	Fus3	

## Product

Table 11: Properties of each product.

Id	Name	SBO
Ste5Ste11GbgFus3	Ste5Ste11GbgFus3	

**Kinetic Law****Derived unit** contains undeclared units

$$v_3 = \text{vol}(\text{compartment}) \cdot k_3 \cdot [\text{Ste5Ste11Gbg}] \cdot [\text{Fus3}] \quad (8)$$

**7.4 Reaction v4**

This is a reversible reaction of one reactant forming one product.

**Name** v4**SBO:0000216** phosphorylation**Reaction equation****Reactant**

Table 12: Properties of each reactant.

Id	Name	SBO
Ste5Ste11GbgFus3	Ste5Ste11GbgFus3	

**Product**

Table 13: Properties of each product.

Id	Name	SBO
Ste5Ste11GbgFus3P	Ste5Ste11GbgFus3P	

**Kinetic Law****Derived unit** contains undeclared units

$$v_4 = \text{vol}(\text{compartment}) \cdot k_4 \cdot [\text{Ste5Ste11GbgFus3}] \quad (10)$$

## 7.5 Reaction v5

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

**Name** v5

**SBO:0000216** phosphorylation

### Reaction equation



### Reactant

Table 14: Properties of each reactant.

Id	Name	SBO
Ste5Ste11GbgFus3P	Ste5Ste11GbgFus3P	

### Products

Table 15: Properties of each product.

Id	Name	SBO
Fus3PP	Fus3PP	
Ste5Ste11GbgP	Ste5Ste11GbgP	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_5 = \text{vol}(\text{compartment}) \cdot k_5 \cdot [\text{Ste5Ste11GbgFus3P}] \quad (12)$$

## 7.6 Reaction v6

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

**Name** v6

**SBO:0000177** non-covalent binding

### Reaction equation



## Reactants

Table 16: Properties of each reactant.

Id	Name	SBO
Fus3	Fus3	
Ste5Ste11GbgP	Ste5Ste11GbgP	

## Product

Table 17: Properties of each product.

Id	Name	SBO
Ste5Ste11GbgFus3P	Ste5Ste11GbgFus3P	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_6 = \text{vol}(\text{compartment}) \cdot k_6 \cdot [\text{Fus3}] \cdot [\text{Ste5Ste11GbgP}] \quad (14)$$

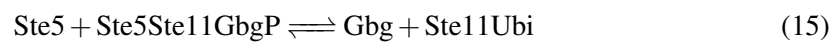
## 7.7 Reaction v7

This is a reversible reaction of two reactants forming two products.

**Name** v7

**SBO:0000180** dissociation

## Reaction equation



## Reactants

Table 18: Properties of each reactant.

Id	Name	SBO
Ste5	Ste5	
Ste5Ste11GbgP	Ste5Ste11GbgP	

## Products

Table 19: Properties of each product.

Id	Name	SBO
Gbg	Gbg	
Ste11Ubi	Ste11Ubi	

**Kinetic Law**

**Derived unit** contains undeclared units

$$v_7 = \text{vol}(\text{compartment}) \cdot k_7 \cdot [\text{Ste5Ste11GbgP}] \tag{16}$$

**7.8 Reaction v8**

This is a reversible reaction of one reactant forming one product.

**Name** v8

**SBO:0000179** degradation

**Reaction equation**



**Reactant**

Table 20: Properties of each reactant.

Id	Name	SBO
Ste11Ubi	Ste11Ubi	

**Product**

Table 21: Properties of each product.

Id	Name	SBO
p	p	

**Kinetic Law**

**Derived unit** contains undeclared units

$$v_8 = \text{vol}(\text{compartment}) \cdot k_8 \cdot [\text{Ste11Ubi}] \tag{18}$$

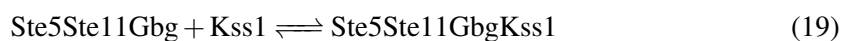
## 7.9 Reaction v9

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

**Name** v9

**SBO:0000177** non-covalent binding

### Reaction equation



### Reactants

Table 22: Properties of each reactant.

