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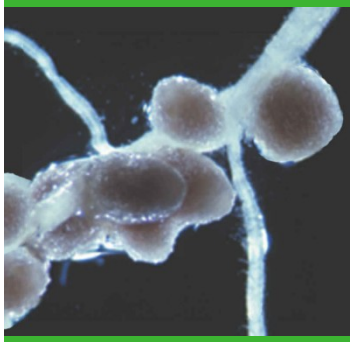


# Nutrients

Katerina Dadakova, Department of Biochemistry

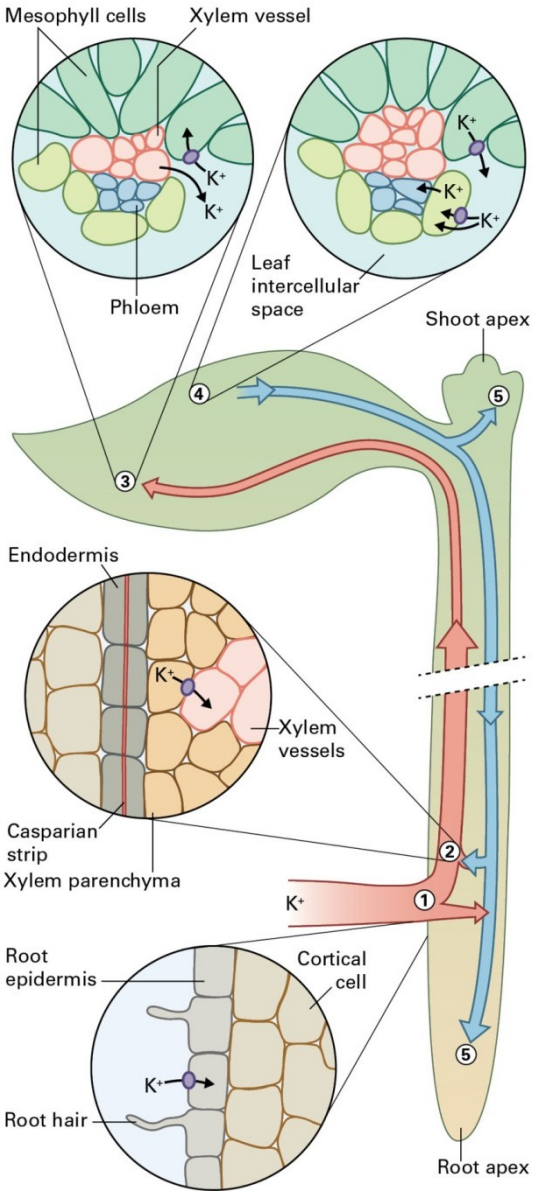
Figures adapted from Buchanan et al., Biochemistry & molecular biology of plants

# 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



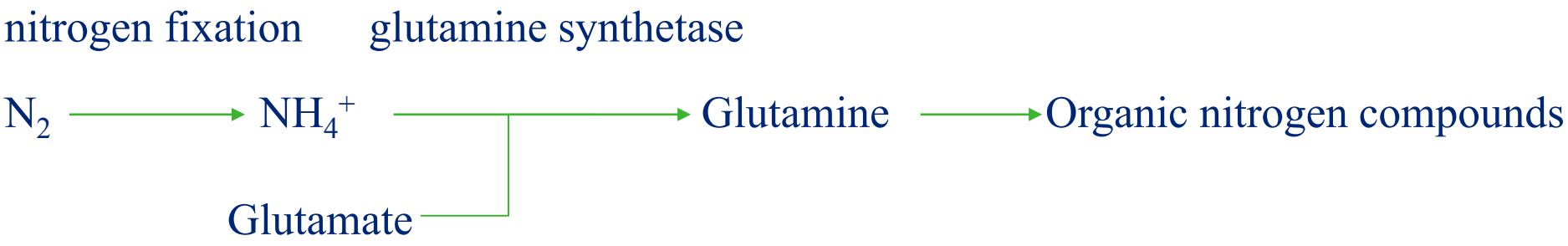

$K^+$ is the most abundant cellular cation

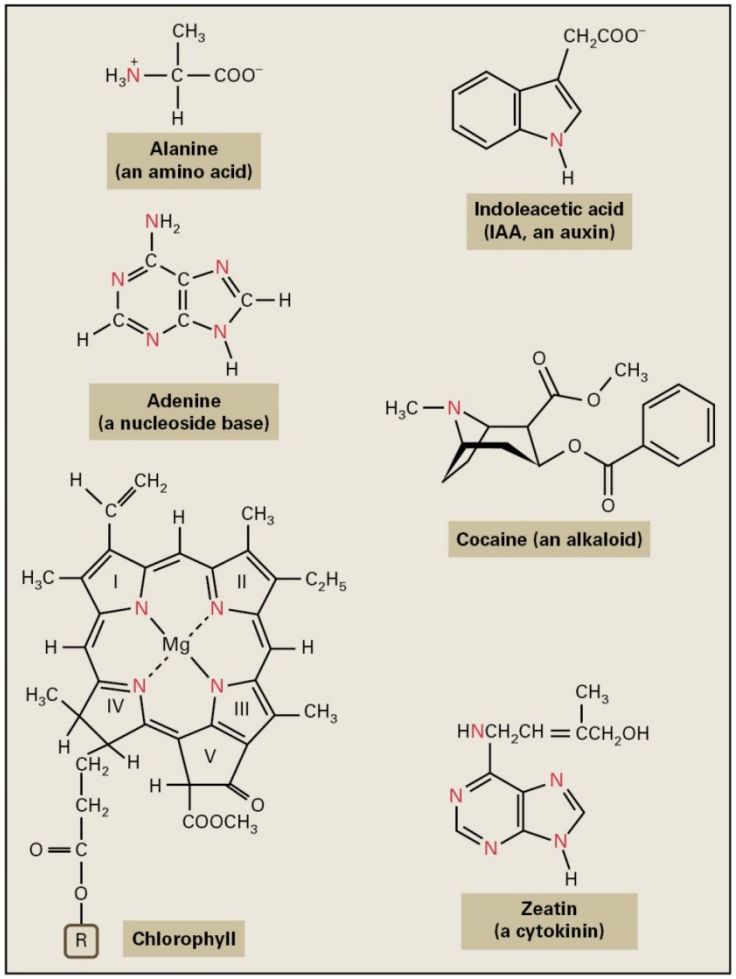
$K^+$ functions:

- 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 |





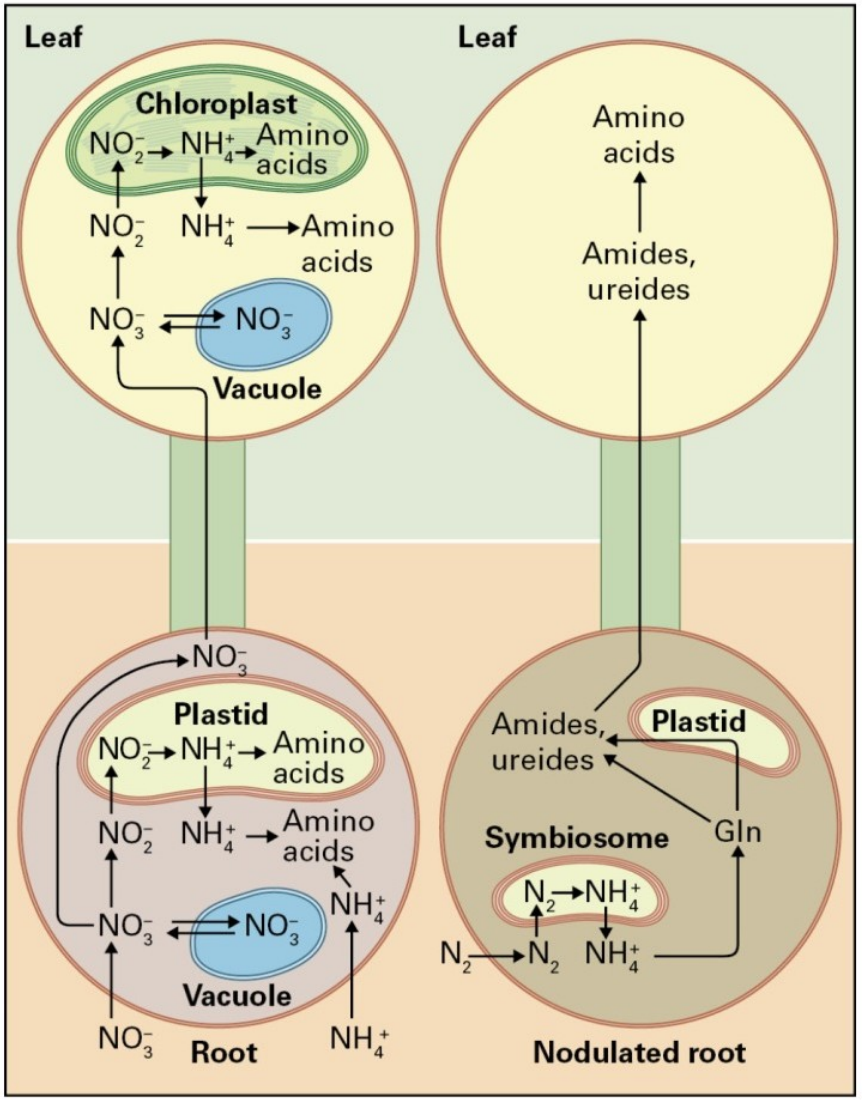

Nitrogen deficiency phenotype

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

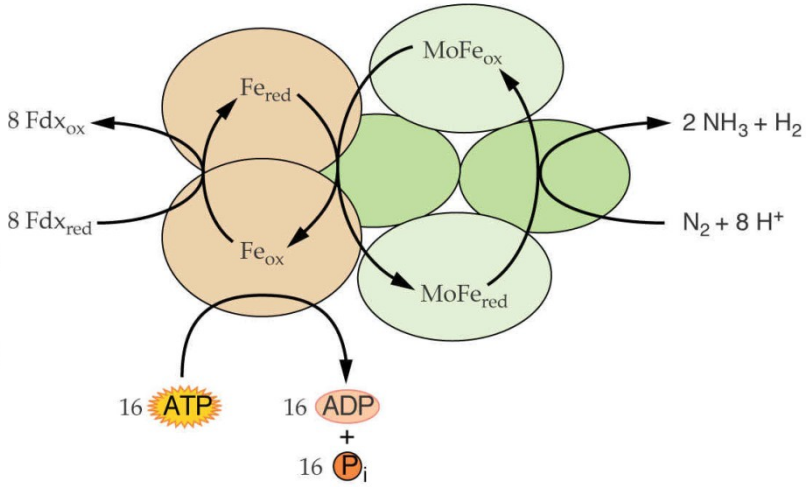


# Nitrogen fixation

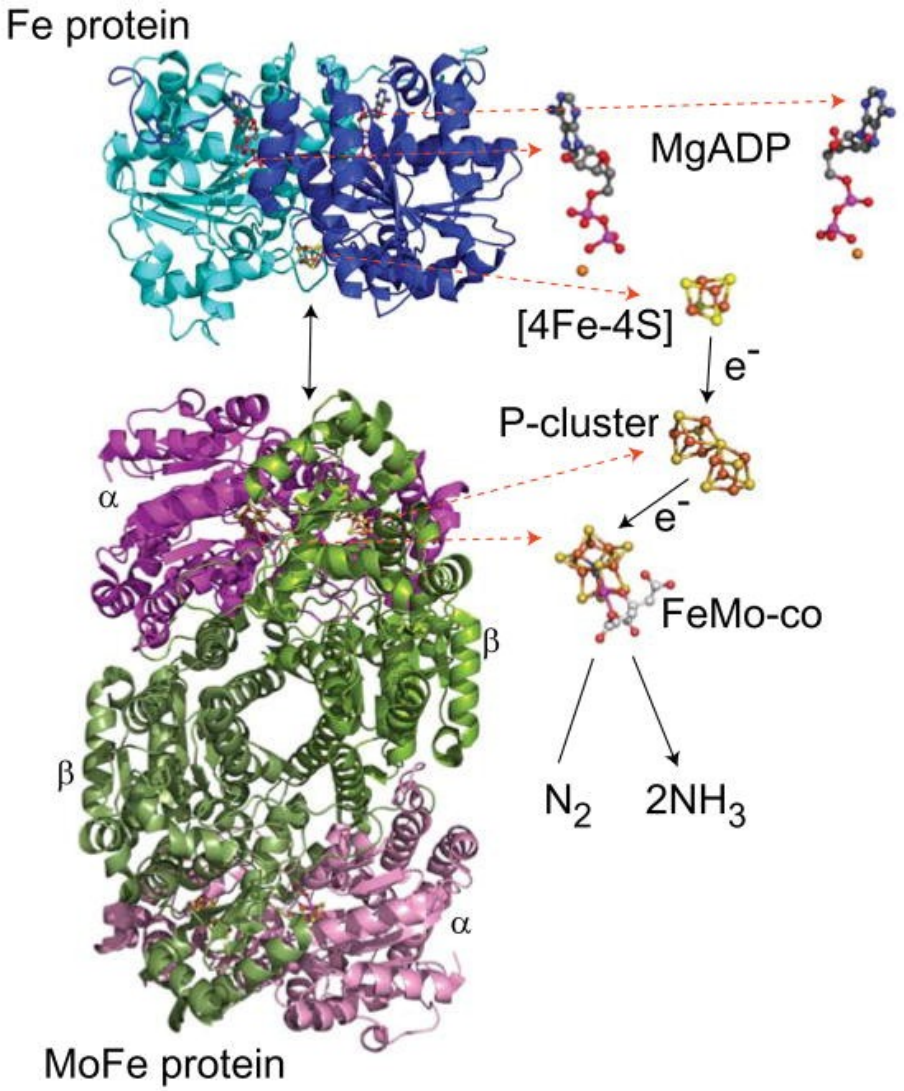
## Nitrogenase complex

Dinitrogenase reductase
Fe protein

Dinitrogenase
MoFe protein




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

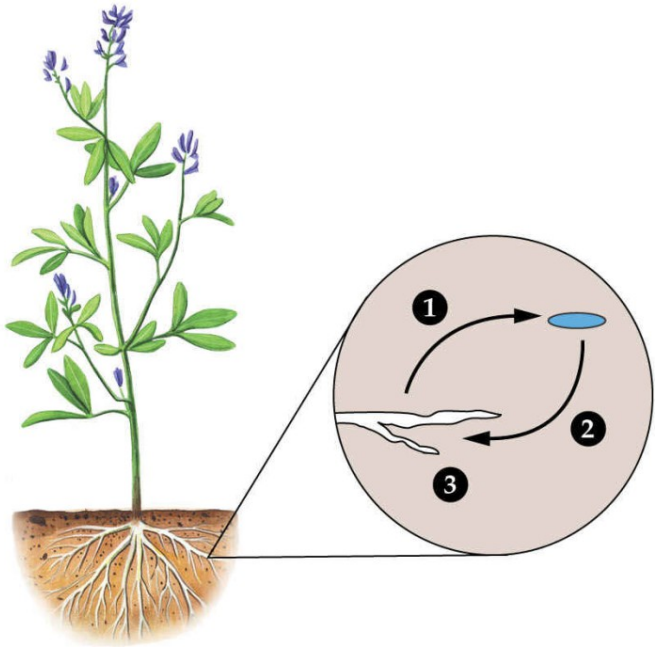


# Legume-rhizobial symbiosis

The plant creates root nodules to ensure:

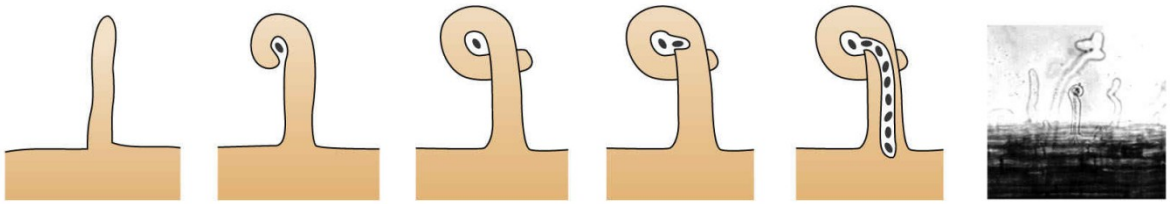
- microaerobic environment
- organic acids to feed the bacteria
- carbon skeletons to transport fixed nitrogen

