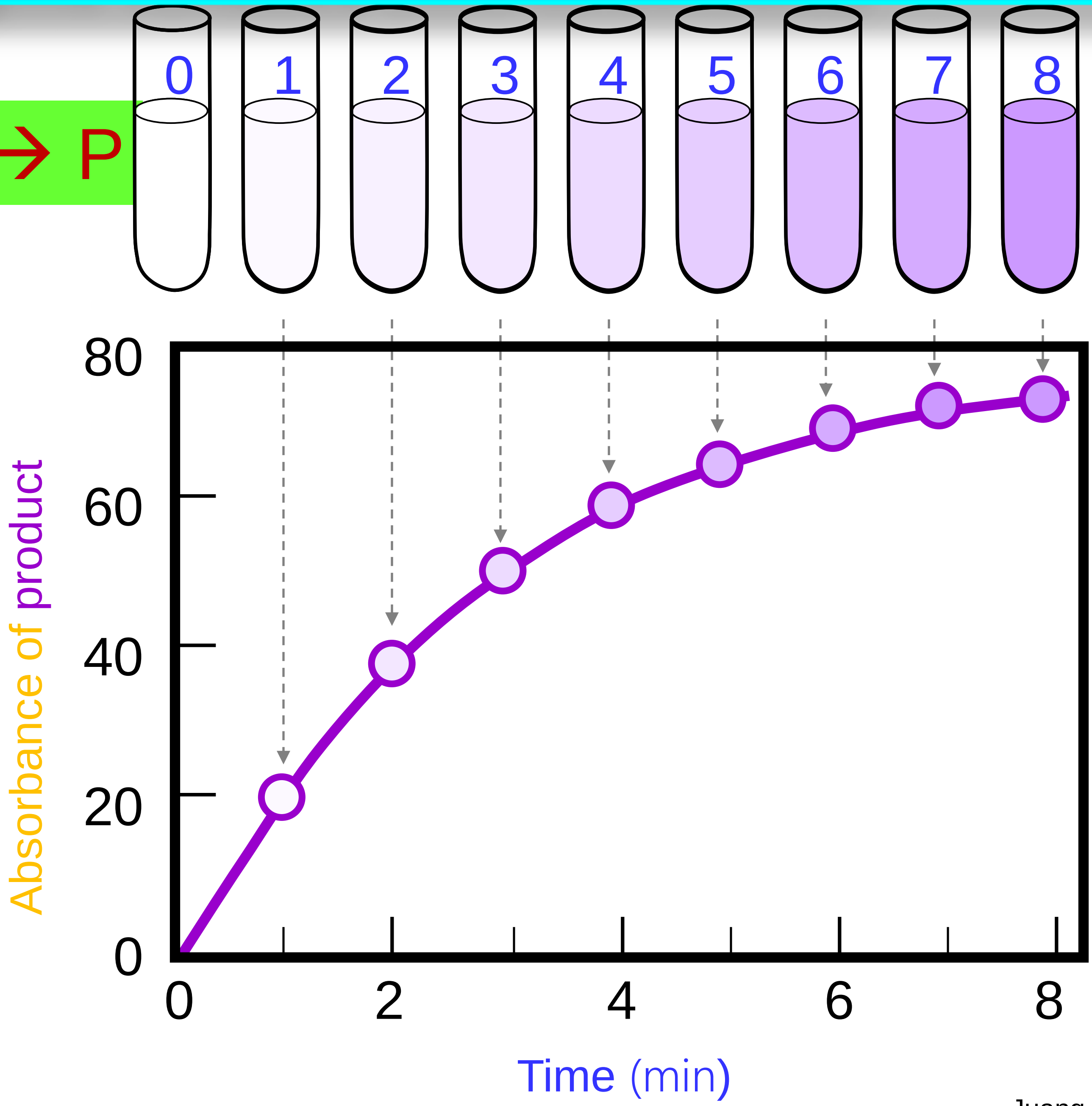
Enzyme Kinetics (จลนศาสตร์ของเอนไซม์)

S + E → P



Juang RH (2004) BCbasics

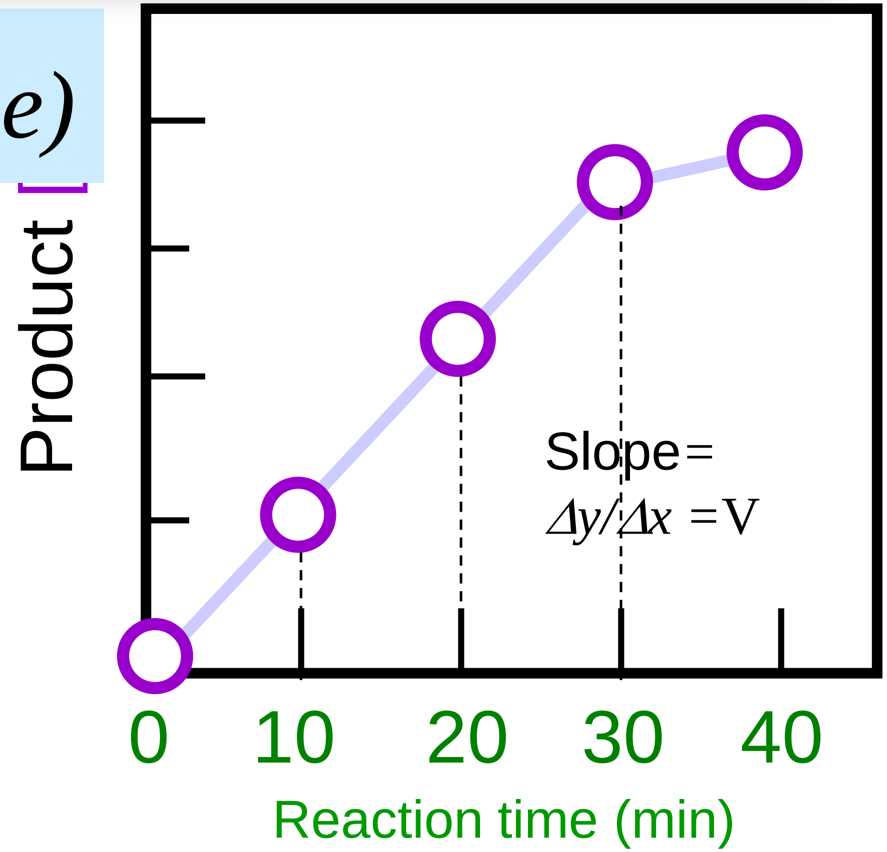
Rate of reaction (V) คือ อัตราการเกิดผลิตภัณฑ์/หน่วยเวลา

$S \xrightarrow[t]{} P$ (หน่วย μ*mole*)