Id	Name	SBO
Ste5Ste11Gbg	Ste5Ste11Gbg	
Kss1	Kss1	

### Product

Table 23: Properties of each product.

Id	Name	SBO
Ste5Ste11GbgKss1	Ste5Ste11GbgKss1	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_9 = \text{vol}(\text{compartment}) \cdot k_9 \cdot [\text{Ste5Ste11Gbg}] \cdot [\text{Kss1}] \quad (20)$$

## 7.10 Reaction v10

This is a reversible reaction of one reactant forming one product.

**Name** v10

**SBO:0000216** phosphorylation

### Reaction equation





## Reactant

Table 24: Properties of each reactant.

Id	Name	SBO
Ste5Ste11GbgKss1	Ste5Ste11GbgKss1	

## Product

Table 25: Properties of each product.

Id	Name	SBO
Ste5Ste11GbgKss1P	Ste5Ste11GbgKss1P	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_{10} = \text{vol}(\text{compartment}) \cdot k_{10} \cdot [\text{Ste5Ste11GbgKss1}] \quad (22)$$

### 7.11 Reaction v11

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

**Name** v11

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 26: Properties of each reactant.

Id	Name	SBO
Ste5Ste11GbgKss1P	Ste5Ste11GbgKss1P	

## Products

Table 27: Properties of each product.

Id	Name	SBO
Ste5Ste11GbgP	Ste5Ste11GbgP	
Kss1PP	Kss1PP	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_{11} = \text{vol}(\text{compartment}) \cdot k_{11} \cdot [\text{Ste5Ste11GbgKss1P}] \quad (24)$$

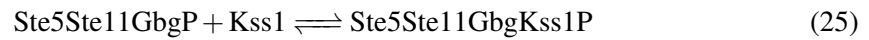
### 7.12 Reaction v12

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

**Name** v12

**SBO:0000177** non-covalent binding

### Reaction equation



### Reactants

Table 28: Properties of each reactant.

Id	Name	SBO
Ste5Ste11GbgP	Ste5Ste11GbgP	
Kss1	Kss1	

### Product

Table 29: Properties of each product.

Id	Name	SBO
Ste5Ste11GbgKss1P	Ste5Ste11GbgKss1P	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_{12} = \text{vol}(\text{compartment}) \cdot k_{12} \cdot [\text{Ste5Ste11GbgP}] \cdot [\text{Kss1}] \quad (26)$$

### 7.13 Reaction v13

This is a reversible reaction of one reactant forming one product.

**Name** v13

**SBO:0000216** phosphorylation

#### Reaction equation



#### Reactant

Table 30: Properties of each reactant.

Id	Name	SBO
Ste11	Ste11	

#### Product

Table 31: Properties of each product.

Id	Name	SBO
Ste11P	Ste11P	

#### Kinetic Law

**Derived unit** contains undeclared units

$$v_{13} = \text{vol}(\text{compartment}) \cdot k_{13} \cdot [\text{Ste11}] \cdot \text{beta} \quad (28)$$

### 7.14 Reaction v14

This is a reversible reaction of one reactant forming one product.

**Name** v14

**SBO:0000330** dephosphorylation

#### Reaction equation



## Reactant

Table 32: Properties of each reactant.

Id	Name	SBO
Ste11P	Ste11P	

## Product

Table 33: Properties of each product.

Id	Name	SBO
Ste11	Ste11	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_{14} = \text{vol}(\text{compartment}) \cdot k_{14} \cdot [\text{Ste11P}] \quad (30)$$

### 7.15 Reaction v15

This is a reversible reaction of one reactant forming one product influenced by two modifiers.

**Name** v15

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 34: Properties of each reactant.

Id	Name	SBO
Kss1	Kss1	

## Modifiers

Table 35: Properties of each modifier.

Id	Name	SBO
Ste11P	Ste11P	
Ste11Ubi	Ste11Ubi	

## Product

Table 36: Properties of each product.

Id	Name	SBO
Kss1PP	Kss1PP	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_{15} = \text{vol}(\text{compartment}) \cdot (k_{15} \cdot [\text{Kss1}] \cdot [\text{Ste11P}] + k_{30} \cdot [\text{Kss1}] \cdot [\text{Ste11Ubi}]) \quad (32)$$

## 7.16 Reaction v16

This is a reversible reaction of one reactant forming one product influenced by one modifier.

