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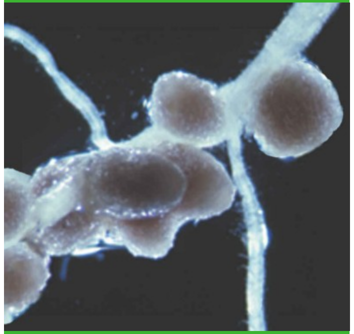
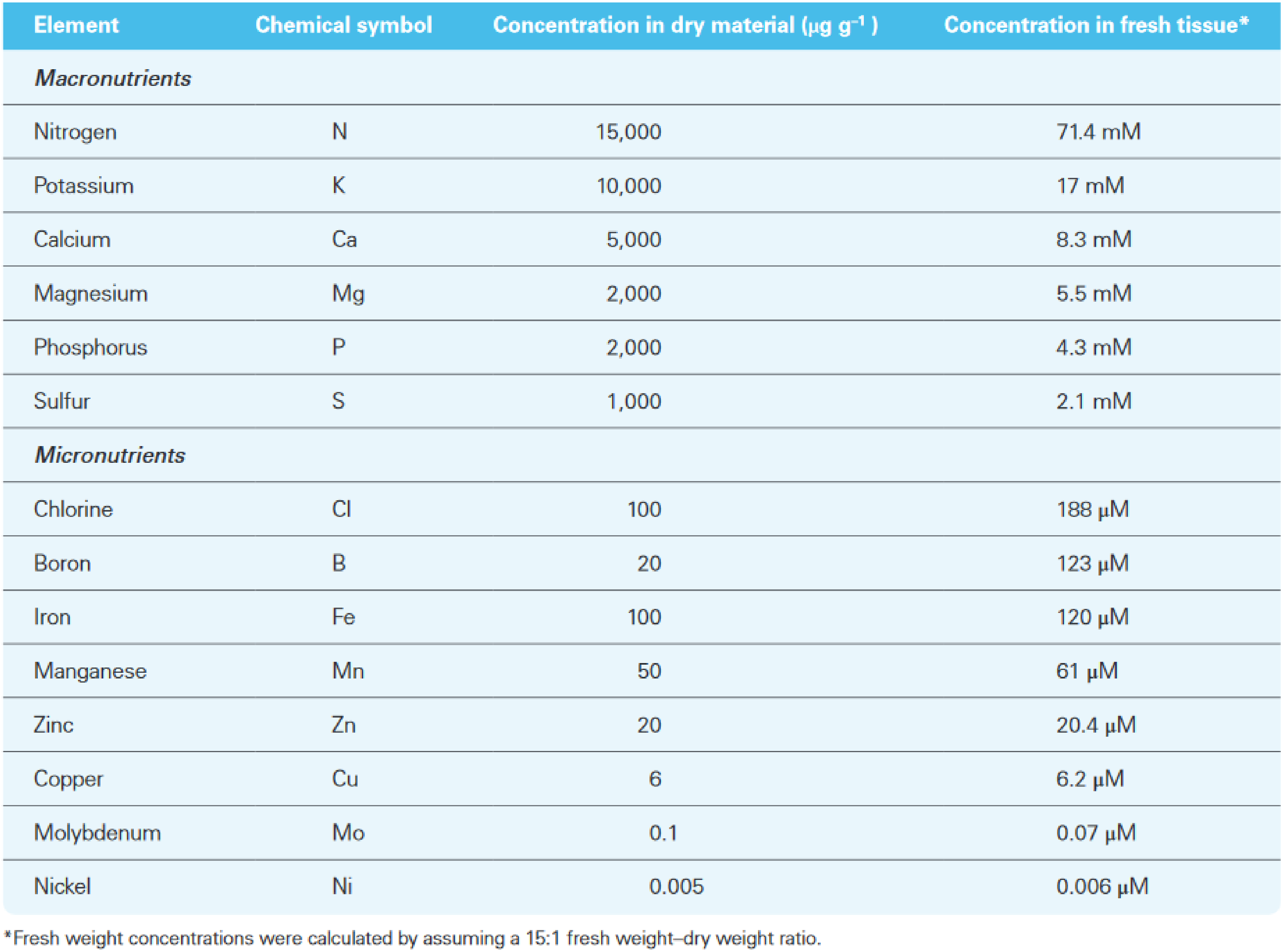


Nutrients

Katerina Dadakova, Department of Biochemistry

Figures adapted from Buchanan et al., Biochemistry & molecular biology of plants

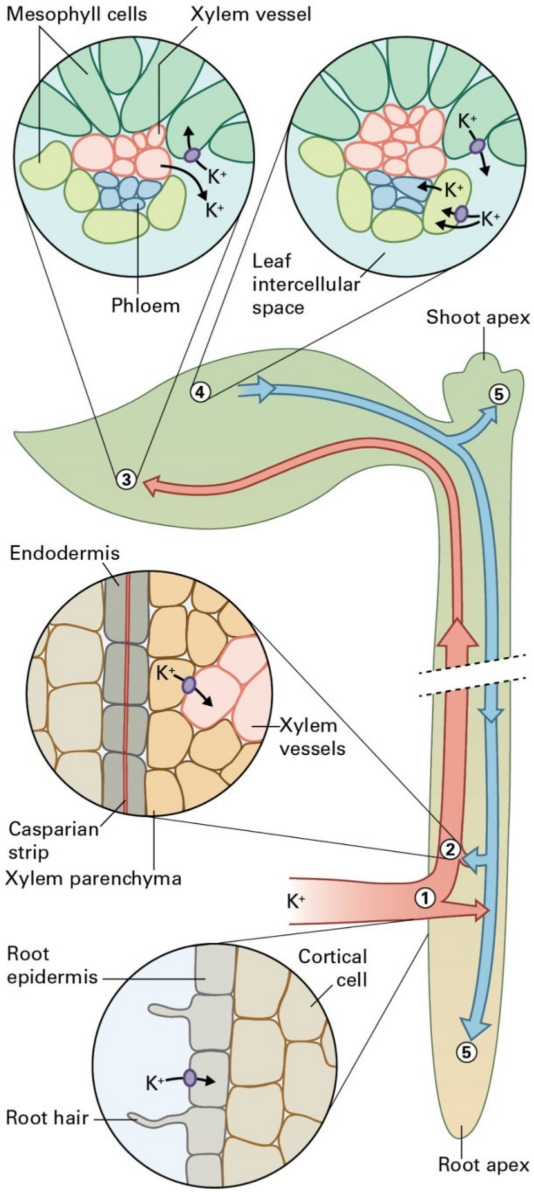
Essential mineral nutrients



Element	Chemical symbol	Concentration in dry material (μg g^{-1})	Concentration in fresh tissue*
Macronutrients			
Nitrogen	N	15,000	71.4 mM
Potassium	K	10,000	17 mM
Calcium	Ca	5,000	8.3 mM
Magnesium	Mg	2,000	5.5 mM
Phosphorus	P	2,000	4.3 mM
Sulfur	S	1,000	2.1 mM
Micronutrients			
Chlorine	Cl	100	188 μM
Boron	B	20	123 μM
Iron	Fe	100	120 μM
Manganese	Mn	50	61 μM
Zinc	Zn	20	20.4 μM
Copper	Cu	6	6.2 μM
Molybdenum	Mo	0.1	0.07 μM
Nickel	Ni	0.005	0.006 μM

*Fresh weight concentrations were calculated by assuming a 15:1 fresh weight–dry weight ratio.

Potassium



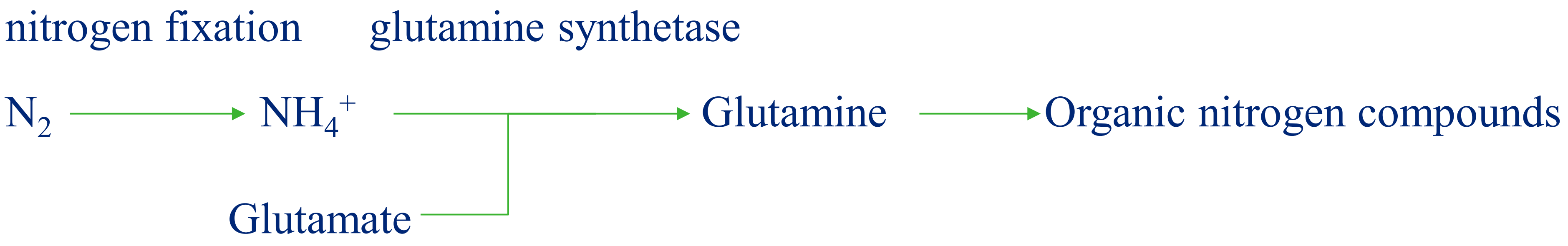
K^+ is the most abundant cellular cation

K^+ functions:

- osmoticum
- charge balance
- enzyme activation

Nitrogen

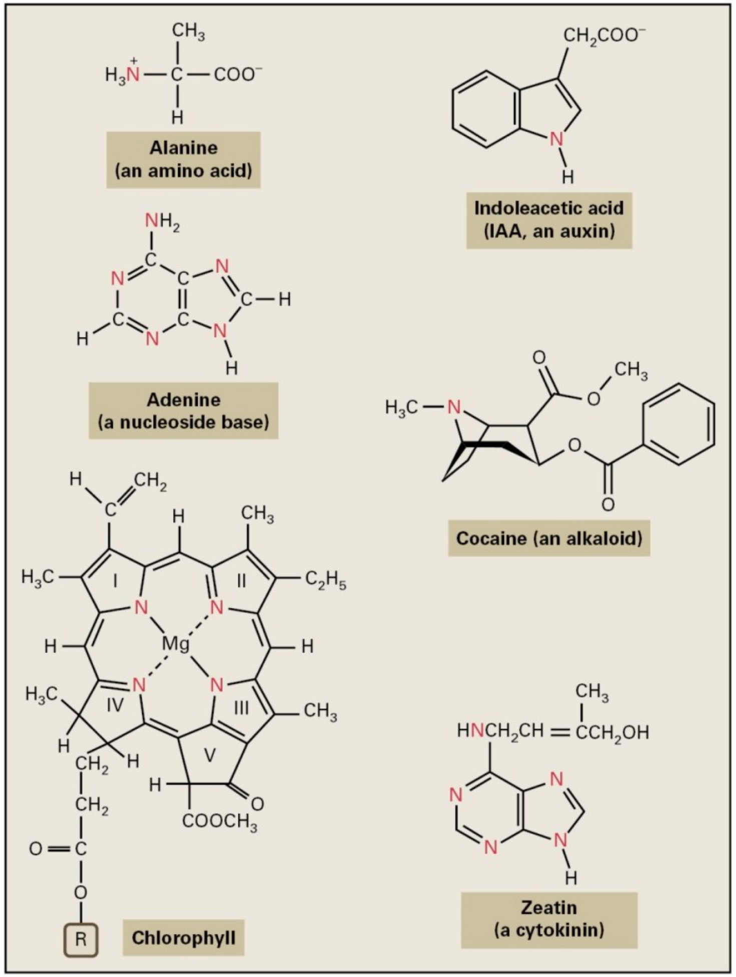
Compound	Oxidation state of N	Name
N_2	0	Dinitrogen (nitrogen gas)
HN_3	-3	Ammonia
NH_4^+	-3	Ammonium ion
N_2O	+1	Nitrous oxide
NO	+2	Nitric oxide
NO_2^-	+3	Nitrite
NO_2	+4	Nitrogen dioxide
NO_3^-	+5	Nitrate



nitrogen fixation glutamine synthetase

$N_2 \rightarrow NH_4^+ \rightarrow$ Glutamine $\rightarrow$ Organic nitrogen compounds

Glutamate



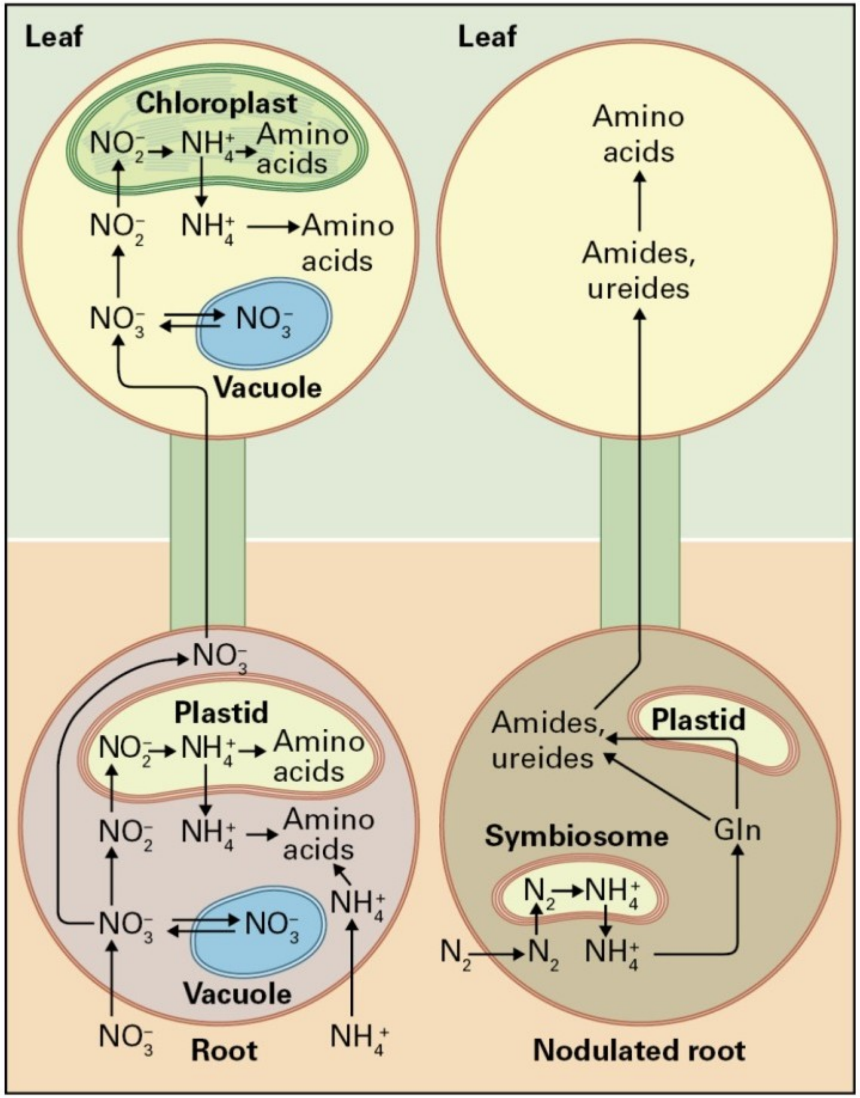
Nitrogen deficiency phenotype

Selected organic nitrogen compounds

Plants may acquire N as:

- ammonium ion
- nitrate
- dinitrogen, only in the case of plant species capable of endosymbiosis with nitrogen-fixing bacteria

Obtaining nitrogen through symbiosis consumes 12 to 17 g of carbohydrate per gram of N fixed