$V = [P] / \text{min}$

ความเร็วของปฏิกิริยา

ผลิตภัณฑ์ ต่อนาที



Juang RH (2004) BCbasics

Enzyme activity **คือ อัตราการเกิดผลิตภัณฑ์ หน่วยไมโครโมล/หน่วยเวลาเป็นนาที**

Enz activity = *μmole* /min

หน่วยของ กิจกรรมของเอนไซม์

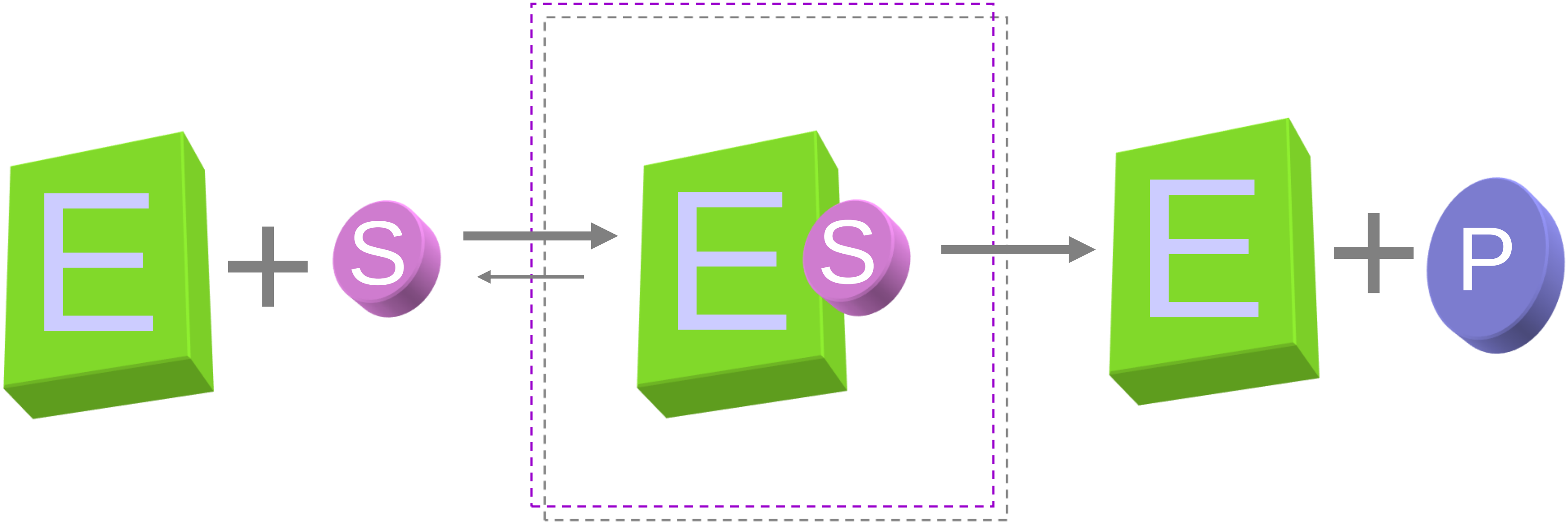
ปริมาณสารตั้งต้น ที่ลดลง หรือ
ปริมาณผลิตภัณฑ์ที่เกิดขึ้น ต่อนาที

Specific activity = enzyme activity **หน่วยเป็น** unit/ **มิลลิกรัมของโปรตีน**

$$\text{Specific Activity} = \frac{\textbf{Enz Activity}}{\text{Protein (mg)}}$$

Juang RH (2004) BCbasics

Steady state (สภาวะคงตัว)



rate of production [ES] = rate of consumption [ES]

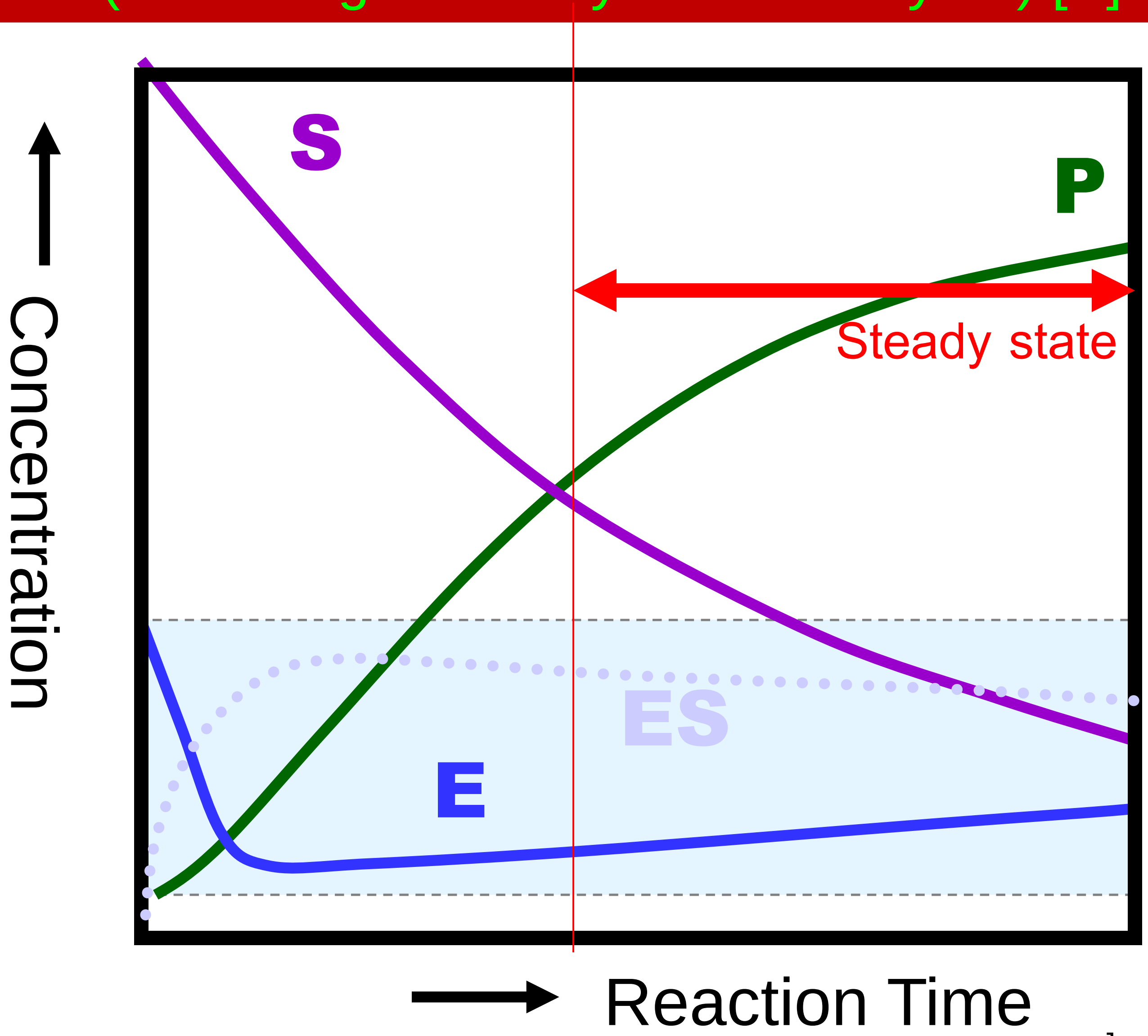
So the concentration of [ES] constant.

Juang RH (2004) BCbasics

Michaelis-Menten Hypothesis:at Steady state

1) No free Enz (all enzymes are active)

2) [ES] const (according to steady state theory 3) [P] V_{max}



Juang RH (2004) BCbasics

How to derive equation for Km and Vmax

$$E + S \underset{k-1}{\overset{k1}{\rightleftharpoons}} ES \xrightarrow{k2} E + P$$

Rate of rx. $$Vi = \frac{d[ES]}{dt}$$

Vi = initial velocity

$$= k1 \boxed{[E]} [S] – k-1[ES] – k2 [ES]$$

$$= k1 \boxed{\{[Et] – [ES]\}} [S] – k-1[ES] – k2[ES]$$

$$= k1 [Et] [S] – k1[ES] [S] – k-1[ES] – k2[ES]$$

How to derive equation for Km and Vmax (cont.)