**Name** v16

**SBO:0000330** dephosphorylation

## Reaction equation



## Reactant

Table 37: Properties of each reactant.

Id	Name	SBO
Kss1PP	Kss1PP	

## Modifier

Table 38: Properties of each modifier.

Id	Name	SBO
Fus3PP	Fus3PP	

## Product

Table 39: Properties of each product.

Id	Name	SBO
Kss1	Kss1	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_{16} = \text{vol}(\text{compartment}) \cdot (k_{16} \cdot [\text{Kss1PP}] + k_{28} \cdot [\text{Kss1PP}] \cdot [\text{Fus3PP}]) \quad (34)$$

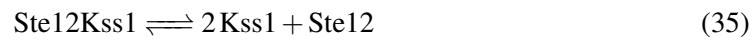
## 7.17 Reaction v17

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

**Name** v17

**SBO:0000180** dissociation

## Reaction equation



## Reactant

Table 40: Properties of each reactant.

Id	Name	SBO
Ste12Kss1	Ste12Kss1	

## Products

Table 41: Properties of each product.

Id	Name	SBO
Kss1	Kss1	
Ste12	Ste12	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_{17} = \text{vol}(\text{compartment}) \cdot k_{17} \cdot [\text{Ste12Kss1}] \quad (36)$$

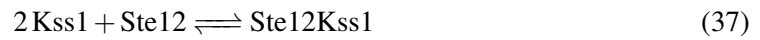
### 7.18 Reaction v18

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

**Name** v18

**SBO:0000177** non-covalent binding

### Reaction equation



### Reactants

Table 42: Properties of each reactant.

Id	Name	SBO
Kss1	Kss1	
Ste12	Ste12	

### Product

Table 43: Properties of each product.

Id	Name	SBO
Ste12Kss1	Ste12Kss1	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_{18} = \text{vol}(\text{compartment}) \cdot k_{18} \cdot [\text{Kss1}] \cdot [\text{Ste12}] \quad (38)$$

### 7.19 Reaction v19

This is a reversible reaction of one reactant forming one product influenced by two modifiers.

**Name** v19

**SBO:0000216** phosphorylation

#### Reaction equation



#### Reactant

Table 44: Properties of each reactant.

Id	Name	SBO
Ste12	Ste12	

#### Modifiers

Table 45: Properties of each modifier.

Id	Name	SBO
Fus3PP	Fus3PP	
Kss1PP	Kss1PP	

#### Product

Table 46: Properties of each product.

Id	Name	SBO
Ste12P	Ste12P	

#### Kinetic Law

**Derived unit** contains undeclared units

$$v_{19} = \text{vol}(\text{compartment}) \cdot (k_{19} \cdot [\text{Ste12}] \cdot [\text{Fus3PP}] + k_{29} \cdot [\text{Ste12}] \cdot [\text{Kss1PP}]) \quad (40)$$



## 7.20 Reaction v20

This is a reversible reaction of one reactant forming one product influenced by one modifier.

**Name** v20

**SBO:0000205** composite biochemical process

### Reaction equation



### Reactant

Table 47: Properties of each reactant.

Id	Name	SBO
s	s	

### Modifier

Table 48: Properties of each modifier.

Id	Name	SBO
Ste12P	Ste12P	

### Product

Table 49: Properties of each product.

Id	Name	SBO
PREP	PREP	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_{20} = \text{vol}(\text{compartment}) \cdot k_{20} \cdot [\text{Ste12P}] \quad (42)$$

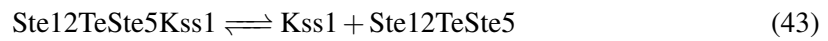
## 7.21 Reaction v21

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

**Name** v21

**SBO:0000180** dissociation

### Reaction equation



### Reactant

Table 50: Properties of each reactant.

Id	Name	SBO
Ste12TeSte5Kss1	Ste12TeSte5Kss1	

### Products

Table 51: Properties of each product.