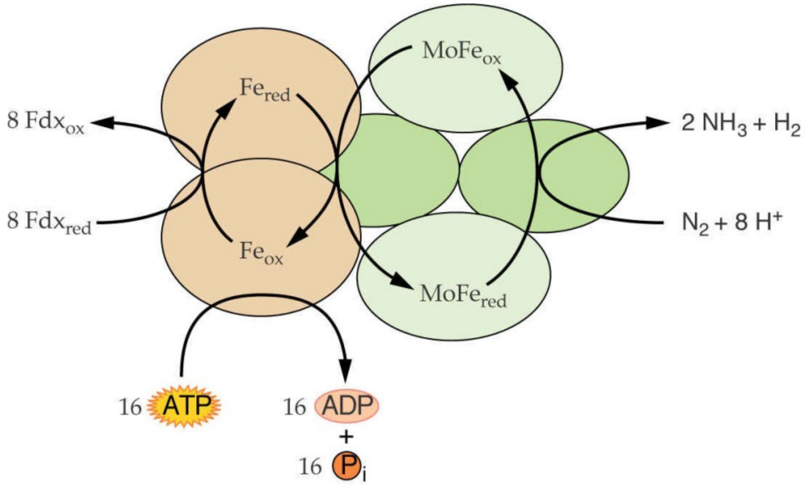


Nitrogen fixation

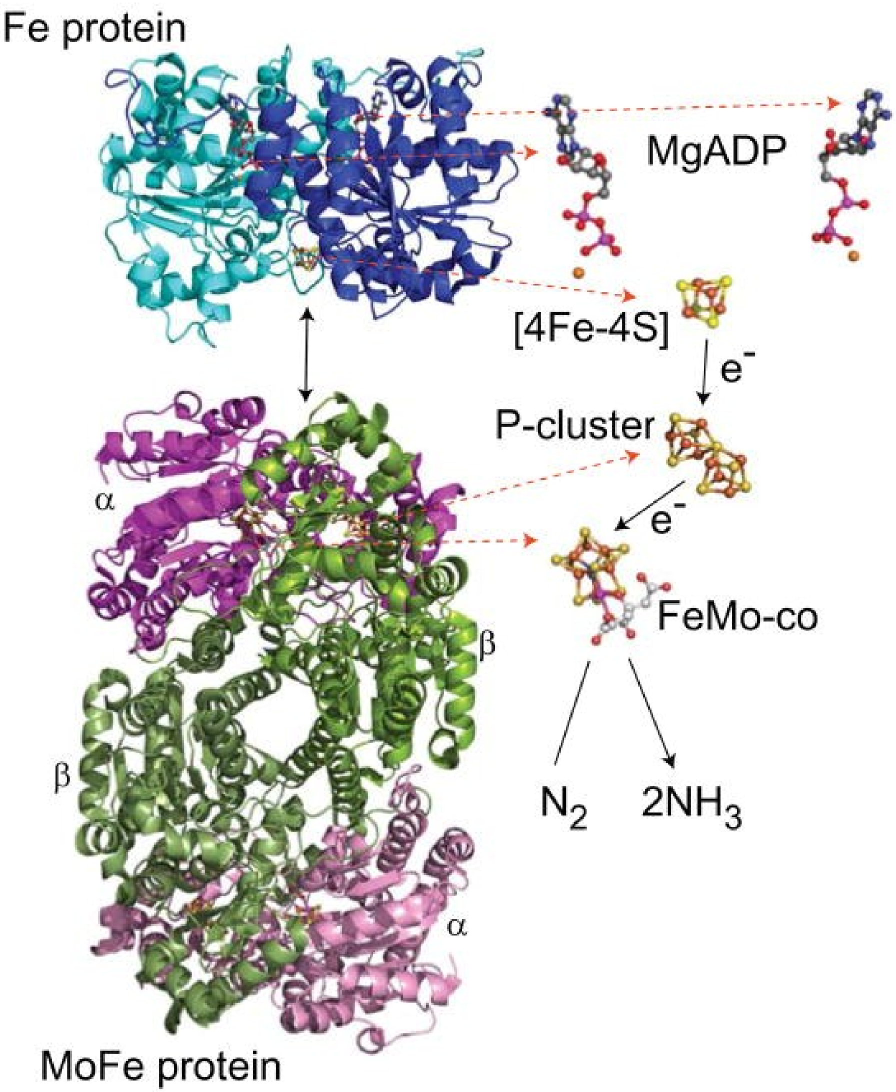
Nitrogenase complex

Dinitrogenase reductase
Fe protein

Dinitrogenase
MoFe protein



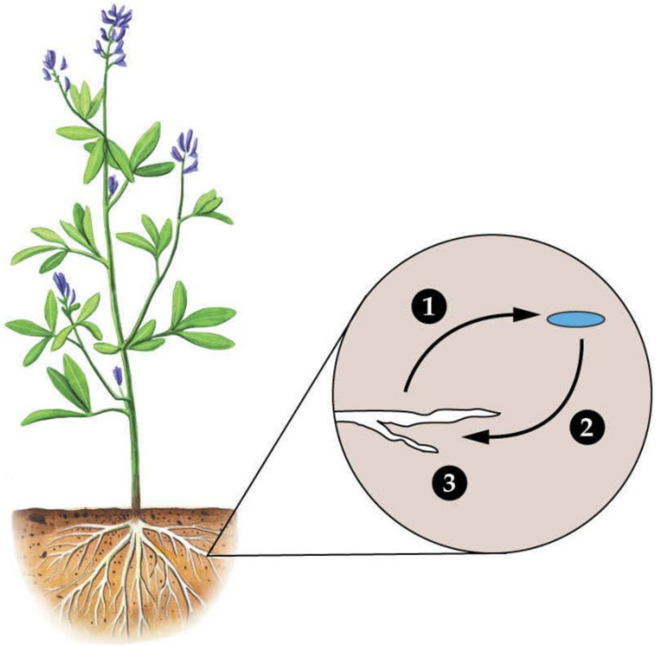
$$N_2 + 16ATP + 8e^- + 8H^+ \longrightarrow$$
$$2NH_3 + H_2 + 16ADP + 16P_i$$



Legume-rhizobial symbiosis

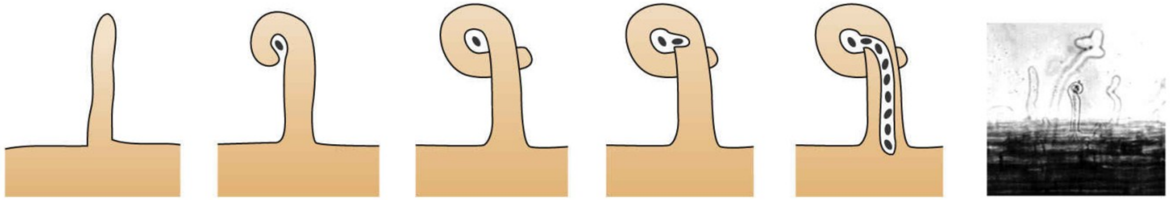
The plant creates root nodules to ensure:
- microaerobic environment
- organic acids to feed the bacteria
- carbon skeletons to transport fixed nitrogen

Bacterial symbionts fix nitrogen and release the resulting ammonia

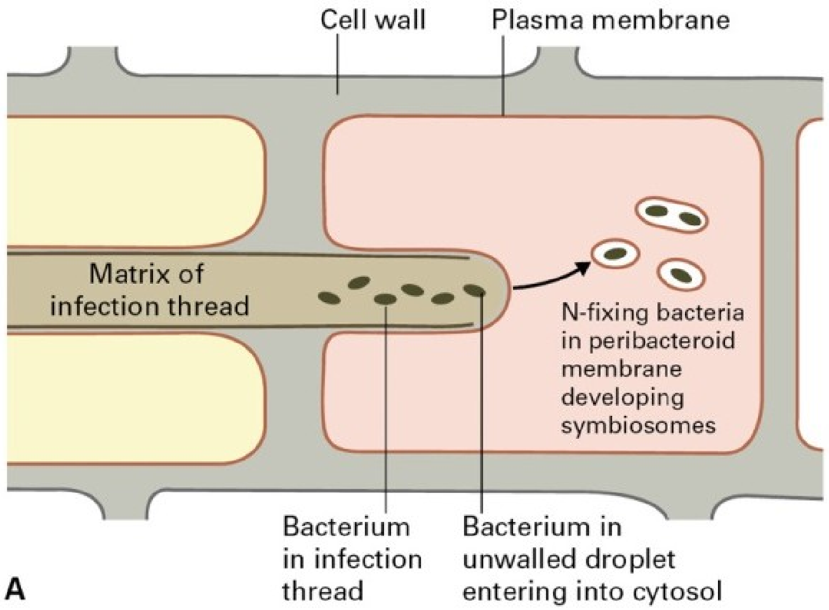


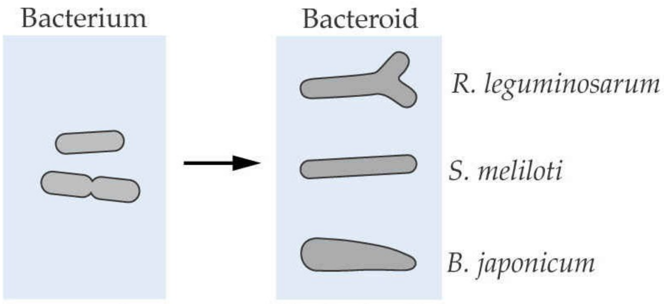
1. Plant signals
2. Nod factors
3. Nodulin proteins