Hypothesis → [ES] constant

Thus $$V_i = \frac{d[ES]}{dt} = 0$$

$$k1\ [Et]\ [S] - k1[ES]\ [S] - k\text{-}1[ES] - k2[ES] = 0$$

$$k1\ [Et]\ [S] = k1[ES]\ [S] + k\text{-}1[ES] + k2[ES]$$

$$k1\ [Et]\ [S] = [ES]\ \{k1\ [S] + k\text{-}1 + k2\}$$

$$\boxed{k1\ [Et]\ [S] = [ES]\ \{k1\ [S] + k\text{-}1 + k2\}}$$

$$[ES] = \frac{k1\ [Et]\ [S]}{k1\ [S] + k\text{-}1 + k2}$$

$$[ES] = \frac{[Et]\ [S]}{[S] + \underbrace{\frac{k\text{-}1 + k2}{k1}}_{Km}}$$

$$k2\ [ES] = Vi$$

$$k2\ [Et] = Vmax$$

$$k2\ [ES] = \frac{\boxed{k2\ [Et]}\ [S]}{[S] + Km}$$

Vmax and Km have meaning
→ application

Km = Michaelis-Menten const.

$$Vi = \frac{Vmax\ [S]}{[S] + Km}$$

Michaelis – Menten equation

Relationship between initial velocity (V) and substrate concentration [S]

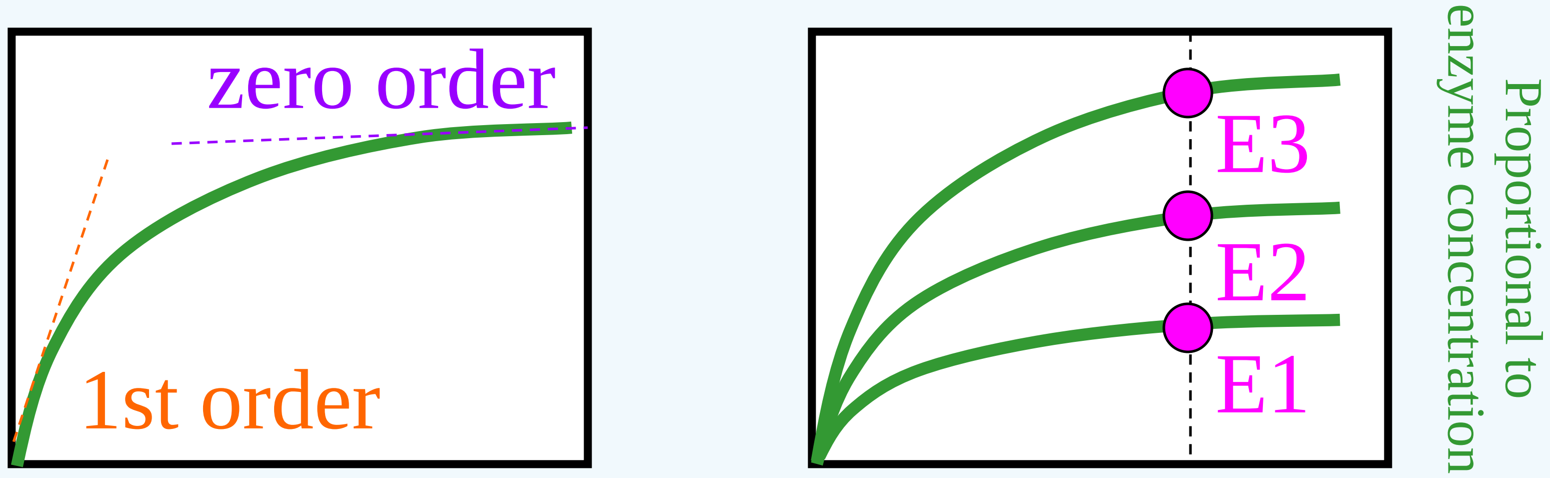
Vmax: Enzyme activity → 1 Enz unit = ...μmol/min

Vmax บอกทางอ้อมถึงปริมาณเอนไซม์ ถ้า Vmax มาก คาดว่าปริมาณเอนไซม์มาก

$$Vi = \frac{V_{max}[S]}{K_m + [S]}$$

Vmax : enzyme activity

Amount of enzyme = ...μmol/min = 1 Enzyme unit



[S] = Low → High

[S] = Fixed concentration

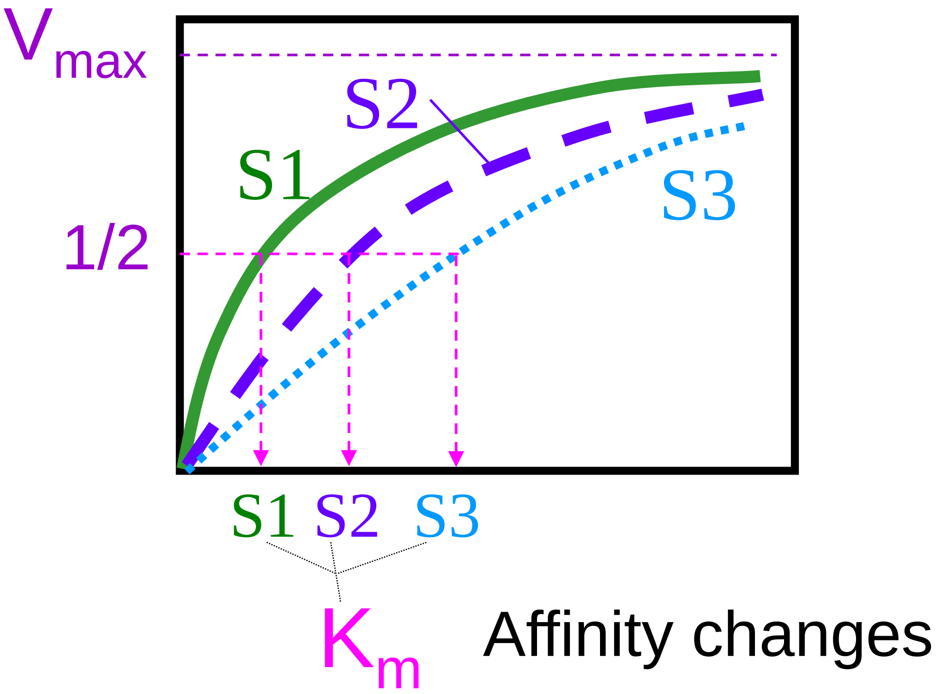
Juang RH (2004) BCbasics

K_m: Affinity with substrate → [S] about 2-5 Km

Km บอกถึงความชอบพอของเอนไซม์กับซับสเตรท Km กับซับสเตรทใดน้อย คาดว่าเอนไซม์ชอบซับสเตรทนั้นมาก

$$K_m = \frac{V_{max}}{2}$$

When using different substrate



- Km is a constant
- Small Km means tight binding
- High Km means weak binding
- Useful to compare Km for different substrates for one enzyme

Hexokinase :

