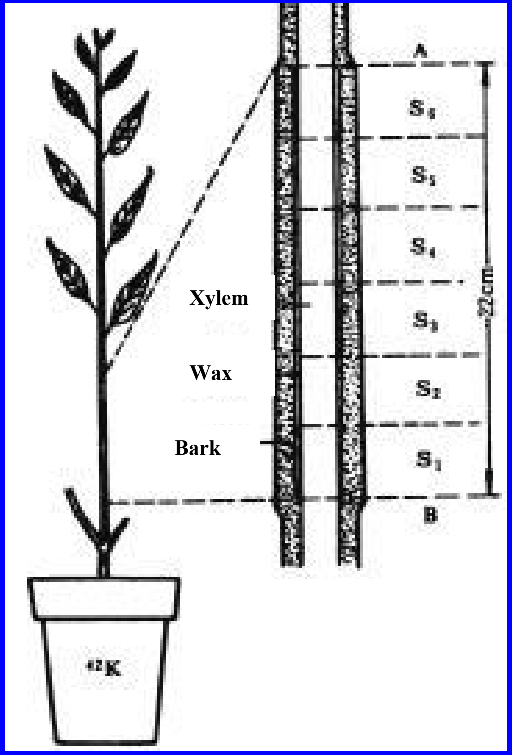
Chapter VI Mineral Nutrients - Transport and Distribution of Minerals in Plants



I. Form of Transport

N - Amino acid (Asp), amide (Asn, Gln) and other organics, a small amount of NO_3^-

P - n-phosphate, a small amount of organic phosphor (phosphatidylcholine and phosphatidylcholine)

S - SO_4^{2-}, a small amount of Met and GSH

M - M^+

II. Pathway and Rate

1. Pathyway

① Xylem transport: The ions absorbed in the root may rise via xylem along with transpirational flow or be transversely transported to phloem;

② Phloem transport: The ions absorbed by blades are transported upwards or downwards via phloem and xylem, but downward transport is dominated by phloem.

2. Rate: 30-100 cm/h

Distribution of ^{42}K in Willow Stems

Part		Insert wax paper betwen phloem and xylem after their separation		Close re-contact between phloem and xylem after separation	
		Phloem ^{42}K (mg/L^{-1})	Xylem ^{42}K (mg/L^{-1})	Phloem ^{42}K (mg/L^{-1})	Xylem ^{42}K (mg/L^{-1})
Part above separation	A	53	47	64	56
Separated part	S6	11.6	119	87	69
	S5	0.9	122		
	S4	0.7	112		
	S3	0.3	98		
	S2	0.3	108		
	S1	20	113		
Part below separation	B	84	58	74	67

Distribution of ^{32}P in cotton stems

Part	Insert wax paper betwen phloem and xylem after their separation		Close re-contact between phloem and xylem after separation	
	Phloem ^{32}P (mg/L^{-1})	Xylem ^{32}P (mg/L^{-1})	Phloem ^{32}P (mg/L^{-1})	Xylem ^{32}P (mg/L^{-1})
A	1.11		0.444	
L	0.458	0.100		
C	0.610			
S1	0.544	0.064	0.160	0.055
S2	0.332	0.004	0.103	0.063
S3	0.592	0.000	0.055	0.018
S4	0.228	0.004	0.026	0.007
B	0.653		0.152	

III. Distribution in Plants

1. Elements participating in circulation
   ① Type: K, N, P, Mg, etc.
   ② Distribution: Growing points, tender leaves and other locations with vigorous metabolism, while deficiency is seen in old leaves
2. Elements that cannot participate in circulation
   ① Type: S, Ca, Fe, Mn, B, etc.
   ② Distribution: After absorption, they are fixed and cannot be moved. The older the organs are, the higher the content will be. Deficiency is seen in tender leaves.
3. Mineral elements, such as K and N, as well as sugar, organic acids and plant hormones may be discharged out of the bodies.

I. Assimilation of N

(I) Metabolic reduction of nitrate

+5 +2e +3 +2e +1 +2e -1 +2e -3

$$HNO_3 \rightarrow HNO_2 \rightarrow [H_2N_2O_2] \rightarrow [NH_2OH] \rightarrow NH_3$$