Id	Name	SBO
Kss1	Kss1	
Ste12TeSte5	Ste12TeSte5	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_{21} = \text{vol}(\text{compartment}) \cdot k_{21} \cdot [\text{Ste12TeSte5Kss1}] \quad (44)$$

## 7.22 Reaction v22

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

**Name** v22

**SBO:0000177** non-covalent binding

### Reaction equation



### Reactants

Table 52: Properties of each reactant.

Id	Name	SBO
Kss1	Kss1	
Ste12TeSte5	Ste12TeSte5	

## Product

Table 53: Properties of each product.

Id	Name	SBO
Ste12TeSte5Kss1	Ste12TeSte5Kss1	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_{22} = \text{vol}(\text{compartment}) \cdot k_{22} \cdot [\text{Kss1}] \cdot [\text{Ste12TeSte5}] \quad (46)$$

## 7.23 Reaction v23

This is a reversible reaction of one reactant forming one product influenced by one modifier.

**Name** v23

**SBO:0000216** phosphorylation

## Reaction equation



## Reactant

Table 54: Properties of each reactant.

Id	Name	SBO
Ste12TeSte5	Ste12TeSte5	

## Modifier

Table 55: Properties of each modifier.

Id	Name	SBO
Kss1PP	Kss1PP	

## Product

Table 56: Properties of each product.

Id	Name	SBO
Ste12TeSte5P	Ste12TeSte5P	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_{23} = \text{vol}(\text{compartment}) \cdot k_{23} \cdot [\text{Ste12TeSte5}] \cdot [\text{Kss1PP}] \quad (48)$$

## 7.24 Reaction v24

This is a reversible reaction of one reactant forming one product influenced by one modifier.

**Name** v24

**SBO:0000179** degradation

## Reaction equation



## Reactant

Table 57: Properties of each reactant.

Id	Name	SBO
Ste12TeSte5	Ste12TeSte5	

## Modifier

Table 58: Properties of each modifier.

Id	Name	SBO
Fus3PP	Fus3PP	

## Product

Table 59: Properties of each product.

Id	Name	SBO
p	p	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_{24} = \text{vol}(\text{compartment}) \cdot k_{24} \cdot [\text{Ste12TeSte5}] \cdot [\text{Fus3PP}] \quad (50)$$

## 7.25 Reaction v25

This is a reversible reaction of one reactant forming one product influenced by one modifier.

**Name** v25

**SBO:0000205** composite biochemical process

## Reaction equation



## Reactant

Table 60: Properties of each reactant.

Id	Name	SBO
s	s	

## Modifier

Table 61: Properties of each modifier.

Id	Name	SBO
Ste12TeSte5P	Ste12TeSte5P	

## Product

Table 62: Properties of each product.

Id	Name	SBO
FREP	FREP	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_{25} = \text{vol}(\text{compartment}) \cdot k_{25} \cdot [\text{Ste12TeSte5P}] \quad (52)$$

## 7.26 Reaction v26

This is a reversible reaction of one reactant forming one product.

**Name** v26

**SBO:0000330** dephosphorylation

## Reaction equation



## Reactant

Table 63: Properties of each reactant.

Id	Name	SBO
Fus3PP	Fus3PP	

## Product

Table 64: Properties of each product.

Id	Name	SBO
Fus3	Fus3	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_{26} = \text{vol}(\text{compartment}) \cdot k_{26} \cdot [\text{Fus3PP}] \quad (54)$$

### 7.27 Reaction v27

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

**Name** v27

**SBO:0000180** dissociation

### Reaction equation



### Reactant

Table 65: Properties of each reactant.

Id	Name	SBO
Ste5Ste11	Ste5Ste11	

### Products

Table 66: Properties of each product.

Id	Name	SBO
Ste5	Ste5	
Ste11	Ste11	

### Kinetic Law

**Derived unit** contains undeclared units

$$v_{27} = \text{vol}(\text{compartment}) \cdot k_{27} \cdot [\text{Ste5Ste11}] \quad (56)$$

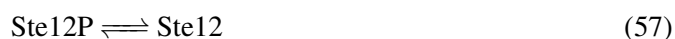
### 7.28 Reaction v28

This is a reversible reaction of one reactant forming one product.