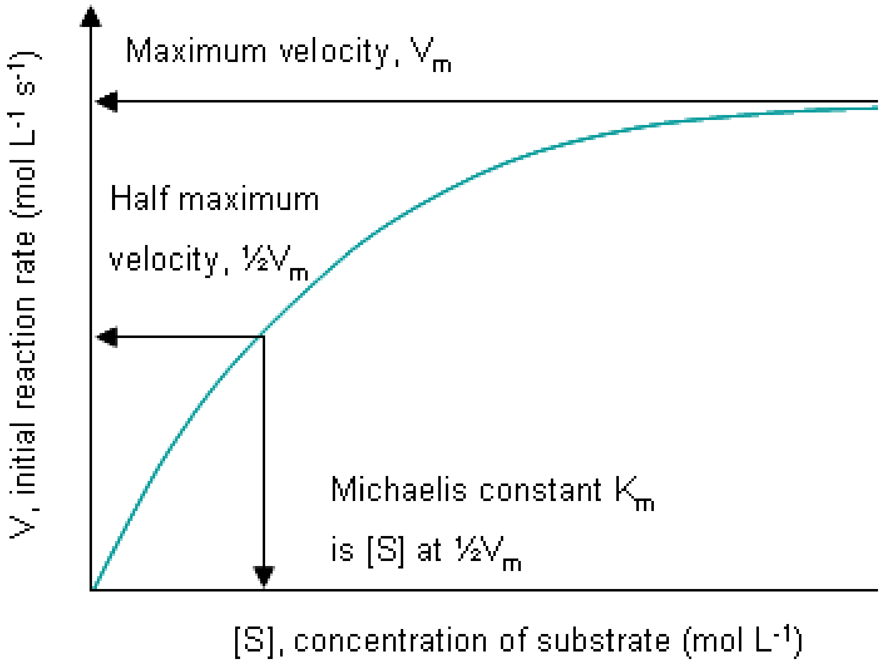
D-fructose – 1.5 mM

D-glucose – 0.15 mM

Juang RH (2004) BCbasics

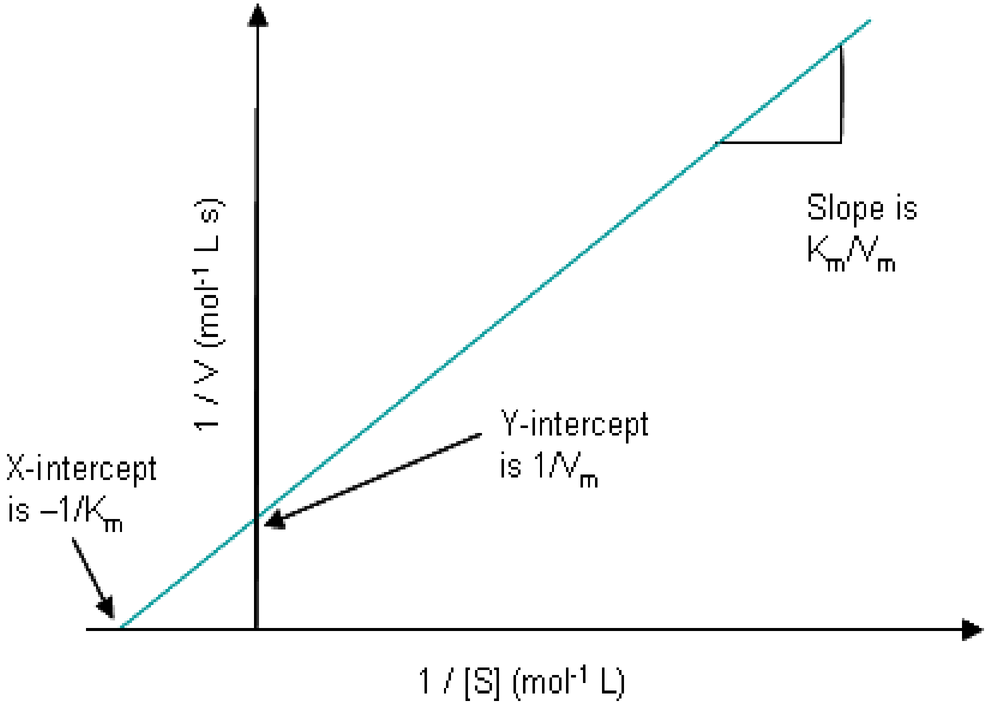
Direct plot & Lineweaver-Burk plot

Direct plot



www.steve.gb.com/science/enzymes.html

Lineweaver-Burk plot (Double reciprocal plot)



www.steve.gb.com/science/enzymes.html

Turn Over Numbers of Enzymes

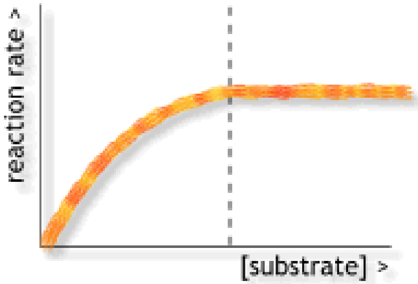
Enzymes	Substrate	k_{cat} (s^{-1})
Catalase	H_2O_2	40,000,000
Carbonic anhydrase	HCO_3^-	400,000
Acetylcholinesterase	Acetylcholine	140,000
β-Lactamase	Benzylpenicillin	2,000
Fumarase	Fumarate	800
RecA protein (ATPase)	ATP	0.4

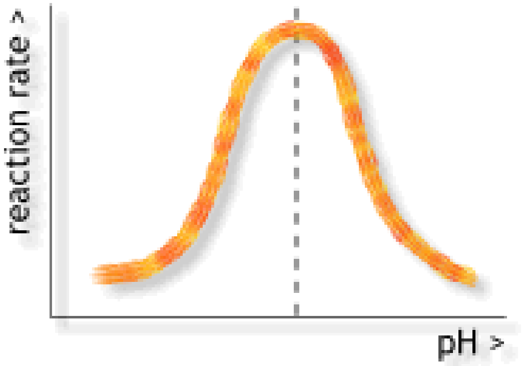
The number of product transformed from substrate by one enzyme molecule in one second

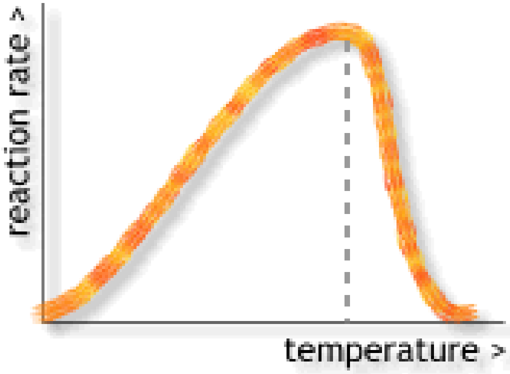
Adapted from Nelson & Cox (2000) Lehninger Principles of Biochemistry (3e) p.263

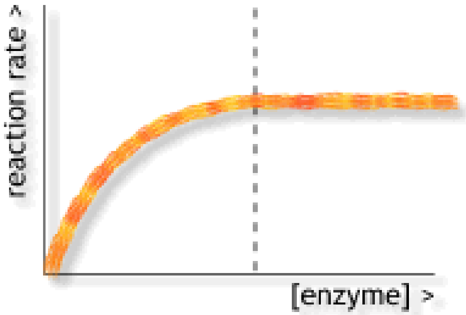
Factors affecting enzyme action

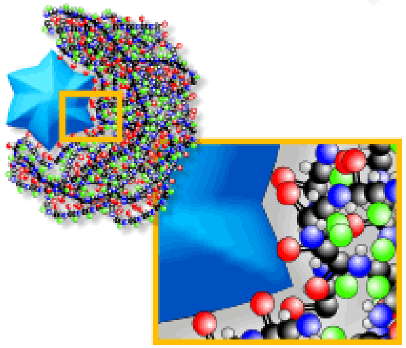
- pH
- Temperature
- Substrate concentration
- Enzyme concentration

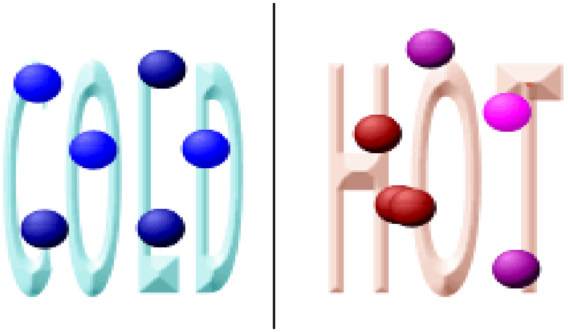












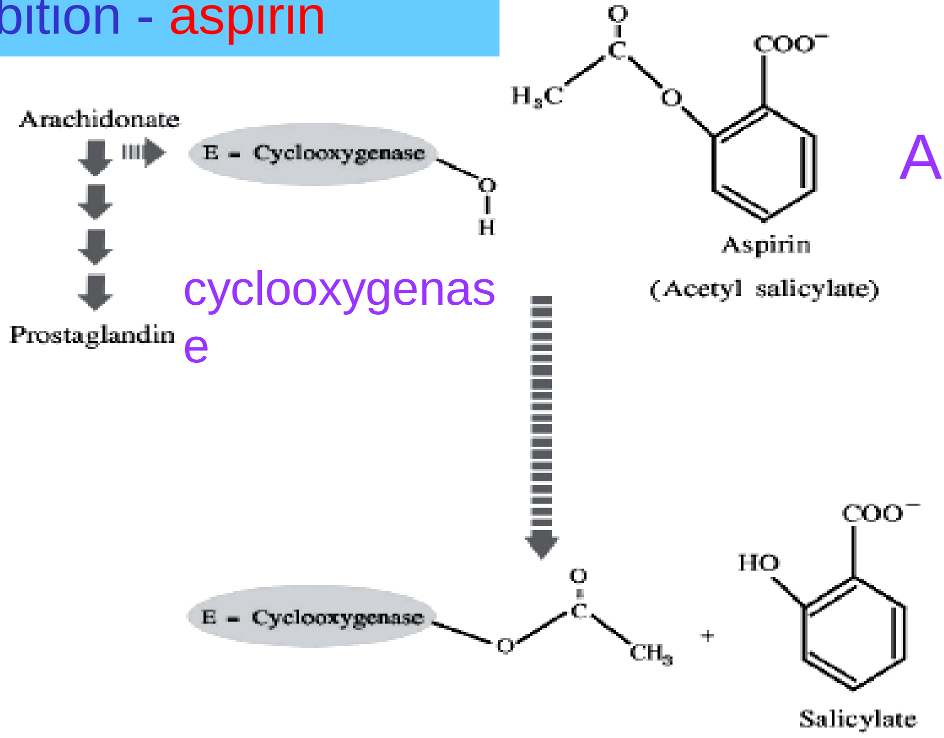
www.blobs.org/science/enzyme/index.shtml