Bacterial symbionts fix nitrogen and release the resulting ammonia

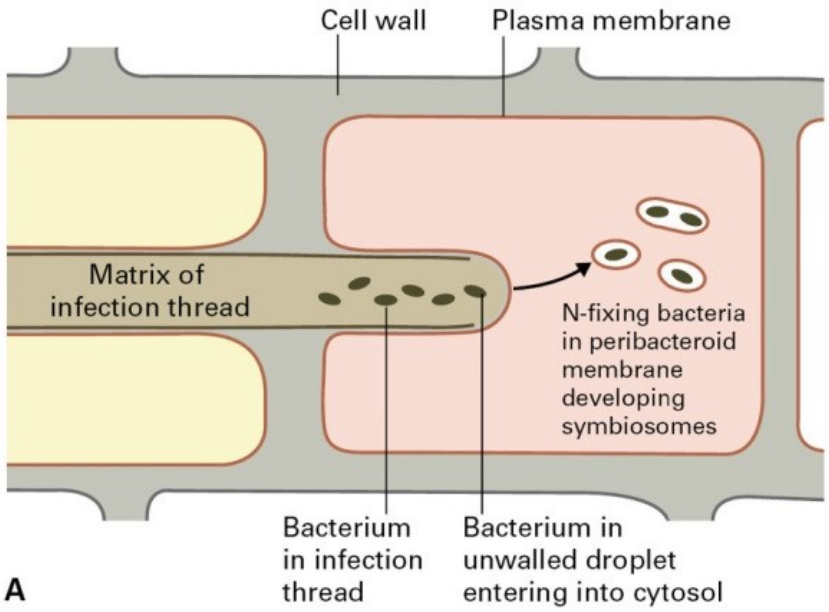


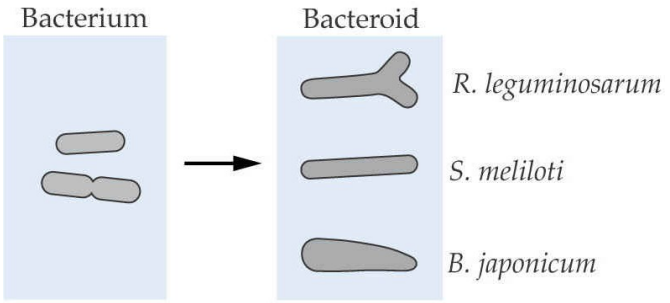

1. Plant signals
2. Nod factors
3. Nodulin proteins

# Nodule morphogenensis

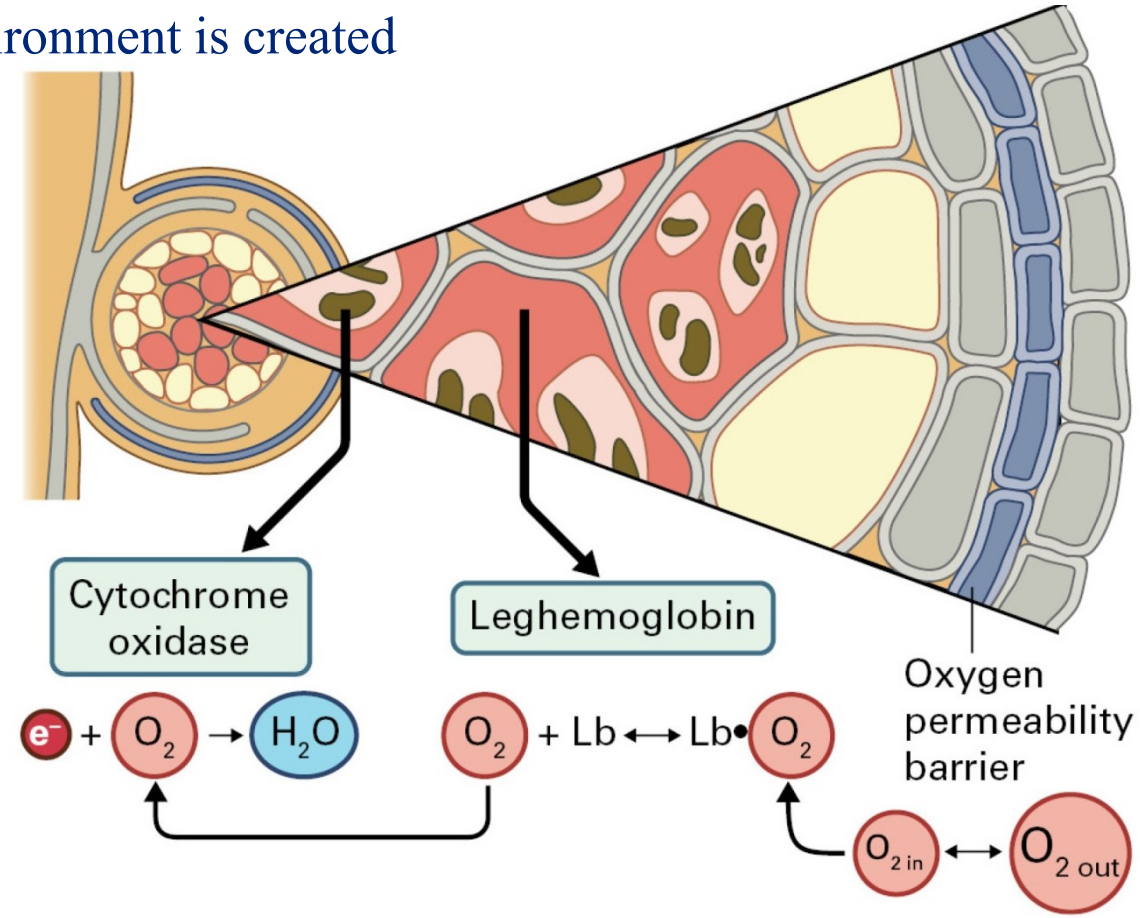