Nodule morphogenensis

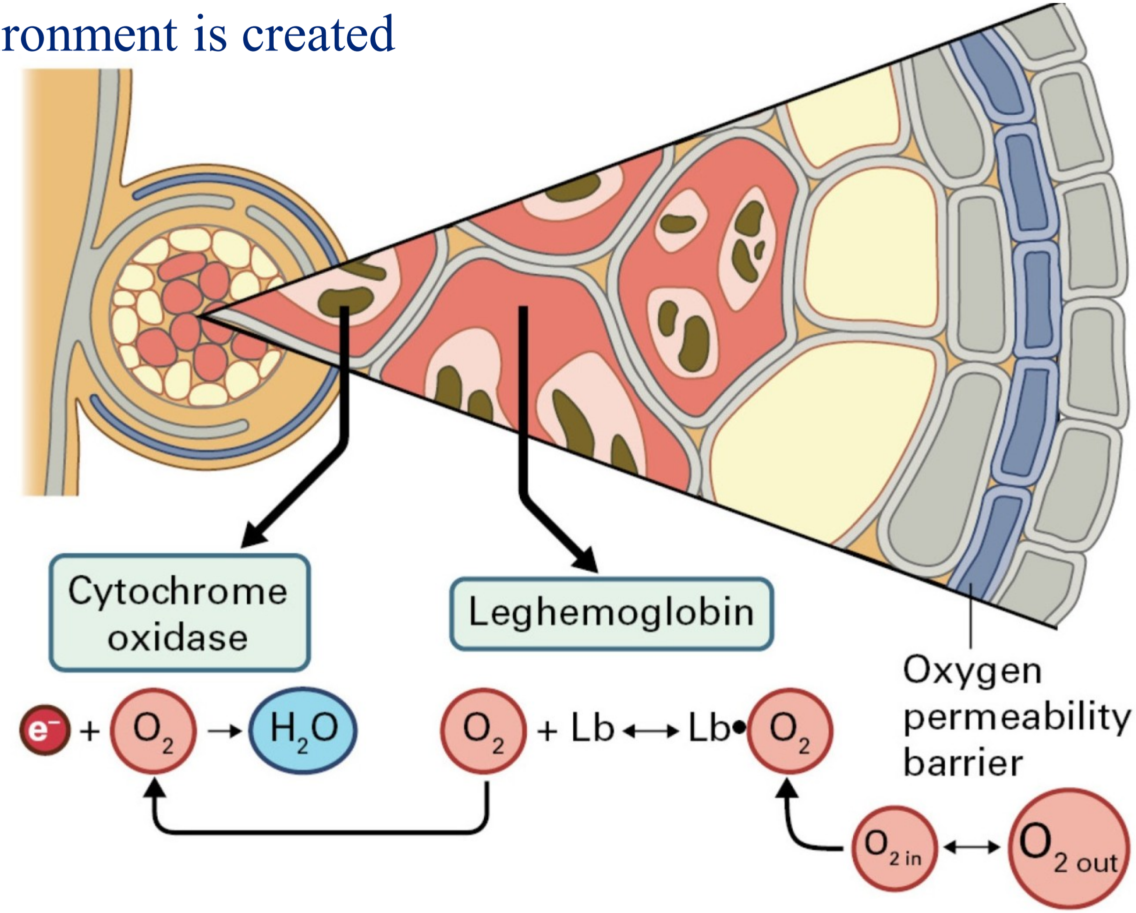


In symbiosomes, bacteria differentiate into bacteroids





Microaerobic nodule environment is created

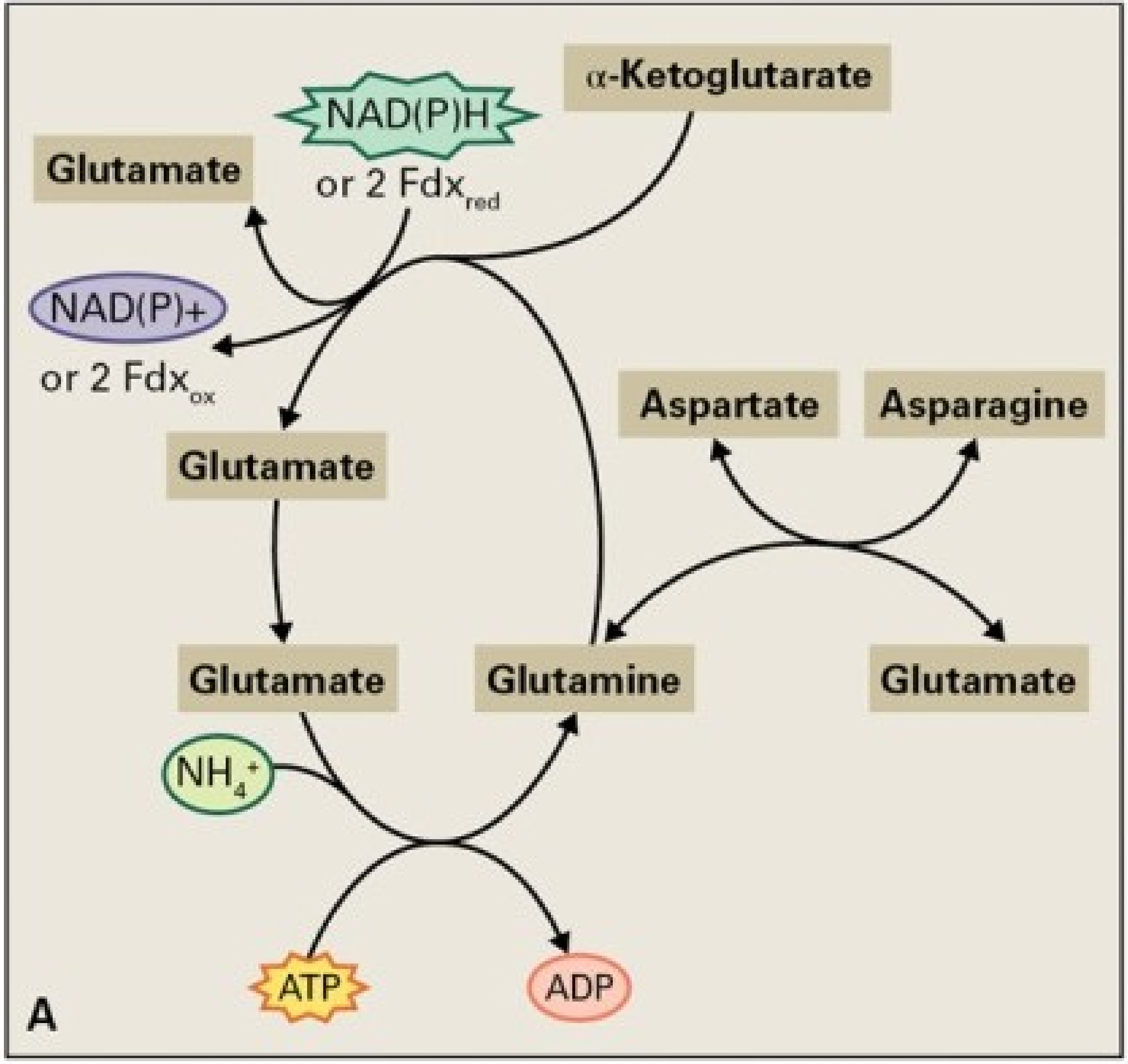


Carbon is provided to the bacteroids as dicarboxylic acids

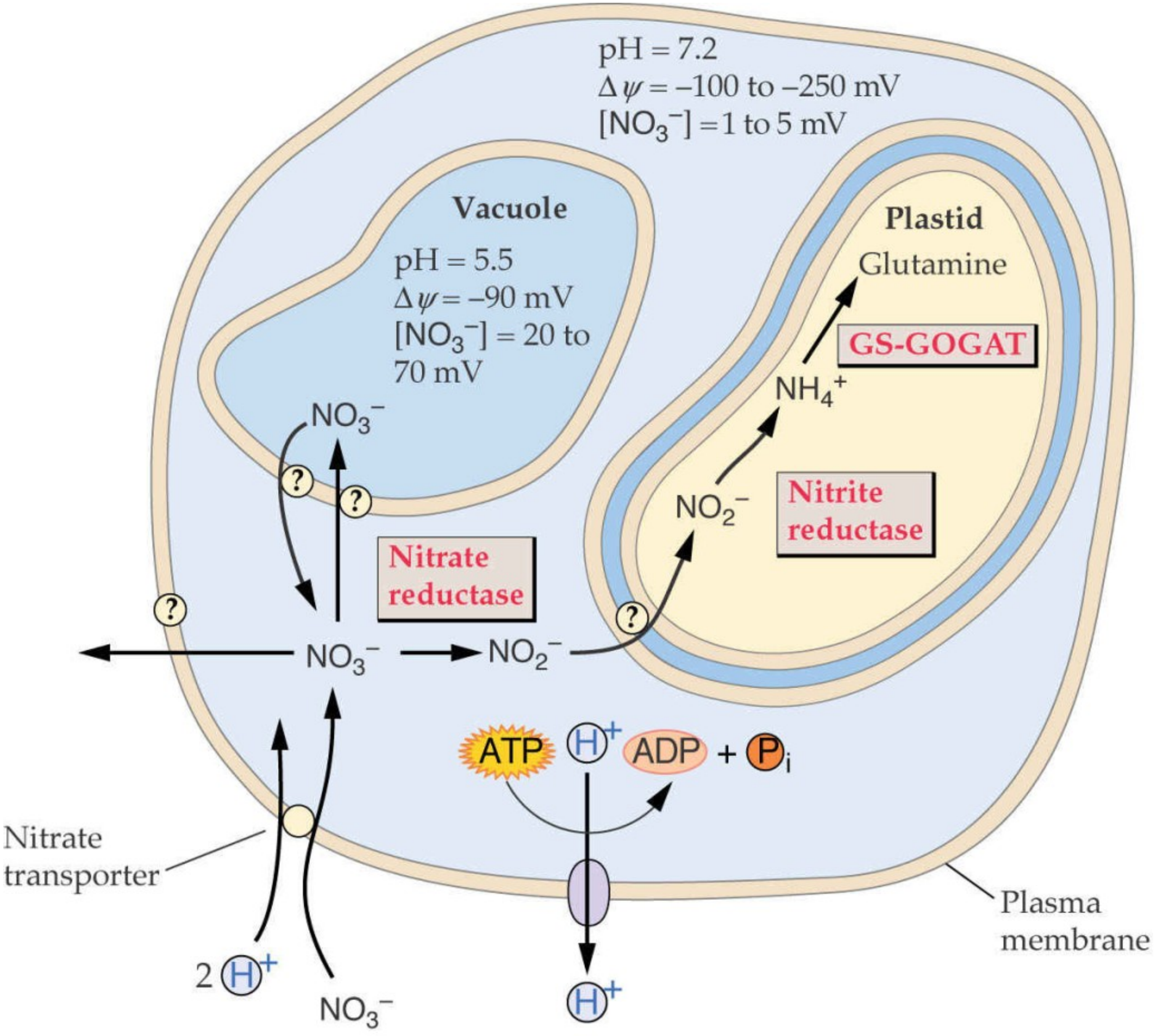
- oxidation of DCA provides ATP
- DCA carbon backbones are used for nitrogen transport