Enzyme inhibition

Irreversible inhibition

Involve with formation of breaking covalent bond

Example of irreversible inhibition - aspirin



cyclooxygenase

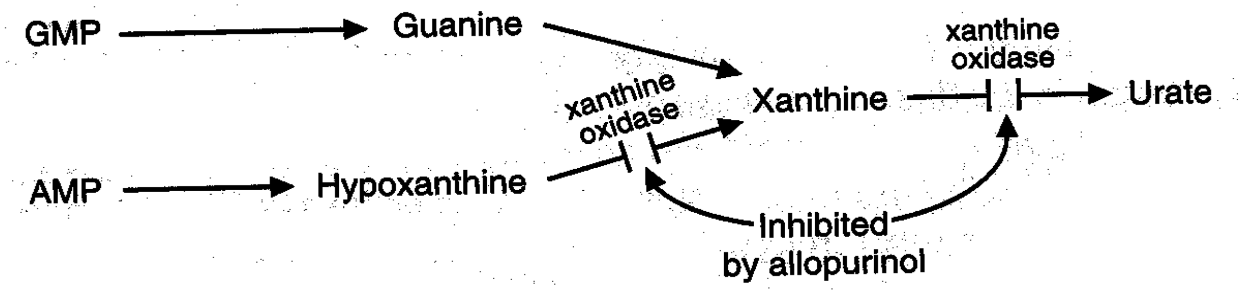
Reversible inhibition

1. Competitive
2. Noncompetitive
3. Uncompetitive

Involve with formation of non-covalent bond

Aspirin

Example of irreversible inhibition - allopurinol


GMP → Guanine → Xanthine

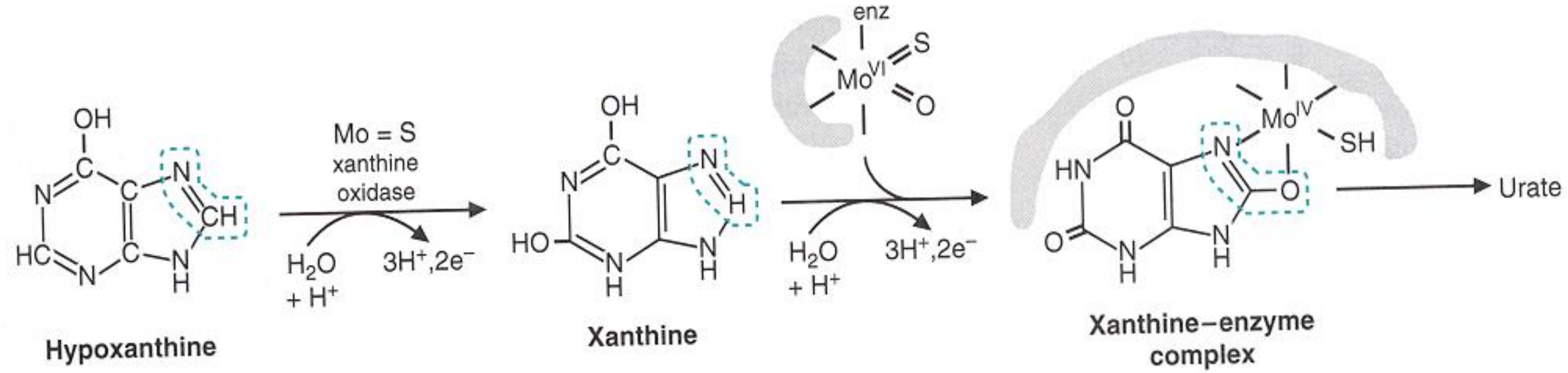
AMP → Hypoxanthine → Xanthine

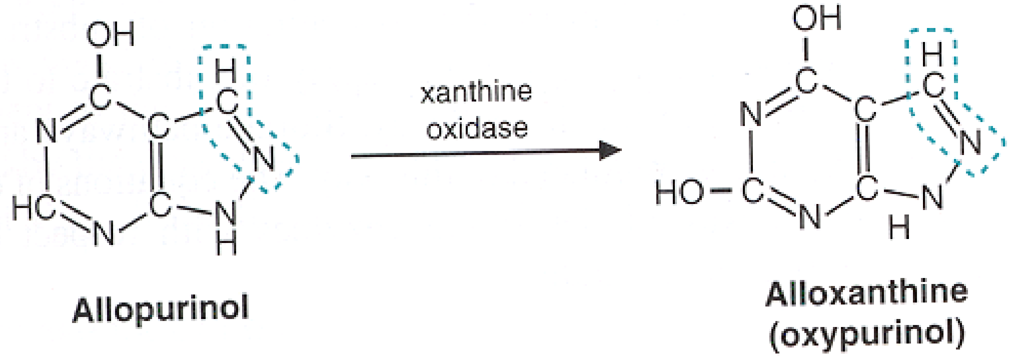
xanthine oxidase

Xanthine → Urate

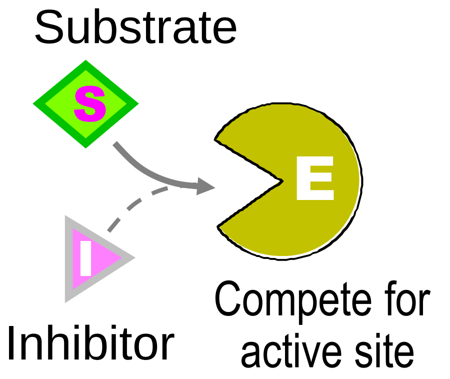
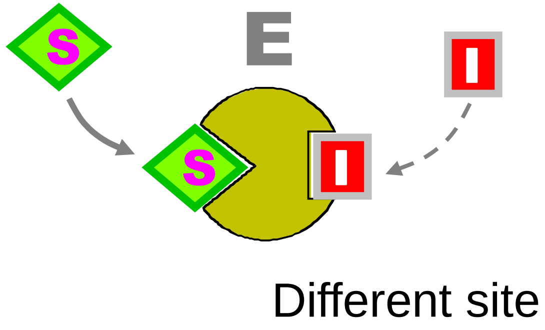
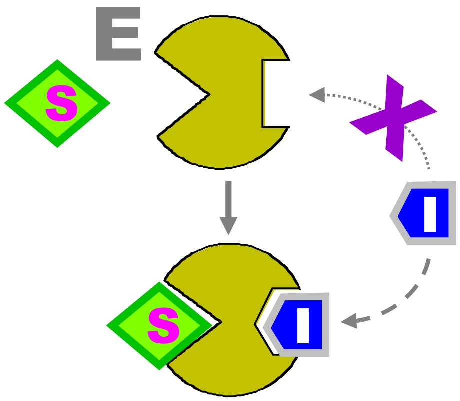
xanthine oxidase