## In symbiosomes, bacteria differentiate into bacteroids



Microaerobic nodule environment is created

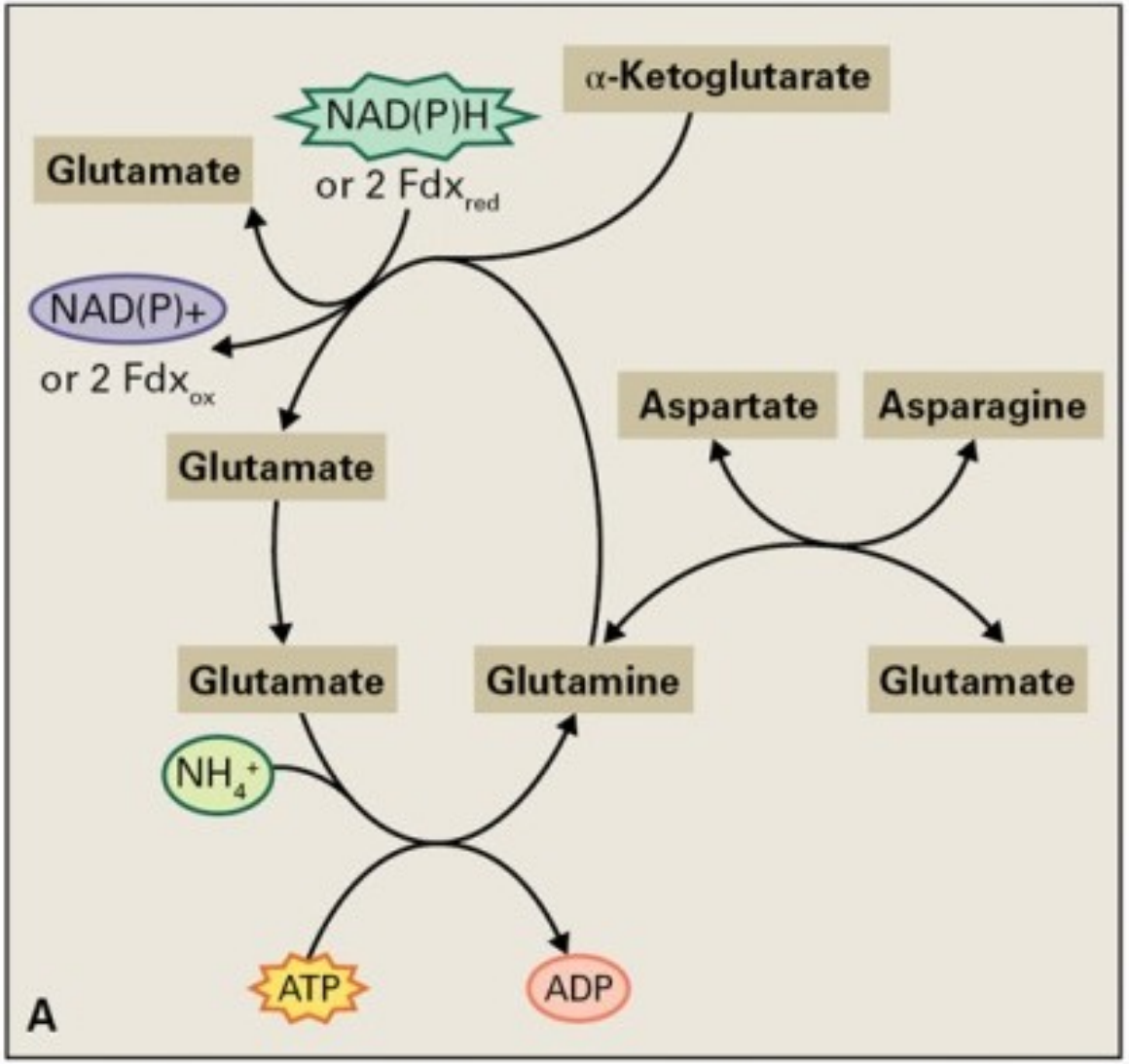



Carbon is provided to the bacteroids as dicarboxylic acids

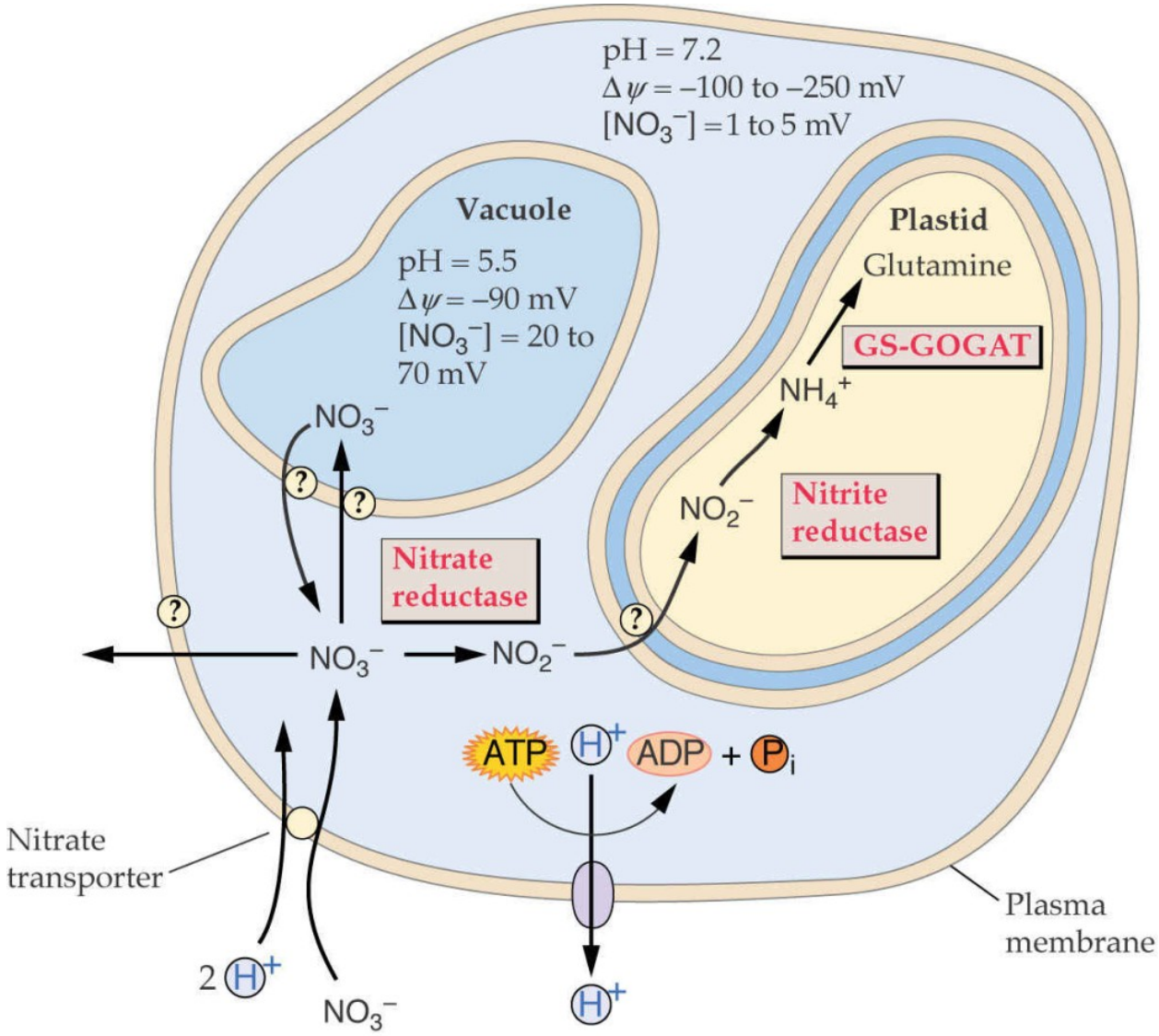
- oxidation of DCA provides ATP
- DCA carbon backbones are used for nitrogen transport