Ammonia assimilation

GS-GOGAT cycle



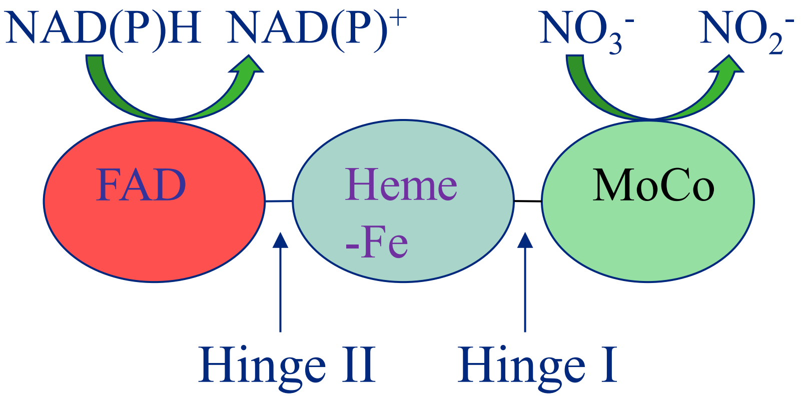
Nitrate assimilation



Nitrate reductase

NR reaction

$$NO_3^- + NAD(P)H + H^+ \longrightarrow NO_2^- + NAD(P)^+ + H_2O$$



$NAD(P)H$ $NAD(P)^+$

NO_3^- NO_2^-

FAD

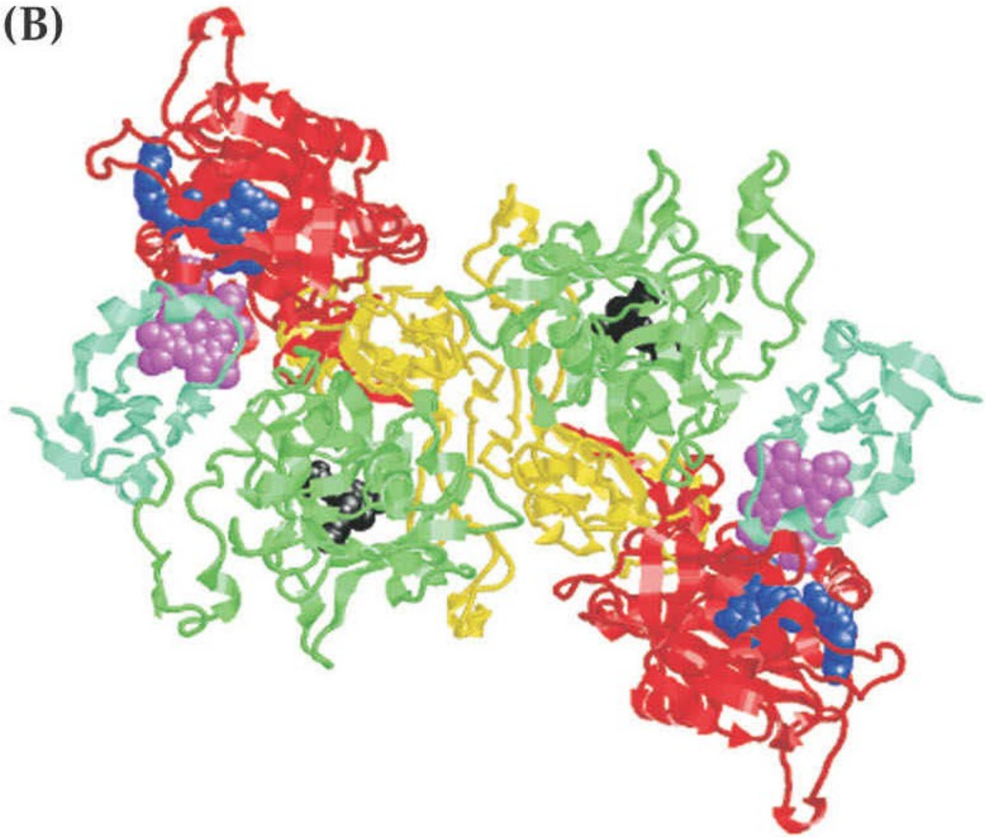
Heme
-Fe

MoCo

Hinge II

Hinge I

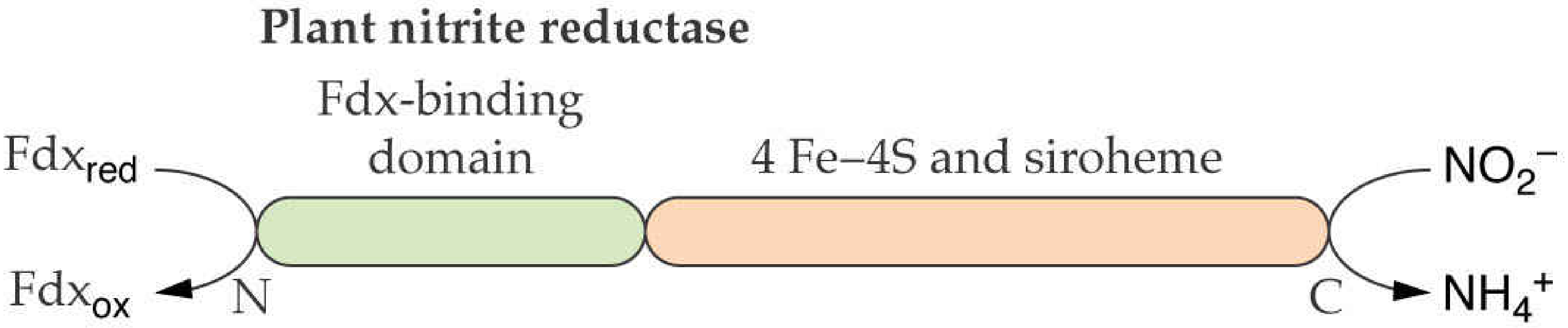
NR homodimer



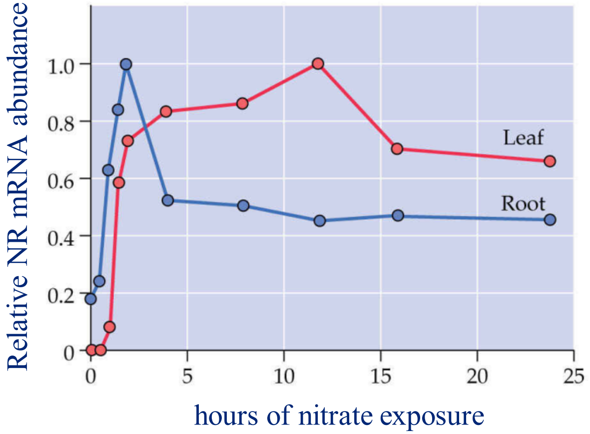
Nitrite reductase

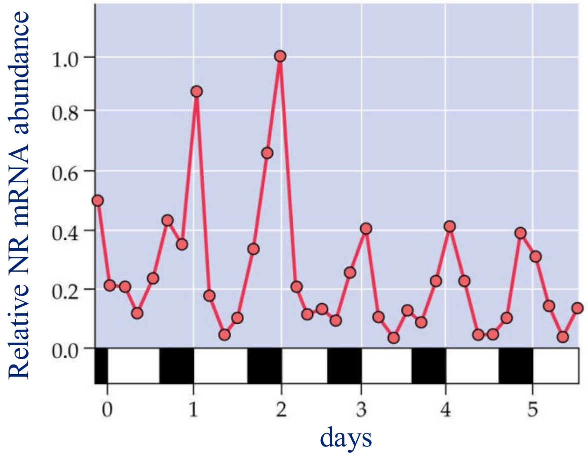
NiR reaction

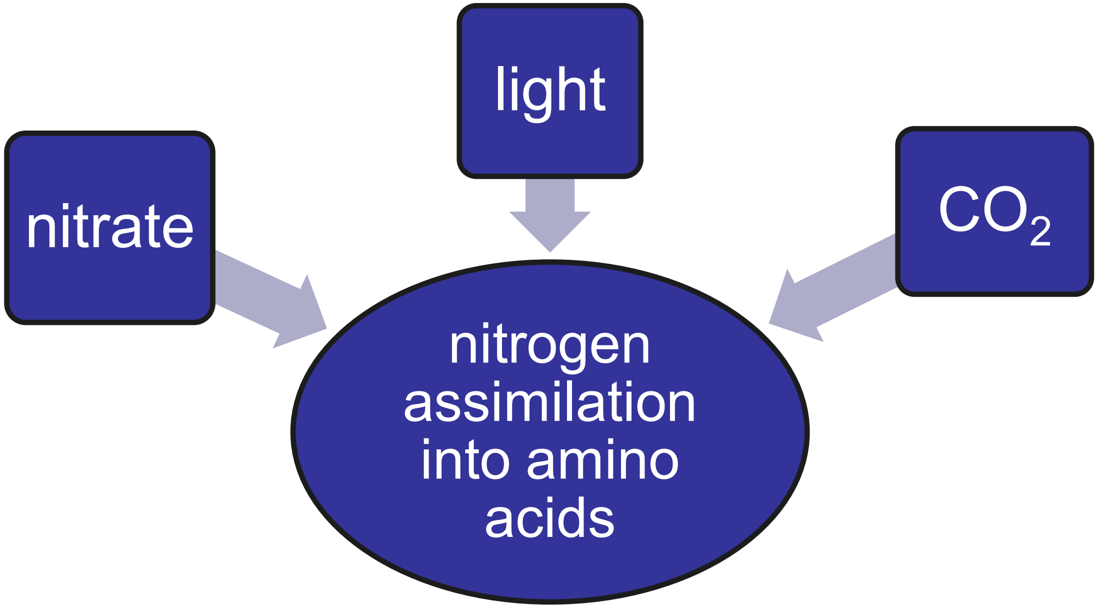
$$NO_2^- + 6\ Fdx_{red} + 8\ H^+ \longrightarrow NH_4^+ + 6\ Fdx_{ox} + 2\ H_2O$$