Inhibited by allopurinol



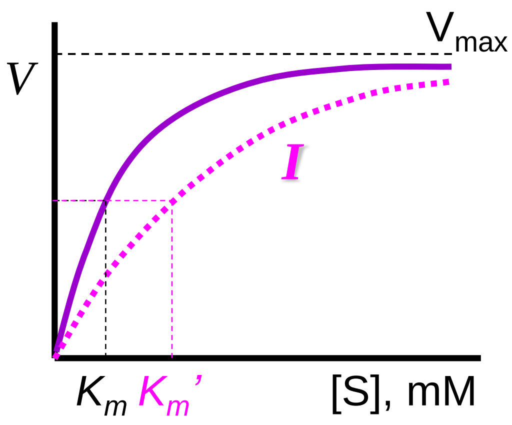
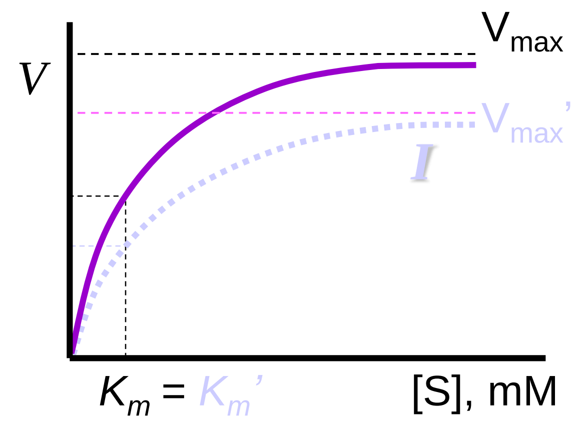
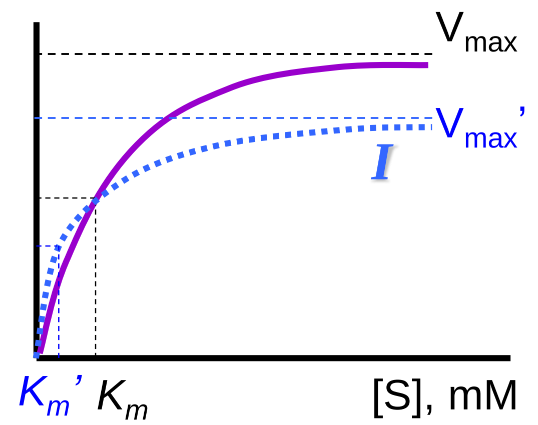
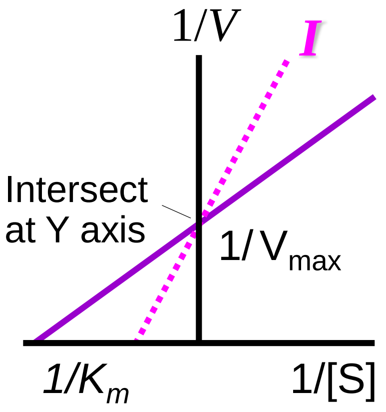
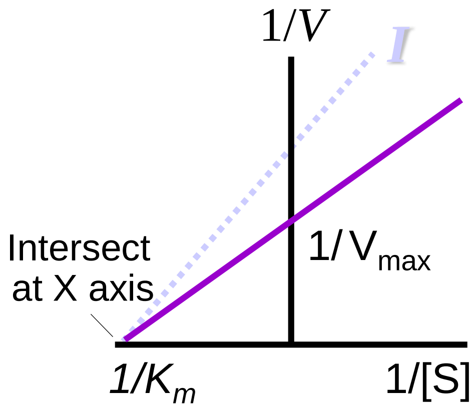
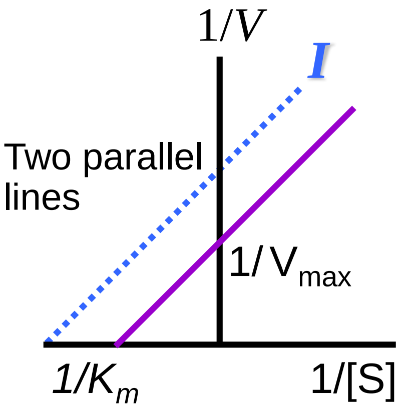


Reversible inhibition mechanism

	Competitive	Non-competitive	Uncompetitive
Cartoon Guide			
Equation and Description	$\begin{array}{l} E + S \rightleftarrows ES \rightarrow E + P \\ + \\ I \\ \downarrow\uparrow \\ EI \end{array}$	$\begin{array}{ccccc} E + S & \rightleftarrows & ES & \rightarrow & E + P \\ + & & + & & \\ I & & I & & \\ \downarrow\uparrow & & \downarrow\ \uparrow & & \\ EI + S & \rightarrow & EIS & & \end{array}$	$\begin{array}{ccccc} E + S & \rightleftarrows & ES & \rightarrow & E + P \\ & & + & & \\ & & I & & \\ & & \downarrow\uparrow & & \\ & & EIS & & \end{array}$
	[*I*] binds to free [E] only, and competes with [S]; increasing [S] overcomes Inhibition by [*I*].	[*I*] binds to free [E] or [ES] complex; Increasing [S] can not overcome [*I*] inhibition.	[*I*] binds to [ES] complex only, increasing [S] favors the inhibition by [*I*].

Juang RH (2004) BCbasics

Enzyme inhibition plots

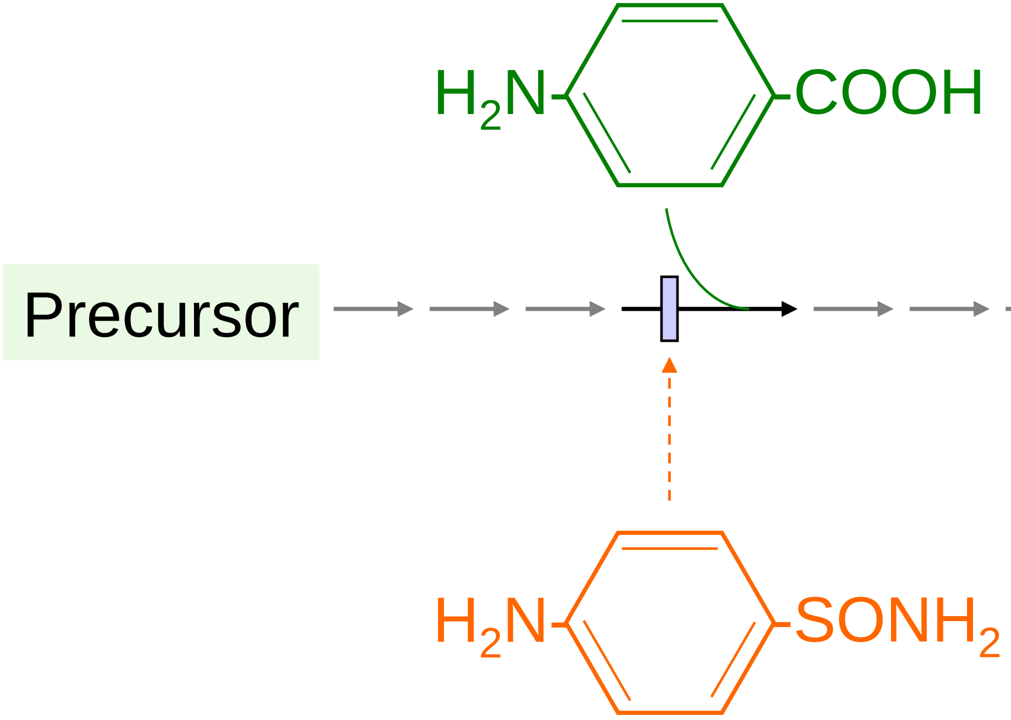
	Competitive	Non-competitive	Uncompetitive
Direct Plots			
	V_{max} unchanged K_m increased	V_{max} decreased K_m unchanged	Both V_{max} & K_m decreased
Double Reciprocal			

Juang RH (2004) BCbasics

Example of reversible inhibition – sulfa drug

Domagk (1939)

Para-aminobenzoic acid (PABA)



Precursor

Folic acid

Tetrahydro-folic acid

Bacteria needs PABA for the biosynthesis of folic acid

Sulfa drugs has similar structure with PABA, and inhibit bacteria growth.