# Ammonia assimilation

## GS-GOGAT cycle



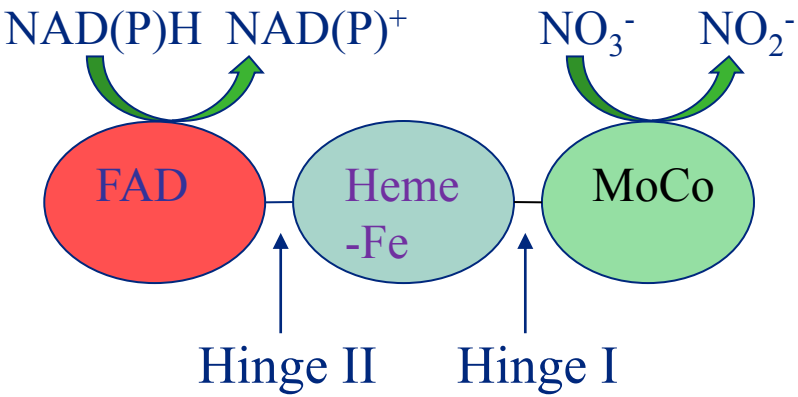
# Nitrate assimilation



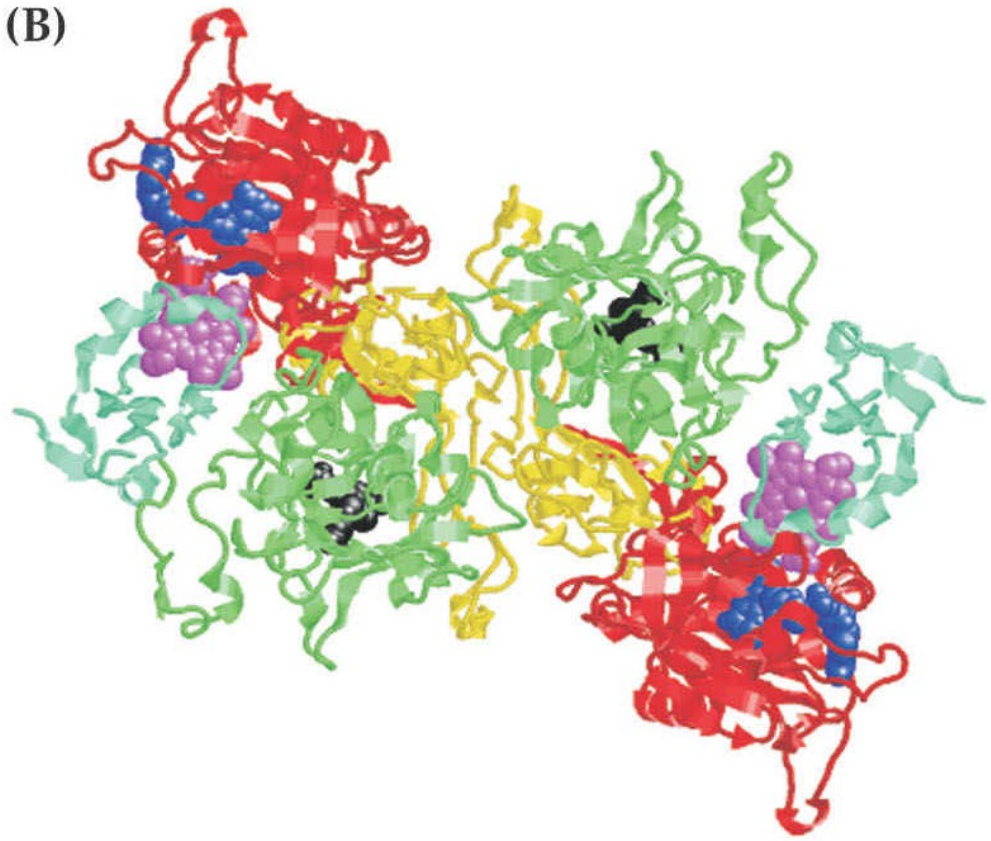
# Nitrate reductase

## NR reaction

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



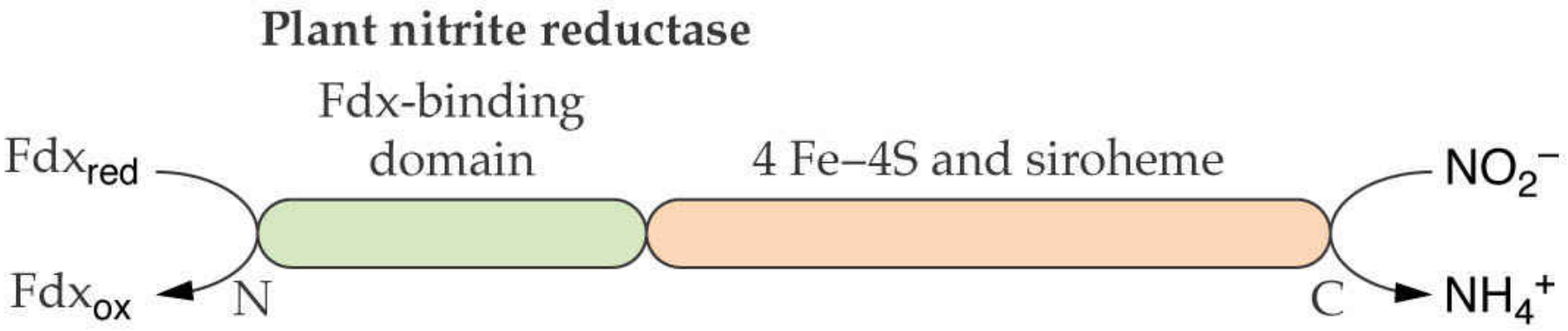

## NR homodimer



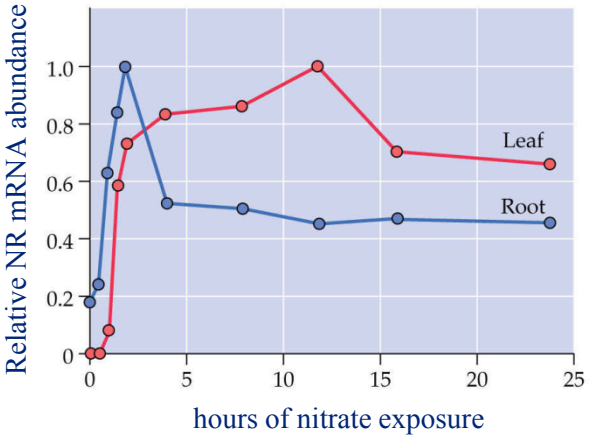
# Nitrite reductase

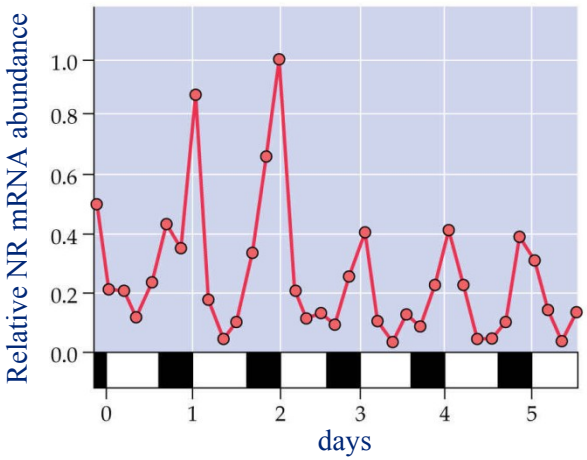
NiR reaction

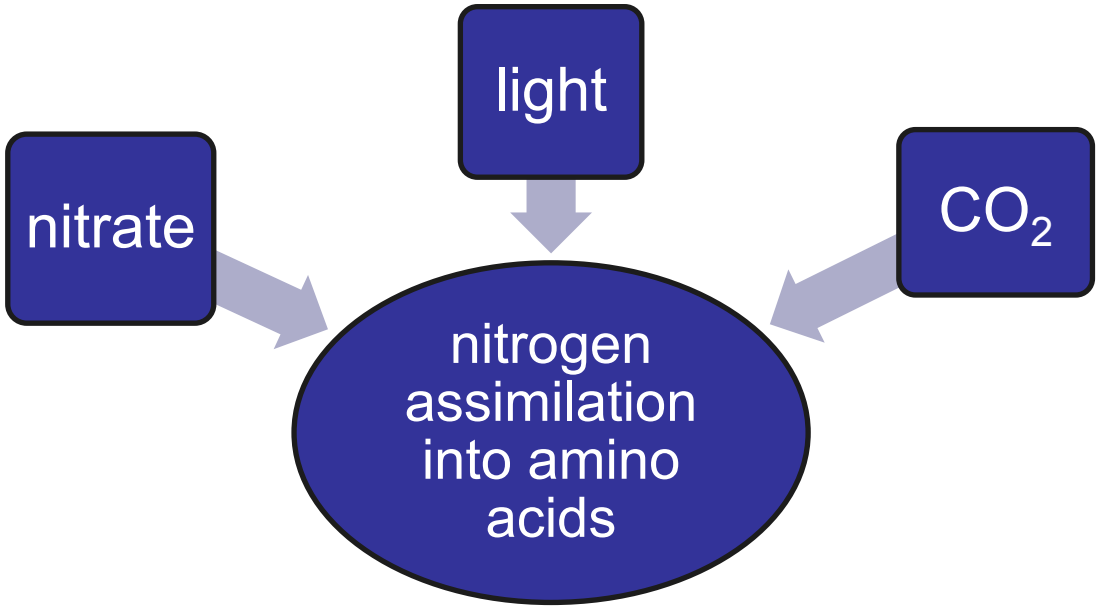
$$NO_2^- + 6\ Fdx_{red} + 8\ H^+ \longrightarrow NH_4^+ + 6\ Fdx_{ox} + 2\ H_2O$$