**Name** v28

**SBO:0000330** dephosphorylation

#### Reaction equation



#### Reactant

Table 67: Properties of each reactant.

Id	Name	SBO
Ste12P	Ste12P	

#### Product

Table 68: Properties of each product.

Id	Name	SBO
Ste12	Ste12	

#### Kinetic Law

**Derived unit** contains undeclared units

$$v_{28} = \text{vol}(\text{compartment}) \cdot k_{31} \cdot [\text{Ste12P}] \quad (58)$$

### 7.29 Reaction v29

This is a reversible reaction of one reactant forming one product.

**Name** v29

**SBO:0000179** degradation

#### Reaction equation



#### Reactant



Table 69: Properties of each reactant.

Id	Name	SBO
PREP	PREP	

## Product

Table 70: Properties of each product.

Id	Name	SBO
P	P	

## Kinetic Law

**Derived unit** contains undeclared units

$$v_{29} = \text{vol}(\text{compartment}) \cdot k_{32} \cdot [\text{PREP}] \quad (60)$$

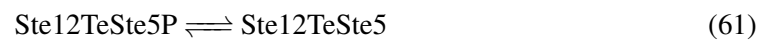
## 7.30 Reaction v30

This is a reversible reaction of one reactant forming one product.

**Name** v30

**SBO:0000330** dephosphorylation

## Reaction equation



## Reactant

Table 71: Properties of each reactant.

Id	Name	SBO
Ste12TeSte5P	Ste12TeSte5P	

## Product

Table 72: Properties of each product.

Id	Name	SBO
Ste12TeSte5	Ste12TeSte5	

**Kinetic Law**

**Derived unit** contains undeclared units

$$v_{30} = \text{vol}(\text{compartment}) \cdot k_{33} \cdot [\text{Ste12TeSte5P}] \quad (62)$$

**7.31 Reaction v31**

This is a reversible reaction of one reactant forming one product.

**Name** v31

**SBO:0000179** degradation

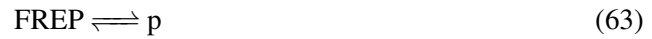
**Reaction equation****Reactant**

Table 73: Properties of each reactant.

Id	Name	SBO
FREP	FREP	

**Product**

Table 74: Properties of each product.

Id	Name	SBO
p	p	

**Kinetic Law**

**Derived unit** contains undeclared units

$$v_{31} = \text{vol}(\text{compartment}) \cdot k_{34} \cdot [\text{FREP}] \quad (64)$$

## 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.

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.

### 8.1 Species Ste5

**Name** Ste5

**SBO:0000252** polypeptide chain

**Initial concentration** 42.3 mol · l<sup>-1</sup>

This species takes part in three reactions (as a reactant in v1, v7 and as a product in v27).

$$\frac{d}{dt}\text{Ste5} = v_{27} - v_1 - v_7 \quad (65)$$

### 8.2 Species Ste11

**Name** Ste11

**SBO:0000252** polypeptide chain

**Initial concentration** 13.3 mol · l<sup>-1</sup>

This species takes part in four reactions (as a reactant in v1, v13 and as a product in v14, v27).

$$\frac{d}{dt}\text{Ste11} = v_{14} + v_{27} - v_1 - v_{13} \quad (66)$$

### 8.3 Species Ste5Ste11

**Name** Ste5Ste11

**SBO:0000297** protein complex

**Initial concentration** 5.6 mol · l<sup>-1</sup>

This species takes part in three reactions (as a reactant in v2, v27 and as a product in v1).

$$\frac{d}{dt}\text{Ste5Ste11} = v_1 - v_2 - v_{27} \quad (67)$$

## 8.4 Species Gbg

**Name** Gbg

**SBO:0000252** polypeptide chain

**Initial concentration** 53 mol · l<sup>-1</sup>

This species takes part in two reactions (as a reactant in v2 and as a product in v7).

$$\frac{d}{dt}\text{Gbg} = v_7 - v_2 \quad (68)$$

## 8.5 Species Ste5Ste11Gbg

**Name** Ste5Ste11Gbg

**SBO:0000297** protein complex

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

This species takes part in three reactions (as a reactant in v3, v9 and as a product in v2).