Sulfanilamide

Sulfa drug (anti-inflammation)

Adapted from Bohinski (1987) Modern Concepts in Biochemistry (5e) p.197

Example of reversible inhibition

Enz = ACE (angiotensin converting enzyme)

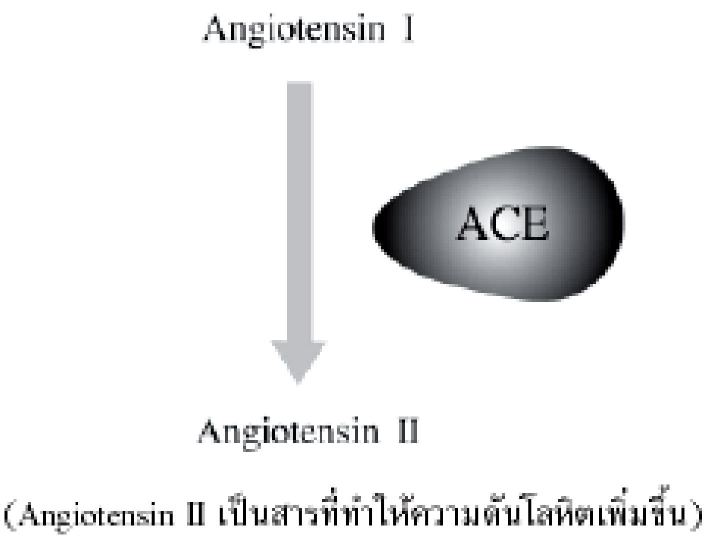
Substrate = angiotensin I

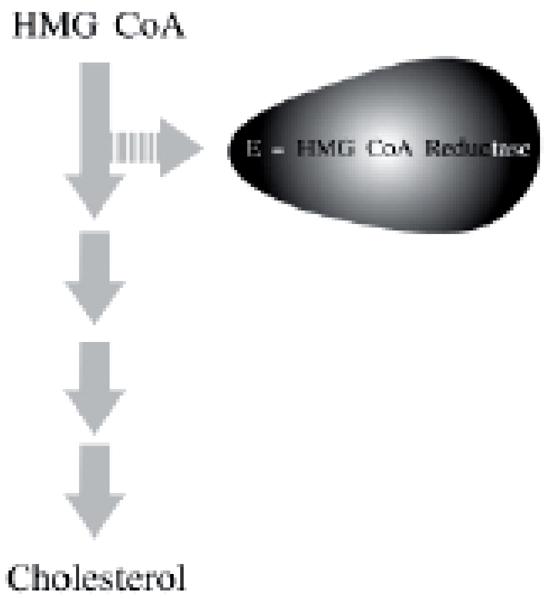
Competitive inhibitor = Captopril and enalapril (blood pressure ↓)

Enz = HMG CoA reductase

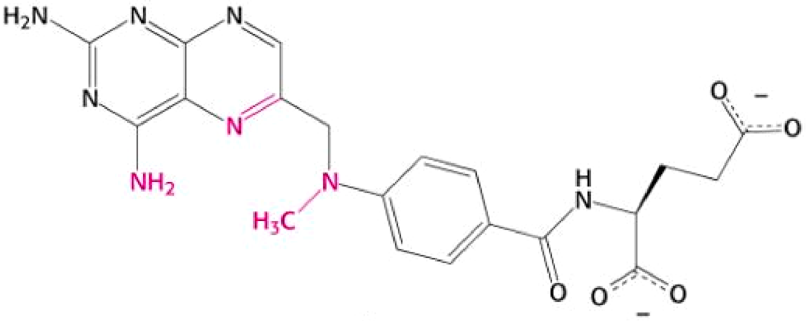
Substrate = HMG CoA

Competitive inhibitor = lavastatin and mevilonin

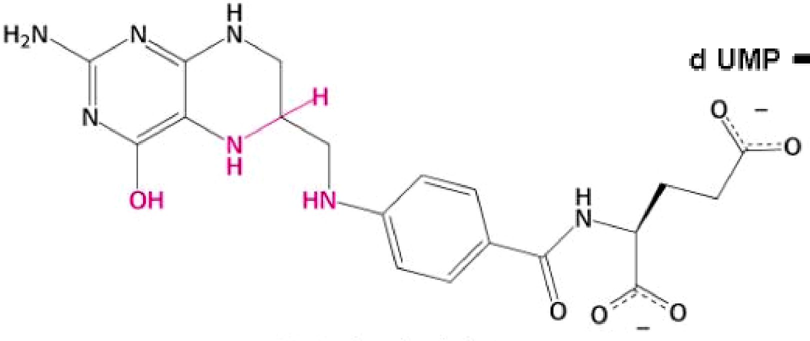




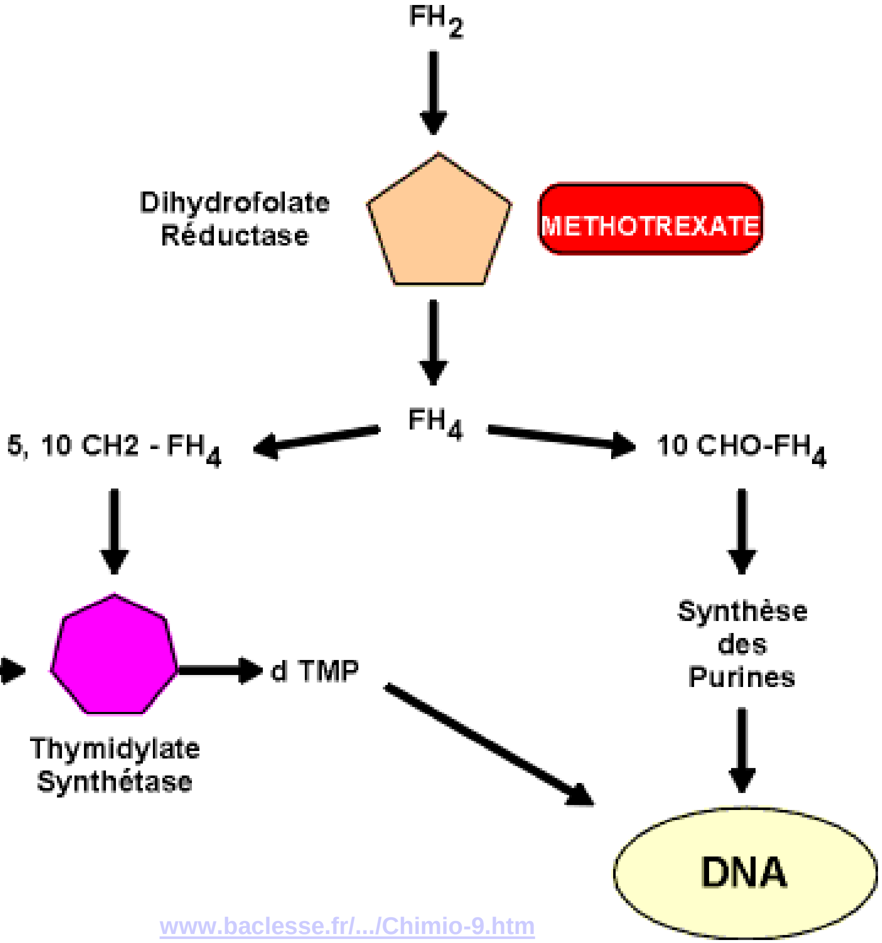
Example of reversible inhibition – cancer treatment