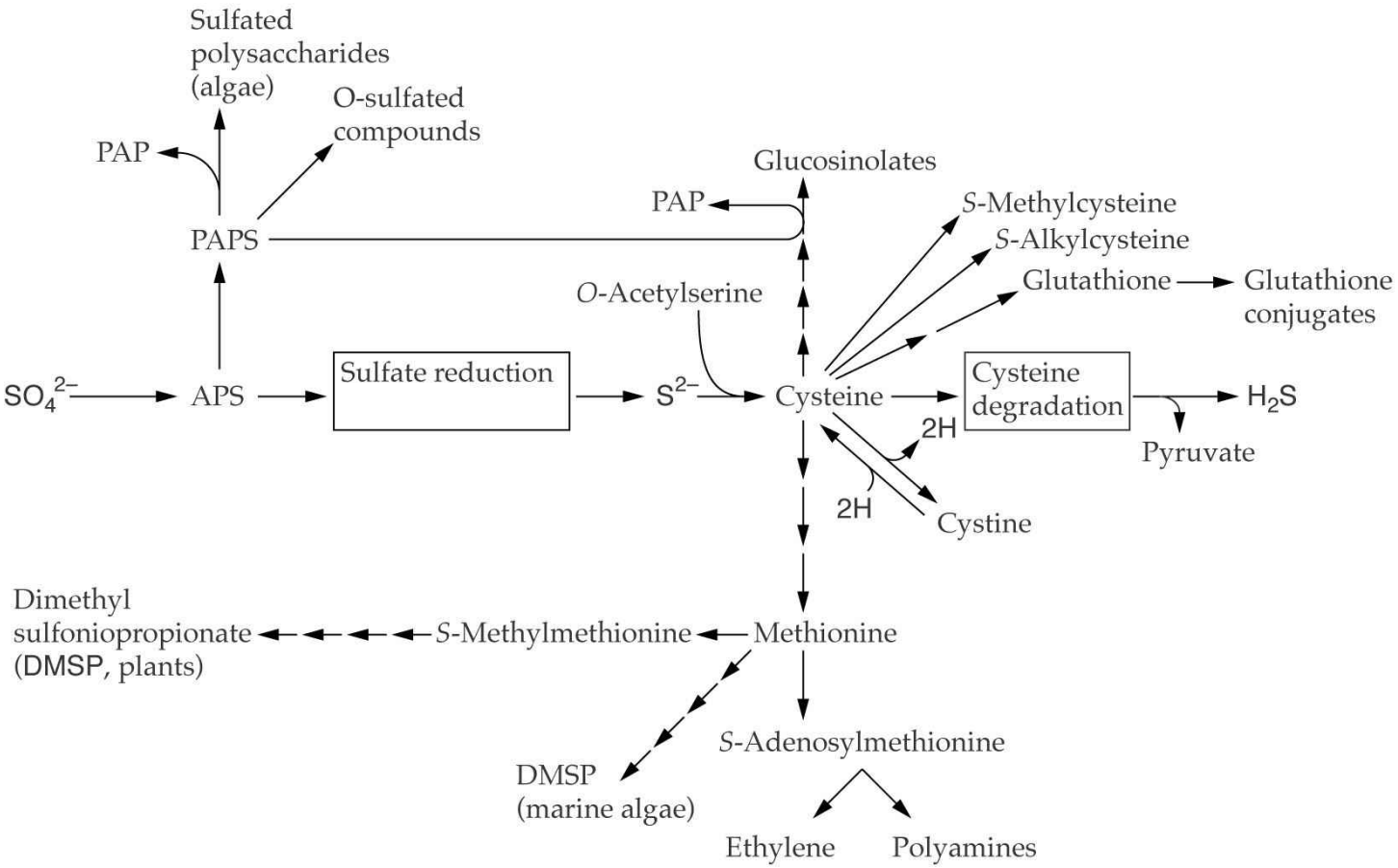
# Regulation of nitrate assimilation



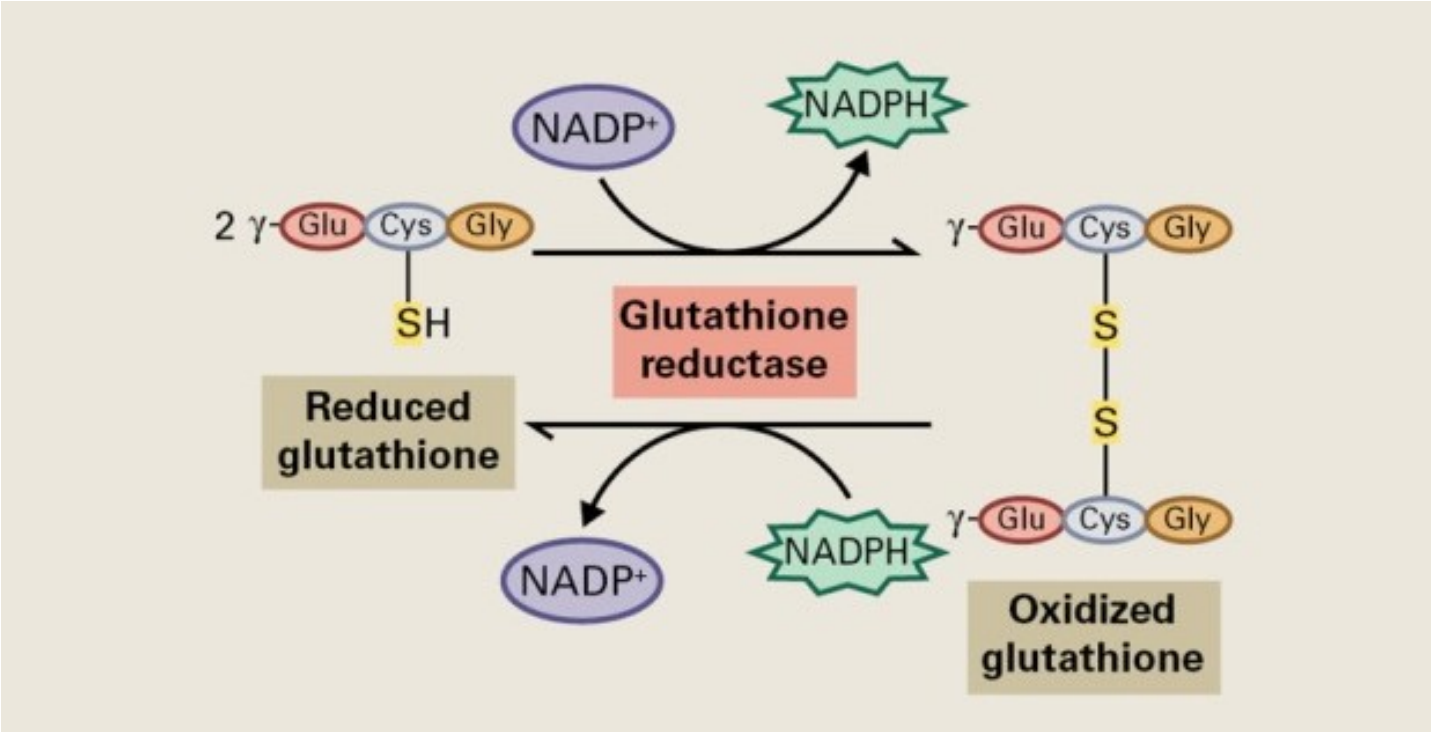



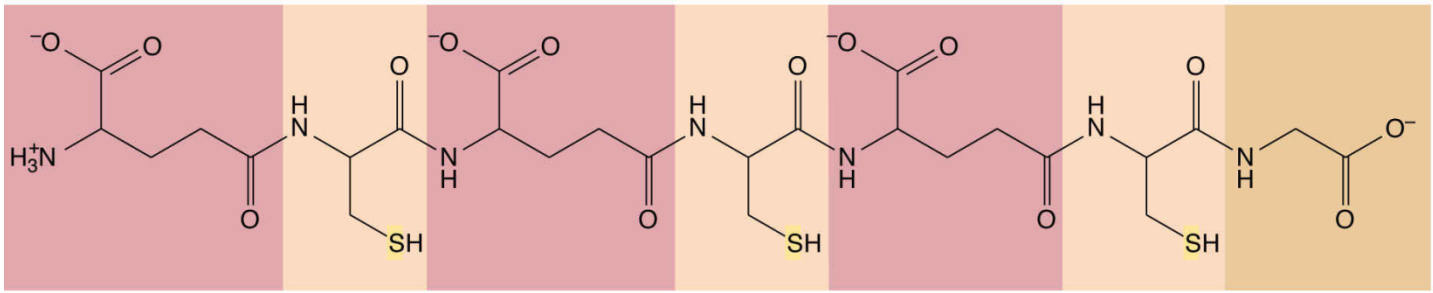
# Sulfur




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

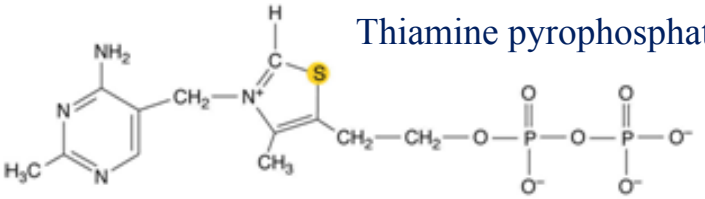



# Phytochelatin molecule

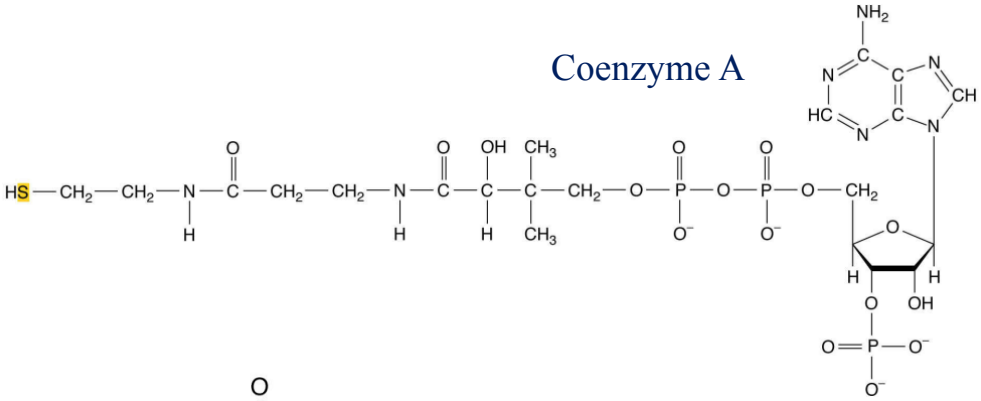