$$\frac{d}{dt}\text{Ste5Ste11Gbg} = v_2 - v_3 - v_9 \quad (69)$$

## 8.6 Species Fus3

**Name** Fus3

**SBO:0000252** polypeptide chain

**Initial concentration** 217 mol · l<sup>-1</sup>

This species takes part in three reactions (as a reactant in v3, v6 and as a product in v26).

$$\frac{d}{dt}\text{Fus3} = v_{26} - v_3 - v_6 \quad (70)$$

## 8.7 Species Ste5Ste11GbgFus3

**Name** Ste5Ste11GbgFus3

**SBO:0000297** protein complex

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

This species takes part in two reactions (as a reactant in v4 and as a product in v3).

$$\frac{d}{dt}\text{Ste5Ste11GbgFus3} = v_3 - v_4 \quad (71)$$

### 8.8 Species Ste5Ste11GbgFus3P

**Name** Ste5Ste11GbgFus3P

**SBO:0000297** protein complex

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

This species takes part in three reactions (as a reactant in v5 and as a product in v4, v6).

$$\frac{d}{dt}\text{Ste5Ste11GbgFus3P} = v_4 + v_6 - v_5 \quad (72)$$

### 8.9 Species Fus3PP

**Name** Fus3PP

**SBO:0000252** polypeptide chain

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

This species takes part in five reactions (as a reactant in v26 and as a product in v5 and as a modifier in v16, v19, v24).

$$\frac{d}{dt}\text{Fus3PP} = v_5 - v_{26} \quad (73)$$

### 8.10 Species Ste5Ste11GbgP

**Name** Ste5Ste11GbgP

**SBO:0000297** protein complex

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

This species takes part in five reactions (as a reactant in v6, v7, v12 and as a product in v5, v11).

$$\frac{d}{dt}\text{Ste5Ste11GbgP} = v_5 + v_{11} - v_6 - v_7 - v_{12} \quad (74)$$

### 8.11 Species Ste11Ubi

**Name** Ste11Ubi

**SBO:0000252** polypeptide chain

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

This species takes part in three reactions (as a reactant in v8 and as a product in v7 and as a modifier in v15).

$$\frac{d}{dt}\text{Ste11Ubi} = v_7 - v_8 \quad (75)$$

## 8.12 Species p

**Name** p

**SBO:0000291** empty set

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

This species takes part in four reactions (as a product in v8, v24, v29, v31), which do not influence its rate of change because this constant species is on the boundary of the reaction system:

$$\frac{d}{dt}p = 0 \quad (76)$$

## 8.13 Species Kss1

**Name** Kss1

**SBO:0000252** polypeptide chain

**Initial concentration** 54.4 mol · l<sup>-1</sup>

This species takes part in eight reactions (as a reactant in v9, v12, v15, v18, v22 and as a product in v16, v17, v21).

$$\frac{d}{dt}Kss1 = v_{16} + 2 v_{17} + v_{21} - v_9 - v_{12} - v_{15} - 2 v_{18} - v_{22} \quad (77)$$

## 8.14 Species Ste5Ste11GbgKss1

**Name** Ste5Ste11GbgKss1

**SBO:0000297** protein complex

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

This species takes part in two reactions (as a reactant in v10 and as a product in v9).

$$\frac{d}{dt}Ste5Ste11GbgKss1 = v_9 - v_{10} \quad (78)$$

## 8.15 Species Ste5Ste11GbgKss1P

**Name** Ste5Ste11GbgKss1P

**SBO:0000297** protein complex

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

This species takes part in three reactions (as a reactant in v11 and as a product in v10, v12).

$$\frac{d}{dt}Ste5Ste11GbgKss1P = v_{10} + v_{12} - v_{11} \quad (79)$$

### 8.16 Species $K_{ss1PP}$

**Name**  $K_{ss1PP}$

**SBO:0000252** polypeptide chain

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

This species takes part in five reactions (as a reactant in [v16](#) and as a product in [v11](#), [v15](#) and as a modifier in [v19](#), [v23](#)).