1. Nitrate is reduced to nitrite (cytoplasm)

① Overall reaction

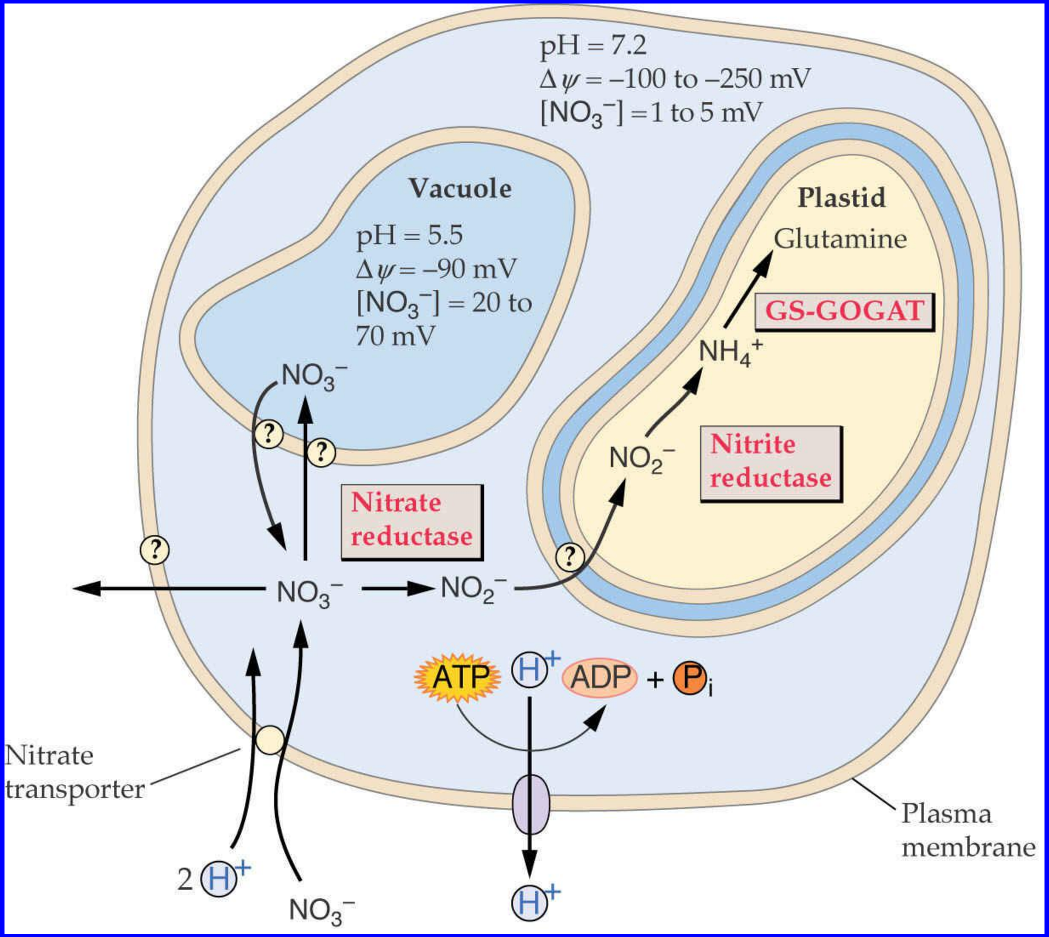
$$NO_3^- + NAD(P)H + H^+ + 2e^- \rightarrow NO_2^- + NAD(P)^+ + H_2O$$

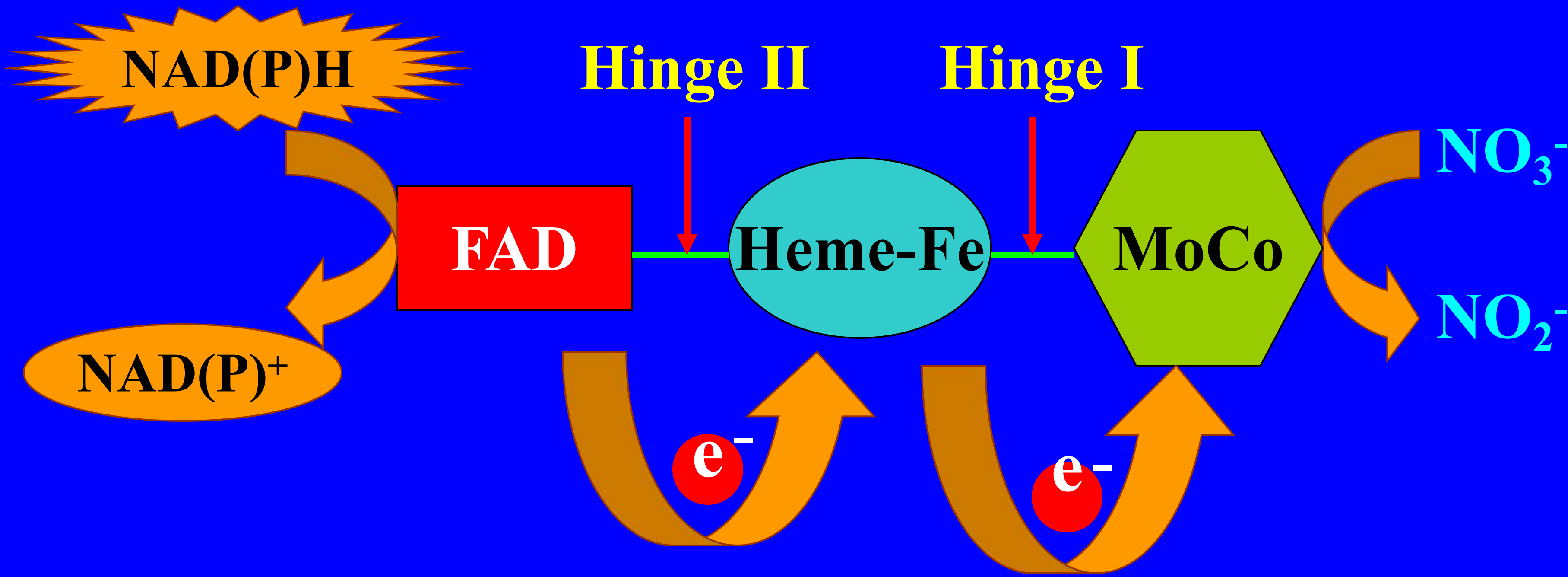
② Nitrate reductase (inducible enzyme)