$(\gamma\text{-Glu-Cys})_3\text{-Gly}$

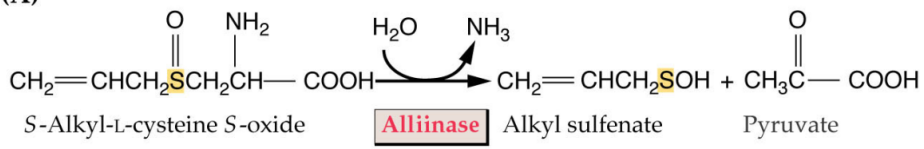
Thiamine pyrophosphate

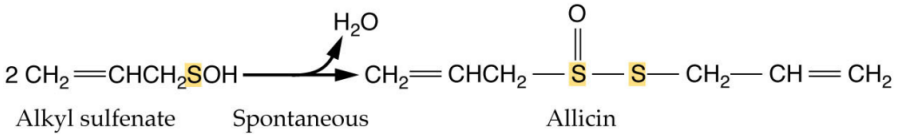


Coenzyme A

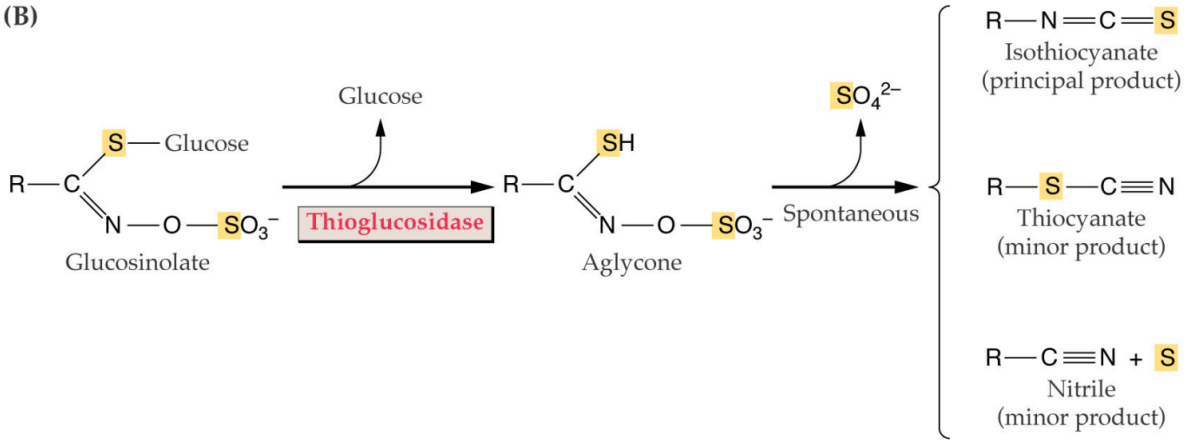


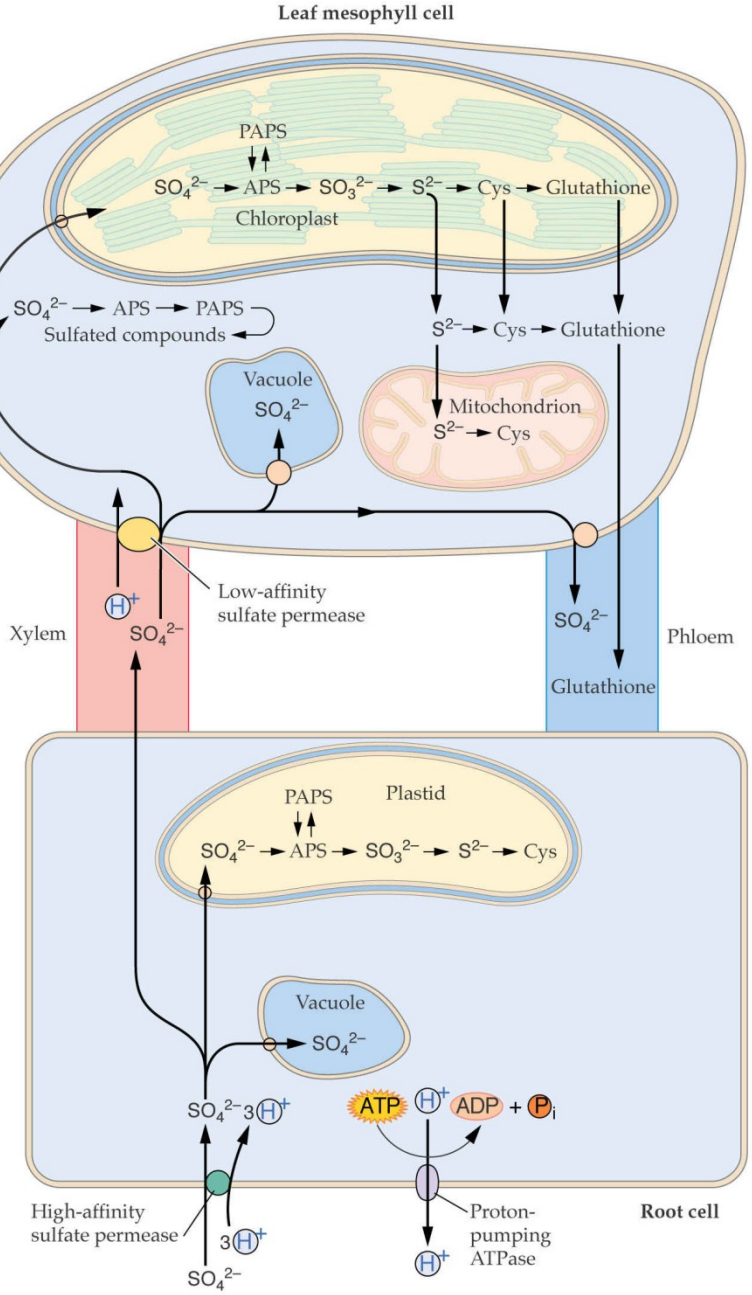
(A)



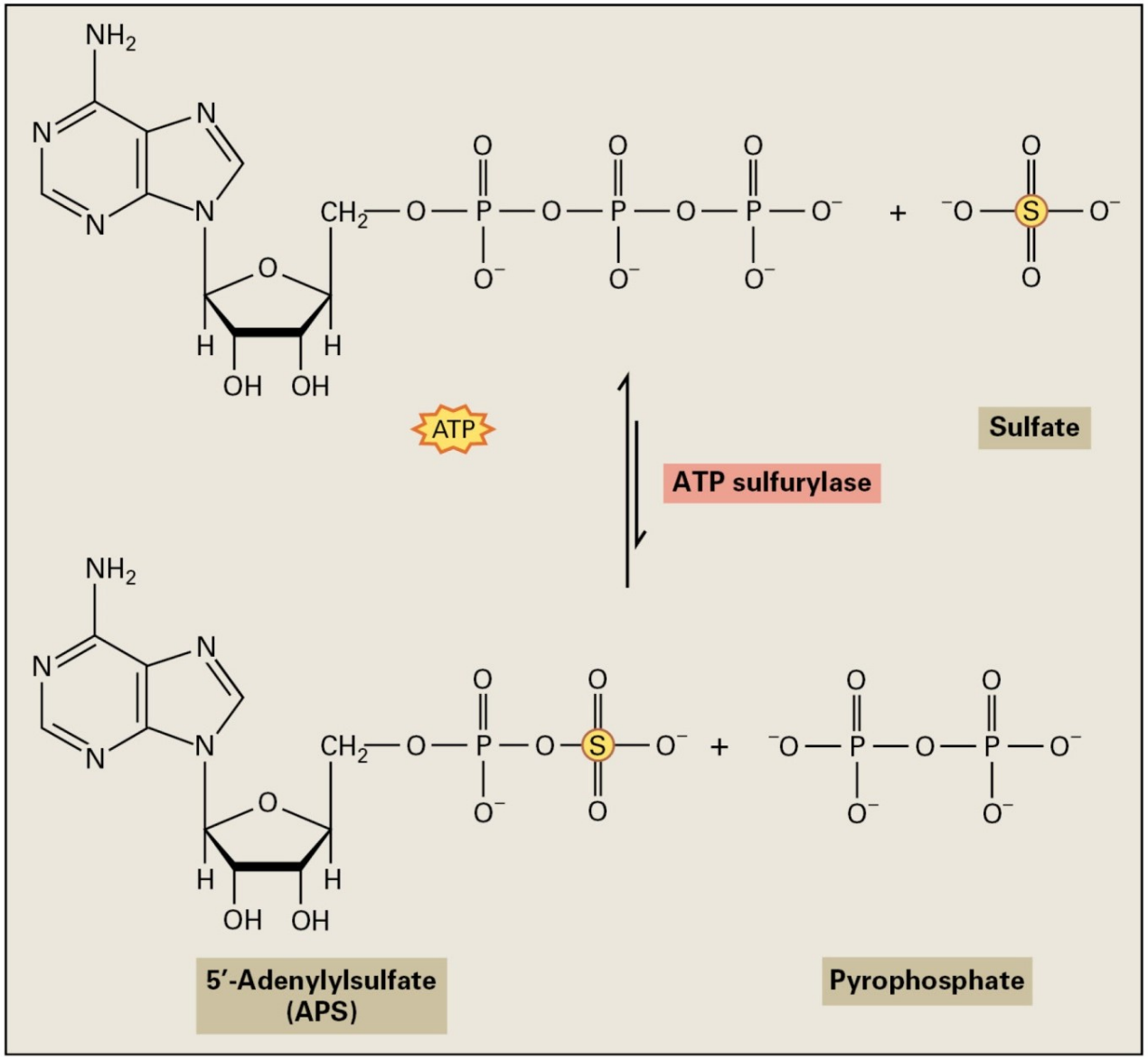




(B)