$$\frac{d}{dt}K_{ss1PP} = v_{11} + v_{15} - v_{16} \quad (80)$$

### 8.17 Species $Ste11P$

**Name**  $Ste11P$

**SBO:0000252** polypeptide chain

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

This species takes part in three reactions (as a reactant in [v14](#) and as a product in [v13](#) and as a modifier in [v15](#)).

$$\frac{d}{dt}Ste11P = v_{13} - v_{14} \quad (81)$$

### 8.18 Species $Ste12K_{ss1}$

**Name**  $Ste12K_{ss1}$

**SBO:0000297** protein complex

**Initial concentration**  $35.9 \text{ mol} \cdot \text{l}^{-1}$

This species takes part in two reactions (as a reactant in [v17](#) and as a product in [v18](#)).

$$\frac{d}{dt}Ste12K_{ss1} = v_{18} - v_{17} \quad (82)$$

### 8.19 Species $Ste12$

**Name**  $Ste12$

**SBO:0000252** polypeptide chain

**Initial concentration**  $0.07 \text{ mol} \cdot \text{l}^{-1}$

This species takes part in four reactions (as a reactant in [v18](#), [v19](#) and as a product in [v17](#), [v28](#)).

$$\frac{d}{dt}Ste12 = v_{17} + v_{28} - v_{18} - v_{19} \quad (83)$$

## 8.20 Species Ste12P

**Name** Ste12P

**SBO:0000252** polypeptide chain

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

This species takes part in three reactions (as a reactant in v28 and as a product in v19 and as a modifier in v20).

$$\frac{d}{dt}\text{Ste12P} = v_{19} - v_{28} \quad (84)$$

## 8.21 Species s

**Name** s

**SBO:0000291** empty set

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

This species takes part in two reactions (as a reactant in v20, v25), which do not influence its rate of change because this constant species is on the boundary of the reaction system:

$$\frac{d}{dt}s = 0 \quad (85)$$

## 8.22 Species PREP

**Name** PREP

**SBO:0000406** observable

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

This species takes part in two reactions (as a reactant in v29 and as a product in v20).

$$\frac{d}{dt}\text{PREP} = v_{20} - v_{29} \quad (86)$$

## 8.23 Species Ste12TeSte5Kss1

**Name** Ste12TeSte5Kss1

**SBO:0000297** protein complex

**Initial concentration** 13.7 mol · l<sup>-1</sup>

This species takes part in two reactions (as a reactant in v21 and as a product in v22).

$$\frac{d}{dt}\text{Ste12TeSte5Kss1} = v_{22} - v_{21} \quad (87)$$



## 8.24 Species Ste12TeSte5

**Name** Ste12TeSte5

**SBO:0000297** protein complex

**Initial concentration**  $0.25 \text{ mol} \cdot \text{l}^{-1}$

This species takes part in five reactions (as a reactant in v22, v23, v24 and as a product in v21, v30).

$$\frac{d}{dt}\text{Ste12TeSte5} = v_{21} + v_{30} - v_{22} - v_{23} - v_{24} \quad (88)$$

## 8.25 Species Ste12TeSte5P

**Name** Ste12TeSte5P

**SBO:0000297** protein complex

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

This species takes part in three reactions (as a reactant in v30 and as a product in v23 and as a modifier in v25).

$$\frac{d}{dt}\text{Ste12TeSte5P} = v_{23} - v_{30} \quad (89)$$

## 8.26 Species FREP

**Name** FREP

**SBO:0000406** observable

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

This species takes part in two reactions (as a reactant in v31 and as a product in v25).

$$\frac{d}{dt}\text{FREP} = v_{25} - v_{31} \quad (90)$$

# A Glossary of Systems Biology Ontology Terms

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

**SBO:0000179 degradation:** Complete disappearance of a physical entity

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

**SBO:0000205 composite biochemical process:** Process that involves the participation of chemical or biological entities and is composed of several elementary steps or reactions.

**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:0000291 empty set:** Entity defined by the absence of any actual object. An empty set is often used to represent the source of a creation process or the result of a degradation process.

**SBO:0000297 protein complex:** Macromolecular complex containing one or more polypeptide chains possibly associated with simple chemicals. CHEBI:3608

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

**SBO:0000406 observable:** An entity that can be measured quantitatively

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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