Regulation of nitrate assimilation







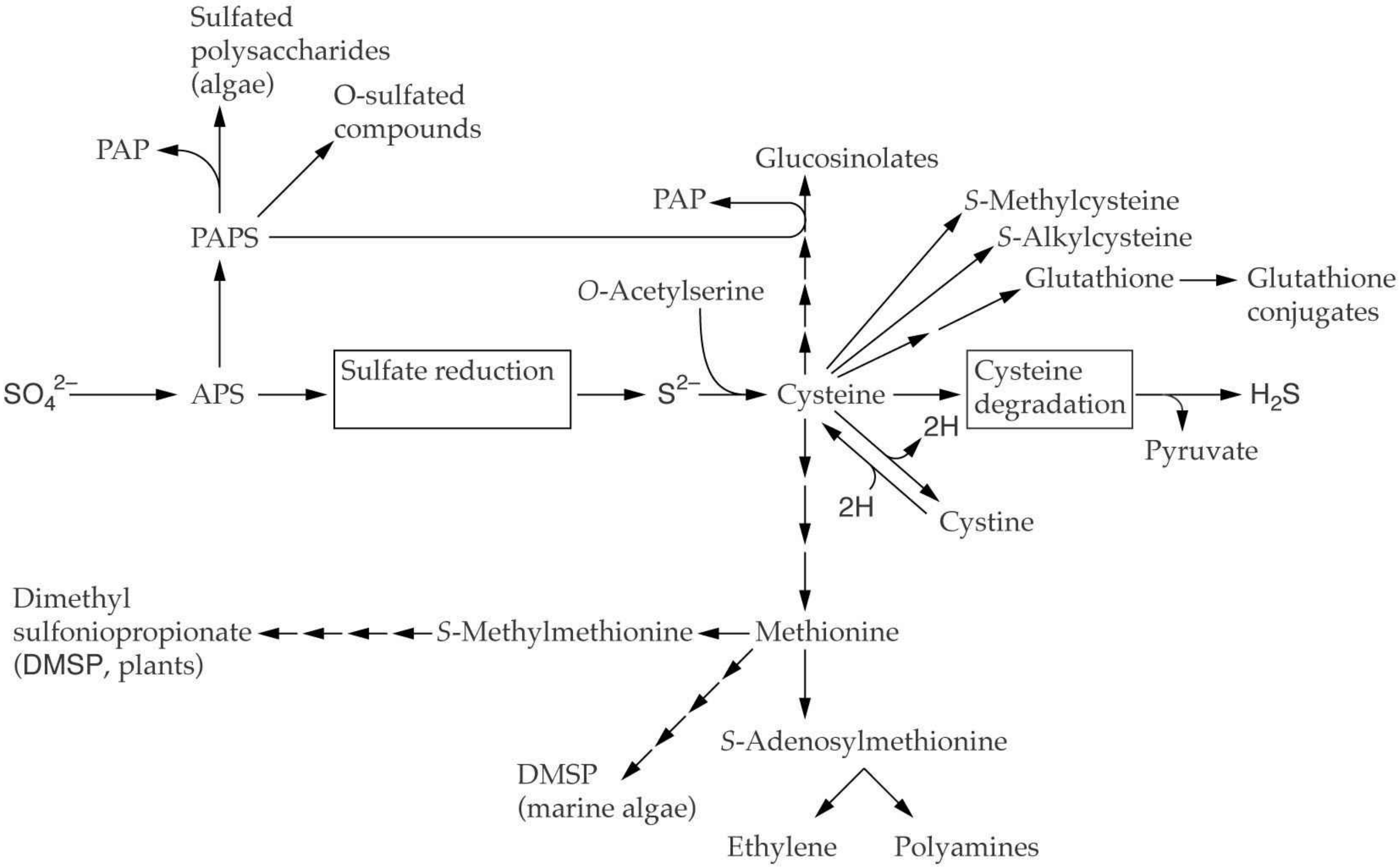
light

nitrate

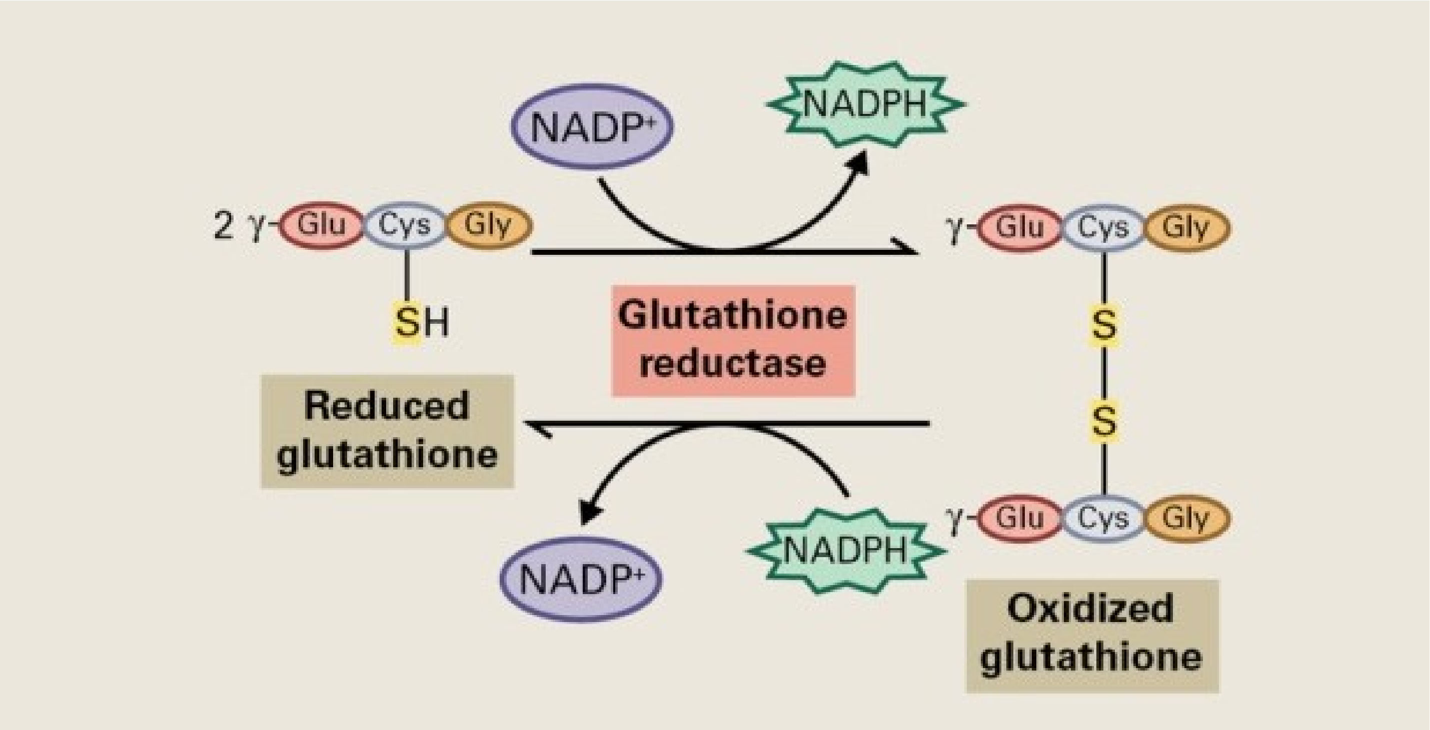
CO_2

nitrogen assimilation into amino acids

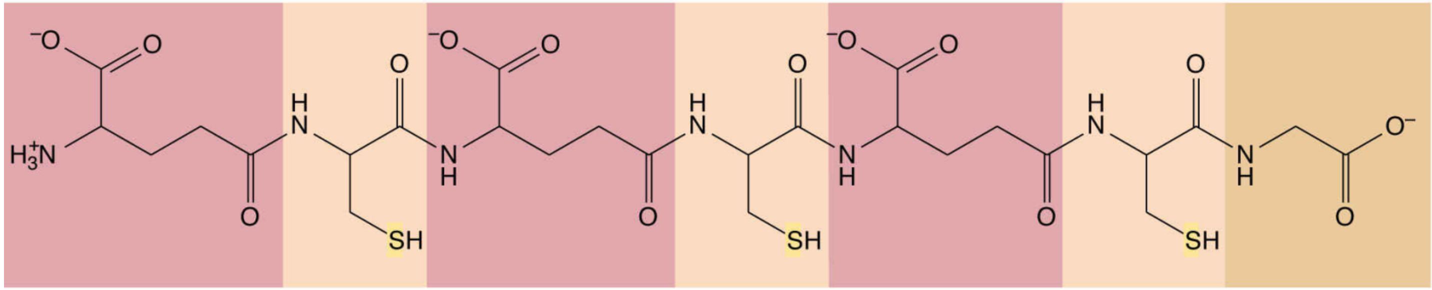
Sulfur



APS – 5-adenylylsulfate
PAPS – 3 phosphoadenosine-5 -phosphosulfate,