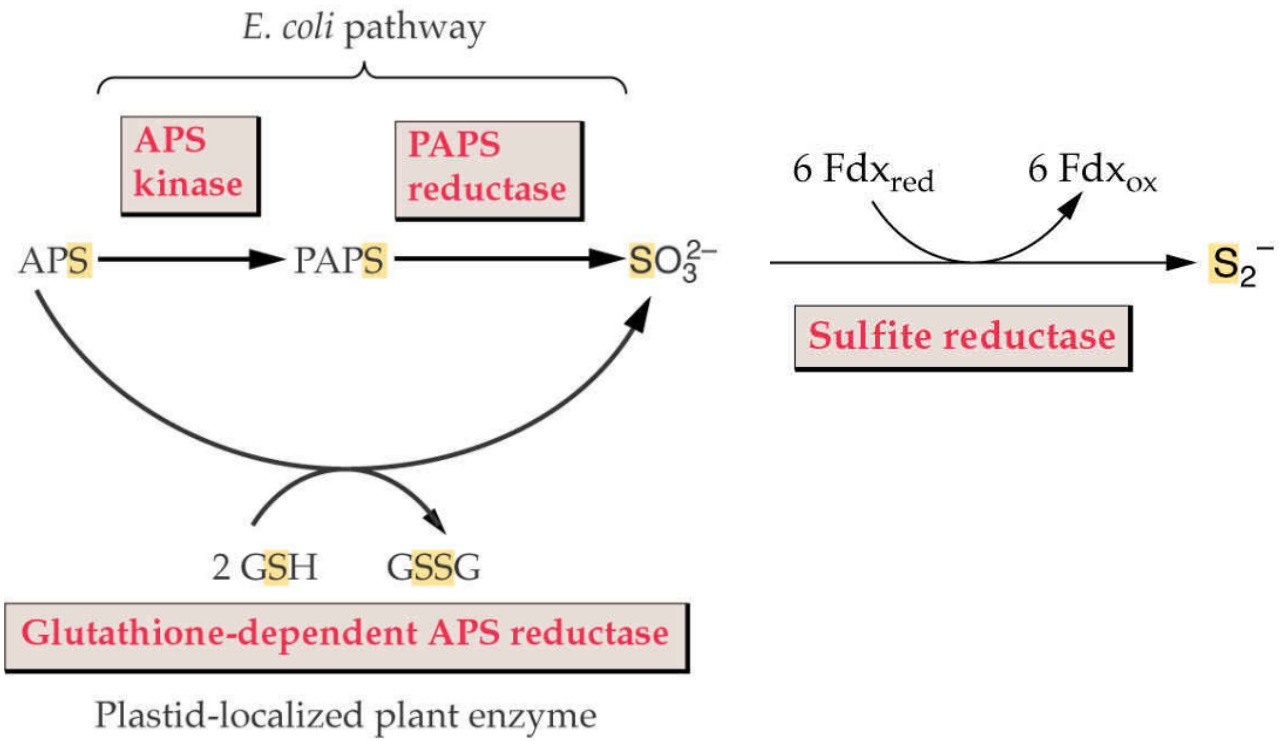



Leaf mesophyll cell
PAPS
$SO_4^{2-}$ → APS → $SO_3^{2-}$ → $S^{2-}$ → Cys → Glutathione
Chloroplast
$SO_4^{2-}$ → APS → PAPS
Sulfated compounds
$S^{2-}$ → Cys → Glutathione
Vacuole
$SO_4^{2-}$
Mitochondrion
$S^{2-}$ → Cys
Xylem
$H^+$
$SO_4^{2-}$
Low-affinity sulfate permease
$SO_4^{2-}$
Glutathione
Phloem
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

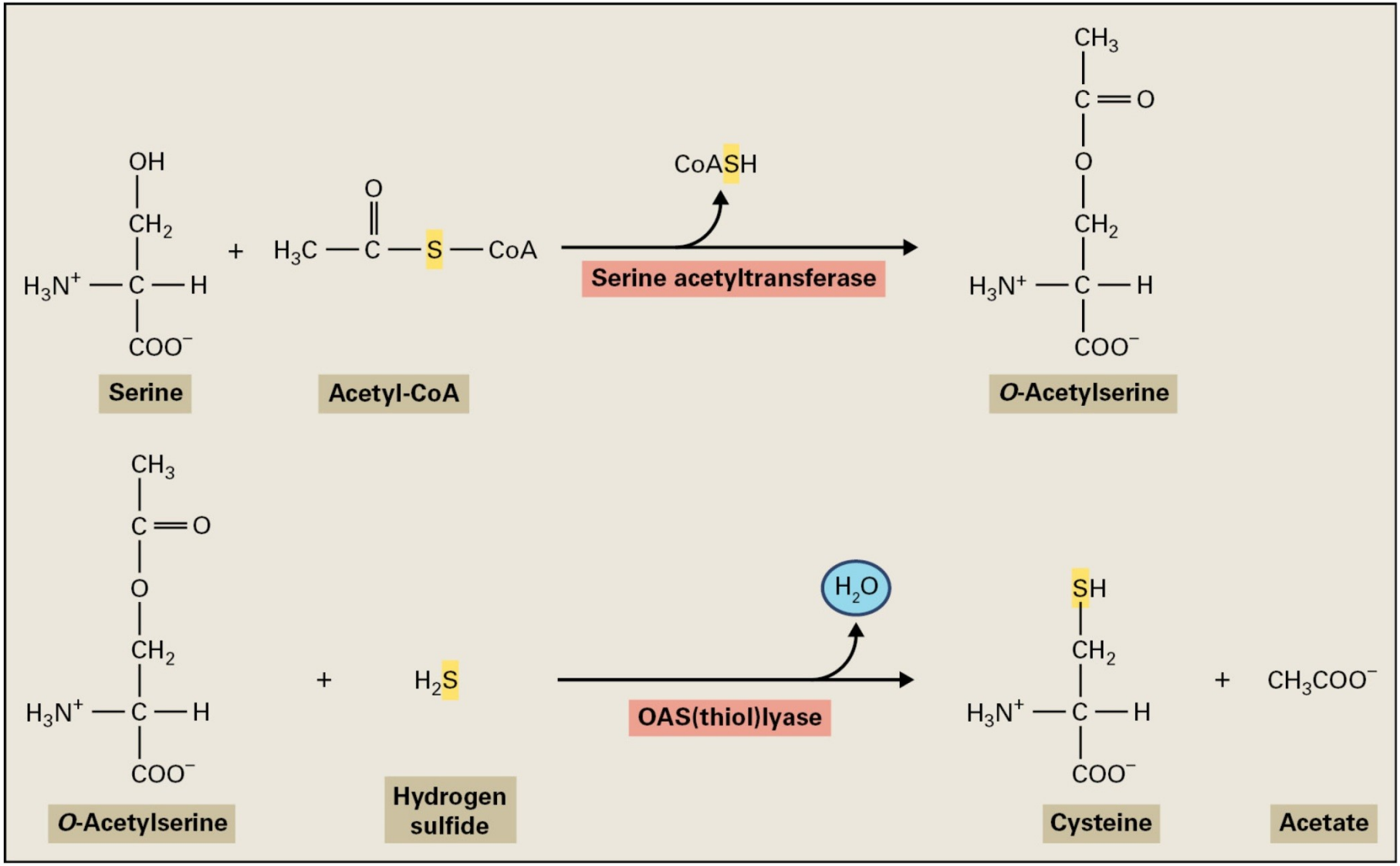
# Sulfate activation



# Sulfate reduction to sulfide



# 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*

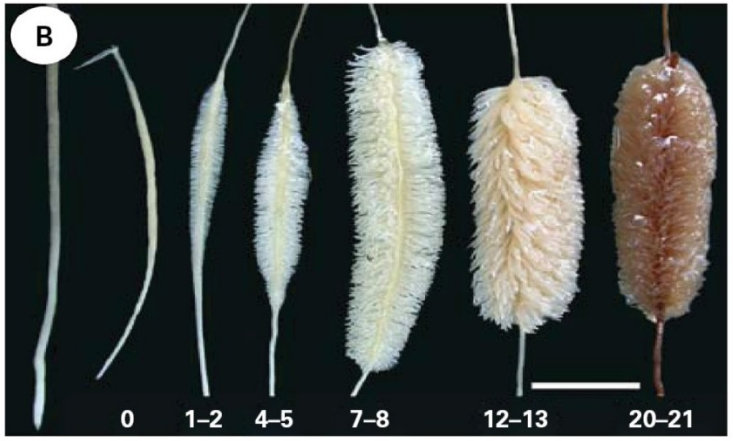
- Sulfur assimilation is regulated in response to the availability of sulfur

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

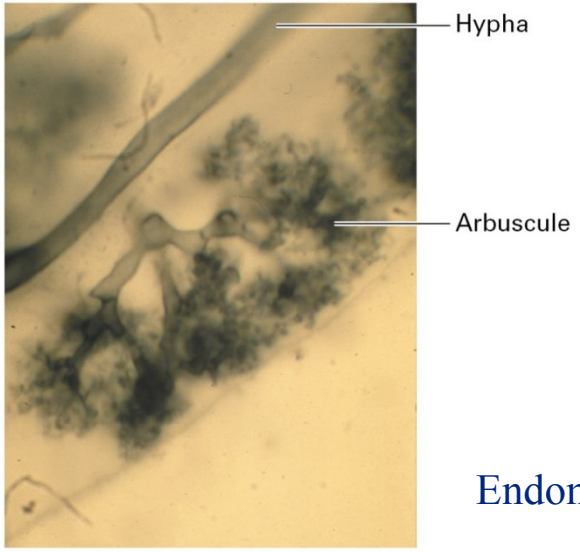
- The content of reduced sulfur and nitrogen is strictly coordinated

- Sulfite and sulfide are not allowed to accumulate

# Phosphorus




Root modifications in low Pi concentration, days




B

Endomycorrhizae

Phosphate functions:

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