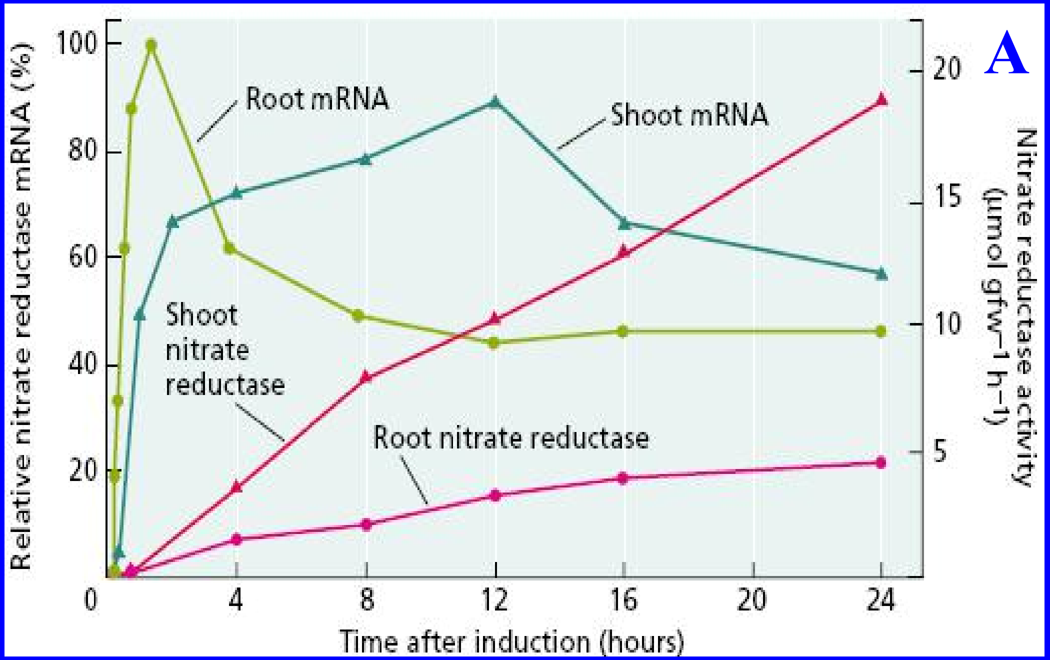
Relative molecular weight: 2×10^5-5×10^5

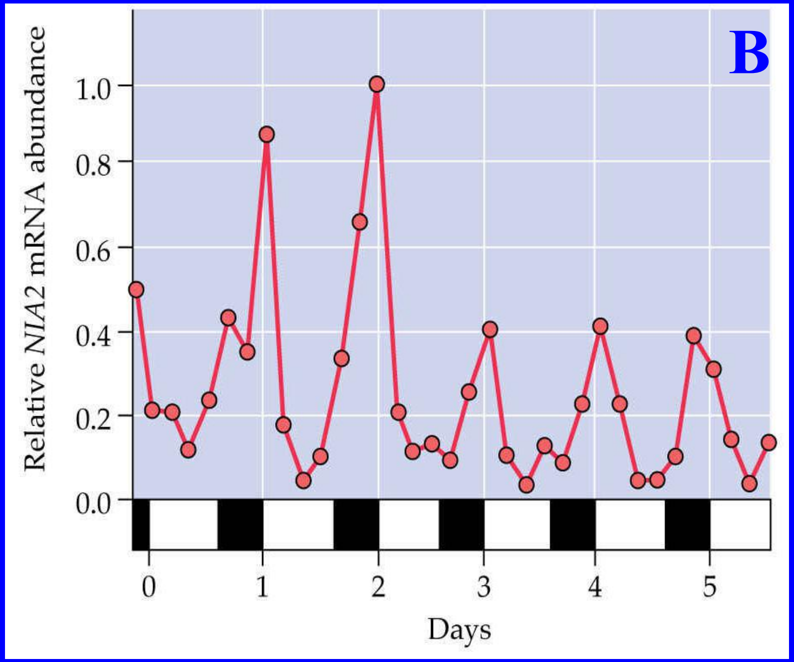
Composition: Every monomer comprises FAD, cytb$_{557}$, MoCo, etc.