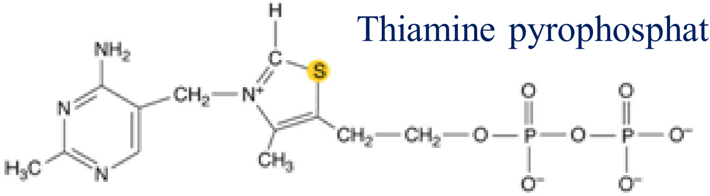


Phytochelatin molecule

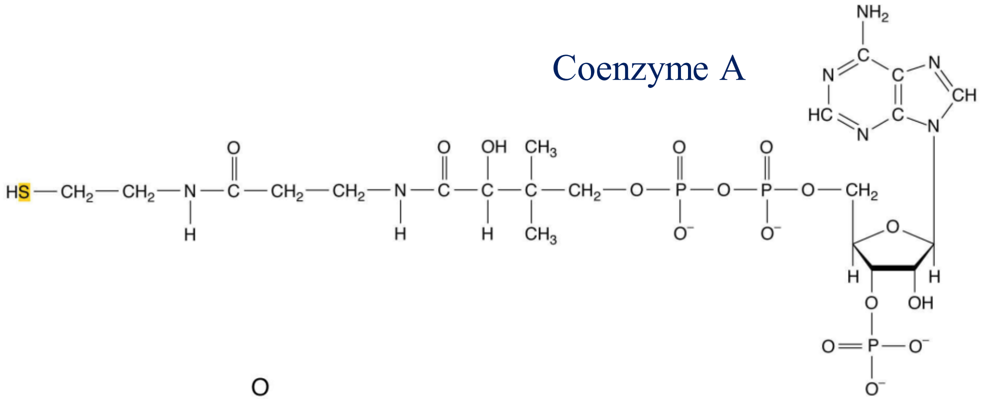


(γ-Glu-Cys)$_3$-Gly

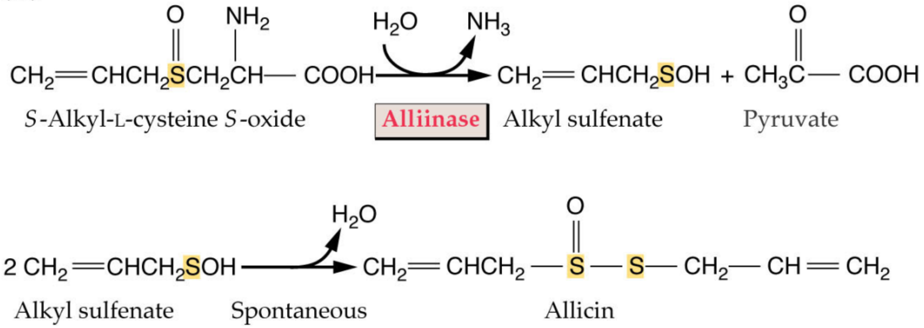
Thiamine pyrophosphate



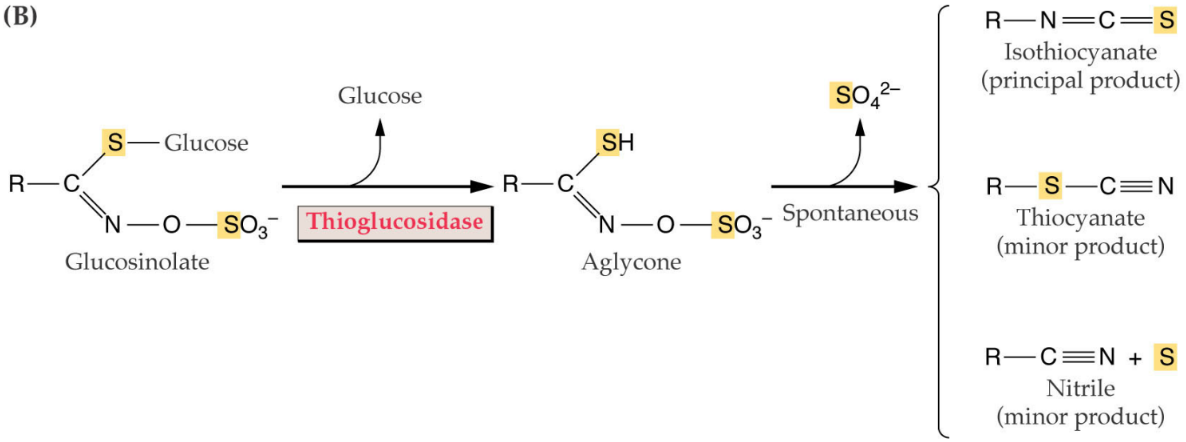
Coenzyme A

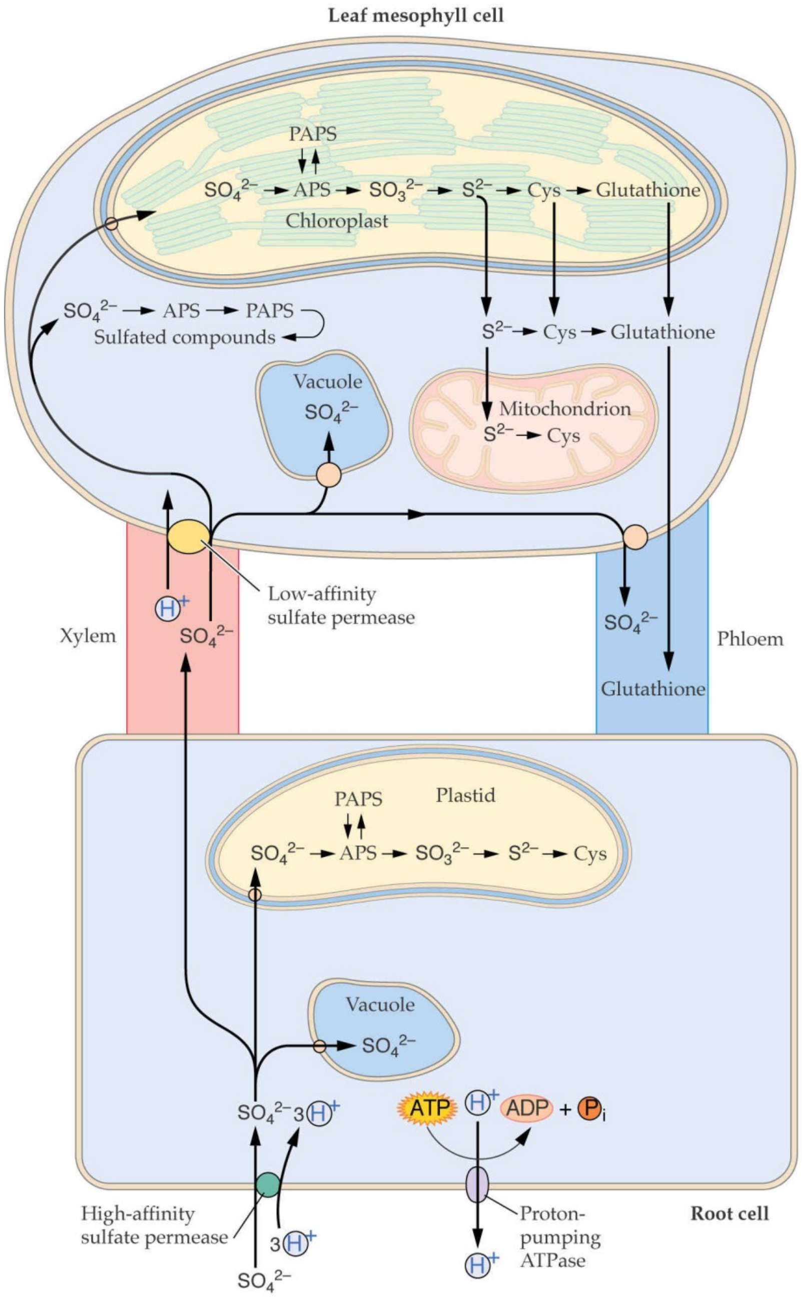


(A)

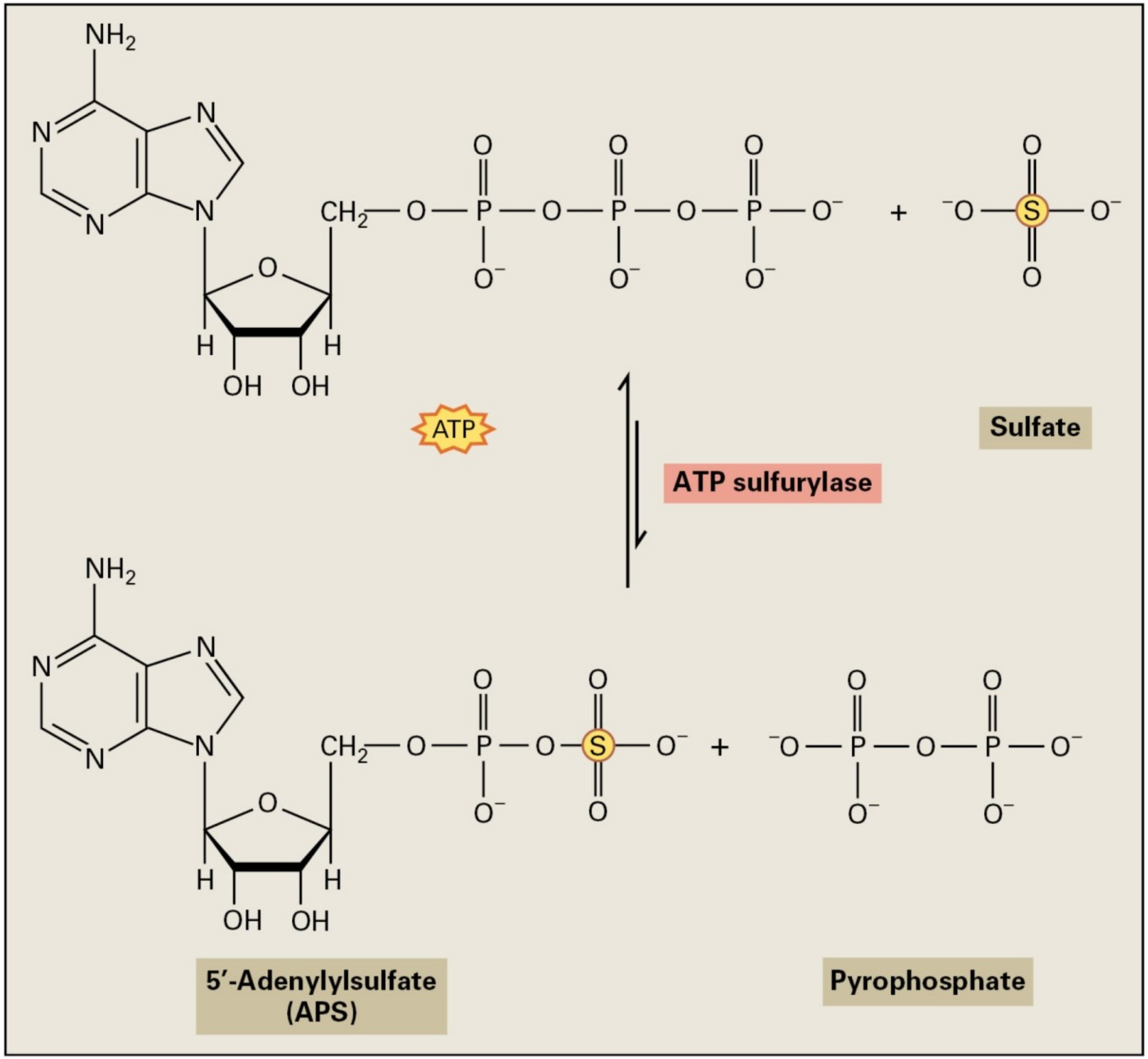


(B)