Methotrexate



Tetrahydrofolate



FH_2

Dihydrofolate Réductase

METHOTREXATE

FH_4

5, 10 CH2 - FH_4

10 CHO-FH_4

d UMP

d TMP

Thymidylate Synthétase

Synthèse des Purines

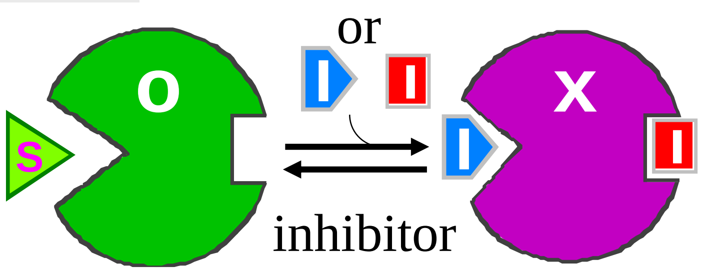
DNA

www.baclesse.fr/.../Chimio-9.htm

oregonstate.edu/.../enzymesoutline.html

Enzyme Regulation

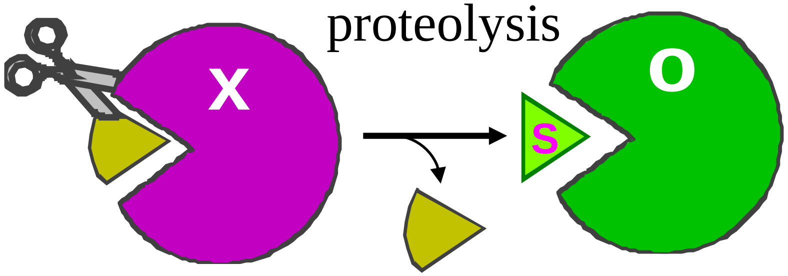
Inhibitor



or

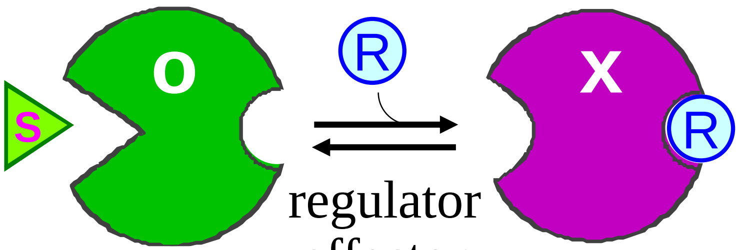
inhibitor

Proteolysis



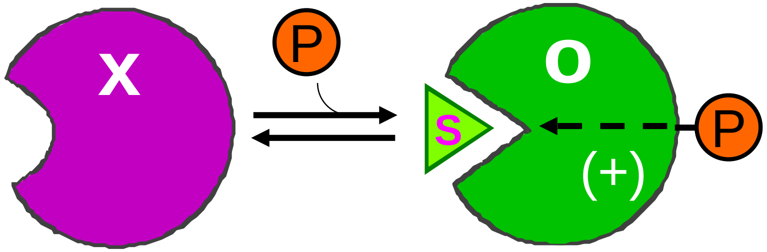
proteolysis

Feedback regulation



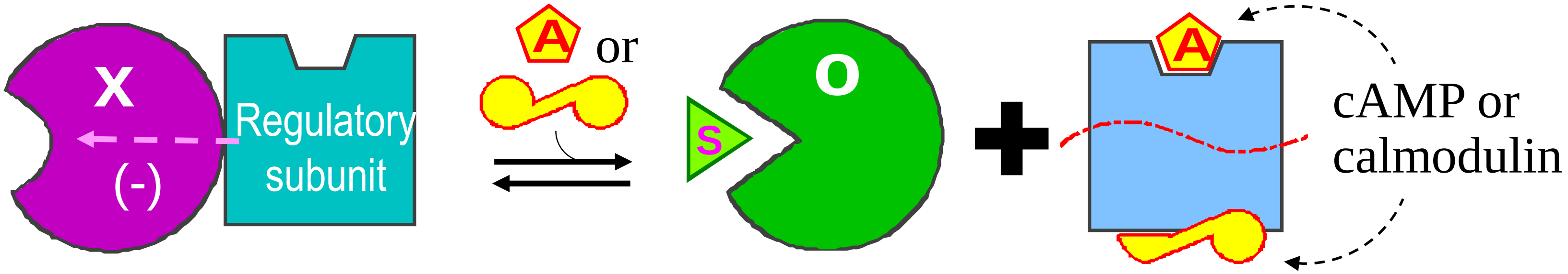
regulator
effector

Covalent modification(Phosophorylation)



phosphorylation

Signal transduction



Regulatory
subunit

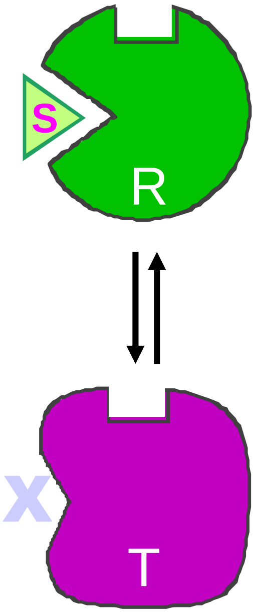
or

cAMP or
calmodulin

Juang RH (2004) BCbasics

Allosteric enzyme

R = Relax
(active)

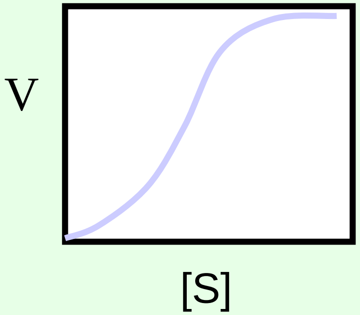


T = Tense
(inactive)

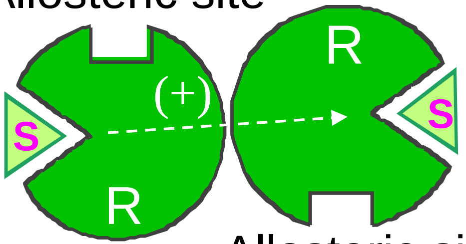
Kinetics

Models

Cooperation

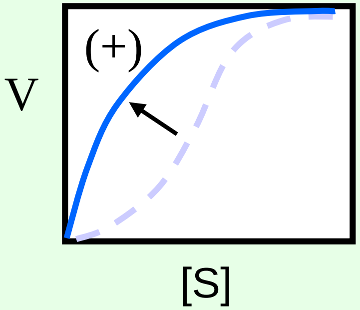


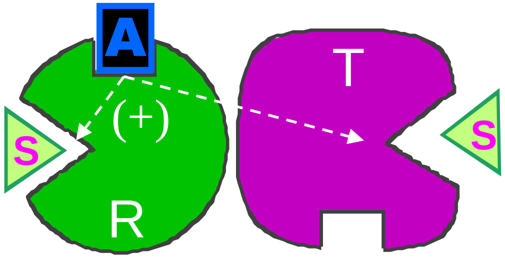
Allosteric site



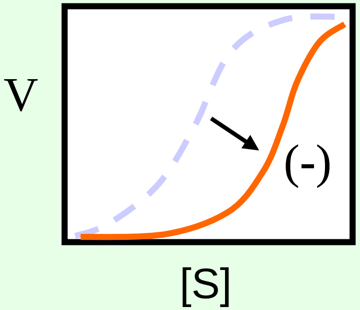
Allosteric site

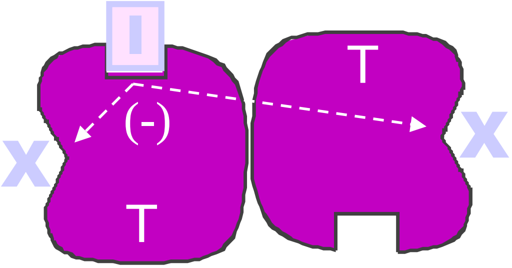
Homotropic
(+)
Concerted





Heterotropic
(+)
Sequential





Heterotropic
(-)
Concerted

Juang RH (2004) BCbasics

Summary

Enzyme is a biological catalyst. It decreases Ea but not ΔG.

Enzyme can be classified into 6 classes. Isoenzymes are different but catalyze the same rx.

Km → affinity for substrate, Vmax→ enzyme activity

Enzyme inhibition consists of irreversible and reversible inhibition. Competitive inhibition is advantage to drug design.

There are many ways to regulate enzymes. Allosteric enzyme is one type of enzyme regulation.