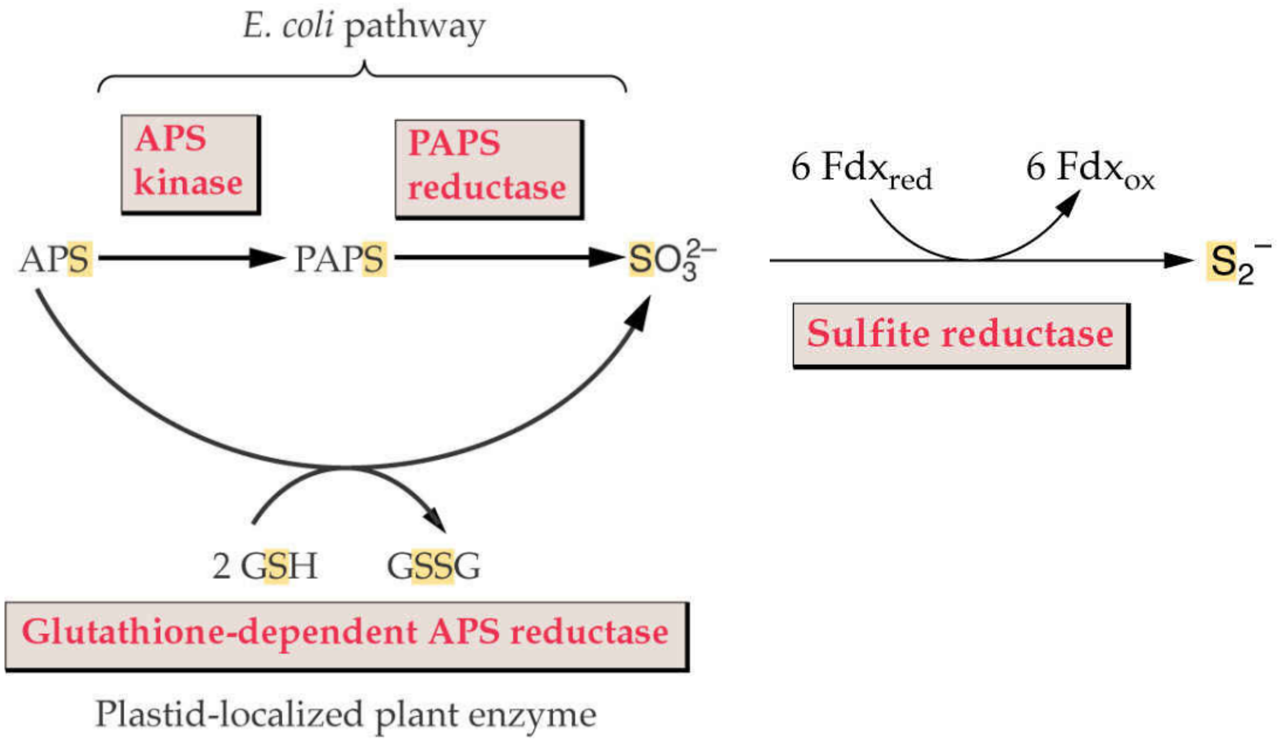



Leaf mesophyll cell
PAPS
SO_4^{2-} → APS → SO_3^{2-} → S^{2-} → Cys → Glutathione
Chloroplast
SO_4^{2-} → APS → PAPS
Sulfated compounds
S^{2-} → Cys → Glutathione
Vacuole
SO_4^{2-}
Mitochondrion
S^{2-} → Cys
Low-affinity sulfate permease
H^+
SO_4^{2-}
Xylem
SO_4^{2-}
Phloem
Glutathione
PAPS
Plastid
SO_4^{2-} → APS → SO_3^{2-} → S^{2-} → Cys
Vacuole
SO_4^{2-}
SO_4^{2-} 3H^+
ATP
H^+
ADP + P_i
High-affinity sulfate permease
3H^+
SO_4^{2-}
Proton-pumping ATPase
H^+
Root cell

Sulfate activation



Sulfate reduction to sulfide


E. coli pathway

APS kinase

PAPS reductase

APS → PAPS → SO_3^{2-}

$6\ Fdx_{red}$ → $6\ Fdx_{ox}$

SO_3^{2-} → S_2^{-}

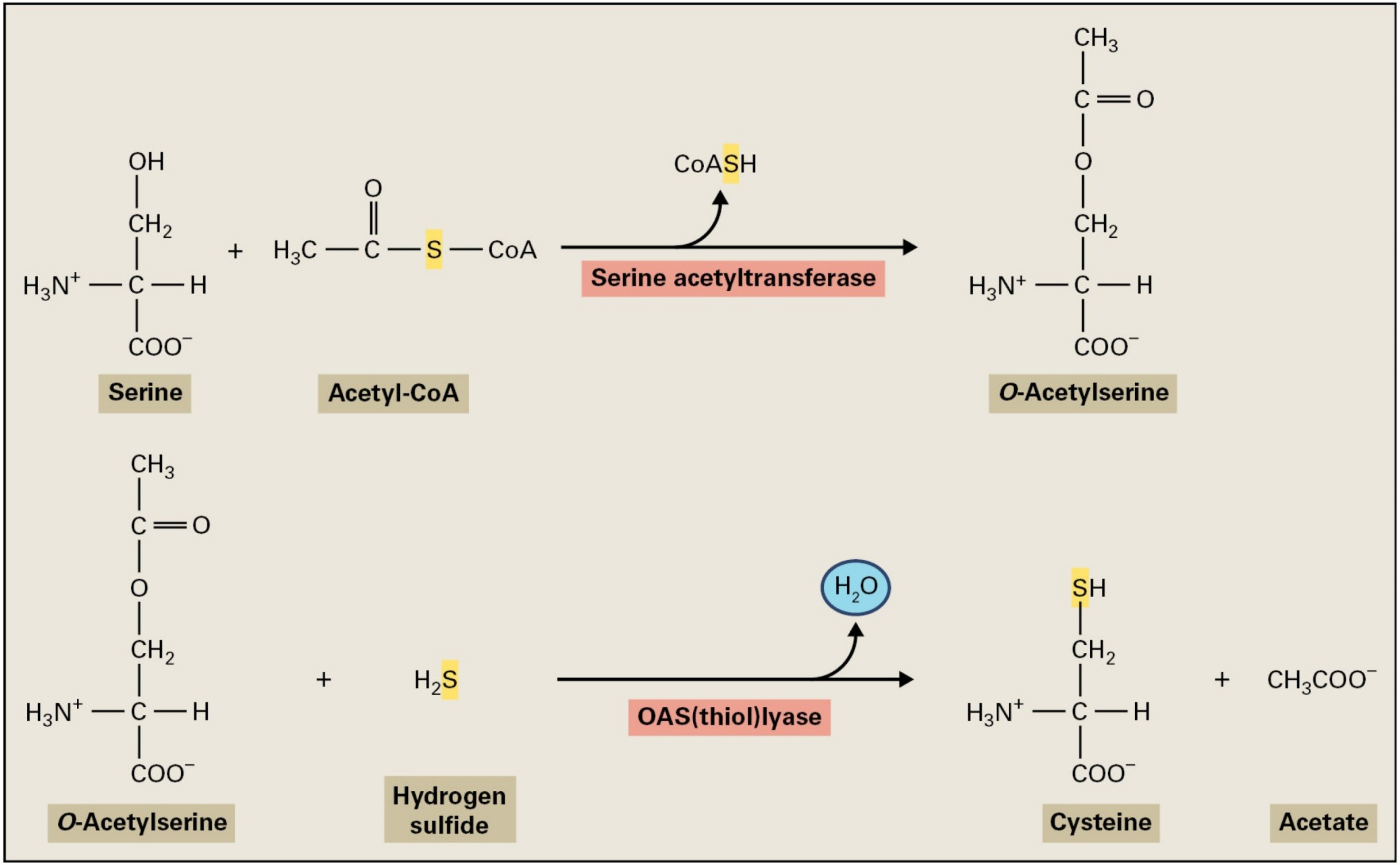
Sulfite reductase

2 GSH → GSSG

Glutathione-dependent APS reductase

Plastid-localized plant enzyme

Cysteine synthesis



Regulation of sulfate assimilation

- Sulfur assimilation is not strongly regulated by light

the enzymes are also active in etiolated plants and do not demonstrate diurnal oscillations

- Sulfur assimilation is regulated by developmental stage

all the enzymes are highly active in young leaves and root tips

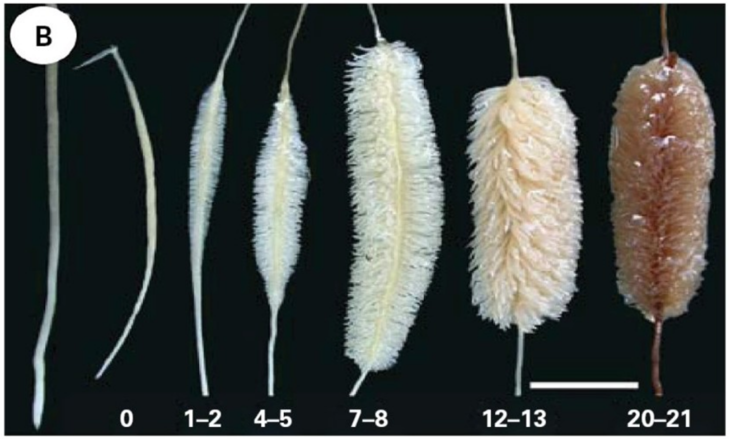
- Sulfur assimilation is regulated in response to the availability of sulfur

sulfur starvation results in the up-regulation of sulfate transport and APS reductase

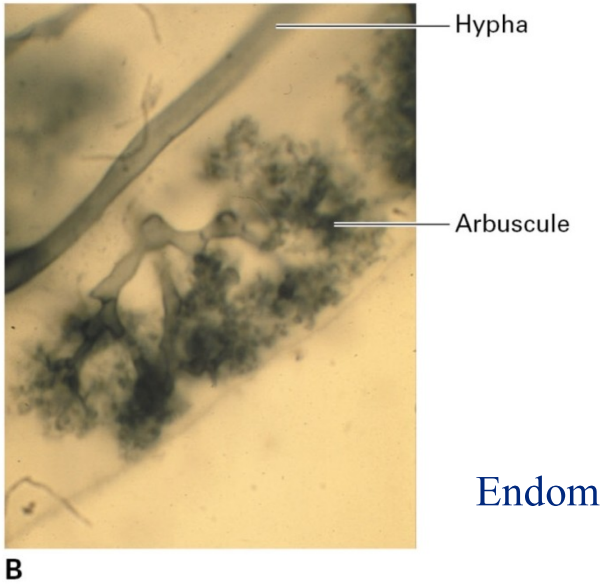
- The content of reduced sulfur and nitrogen is strictly coordinated

- Sulfite and sulfide are not allowed to accumulate

Phosphorus



Root modifications in low Pi concentration



Endomycorrhizae

Phosphate functions:

- component of nucleic acids and phospholipids
- energy conversion (ATP)
- regulation