Nitrate assimilation by plant cells involves transport of nitrate across the plasma membrane and then reduction to ammonia in a two-step process.



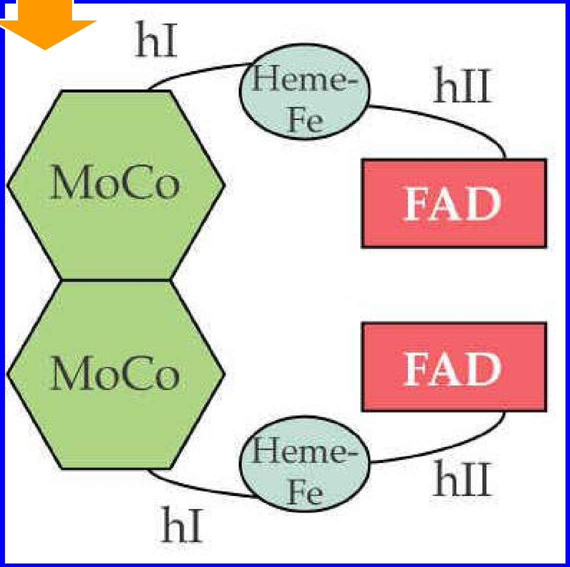

NAD(P)H
Hinge II
Hinge I
FAD
Heme-Fe
MoCo
NO_3^-
NO_2^-
$NAD(P)^+$
e^-
e^-

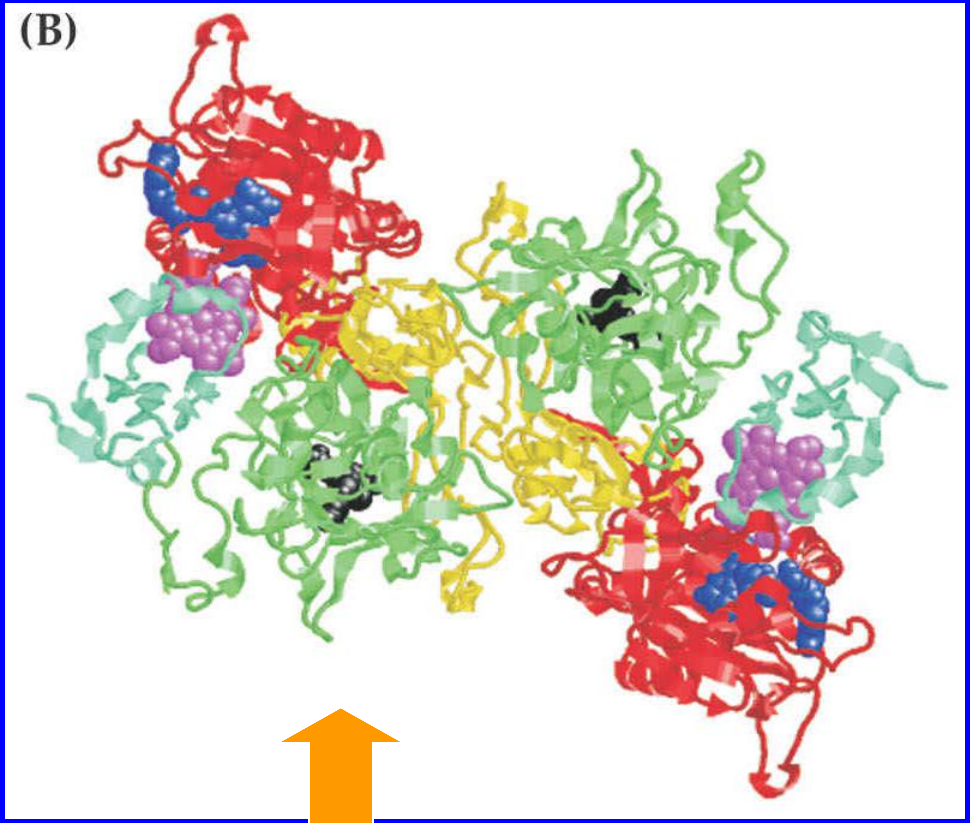




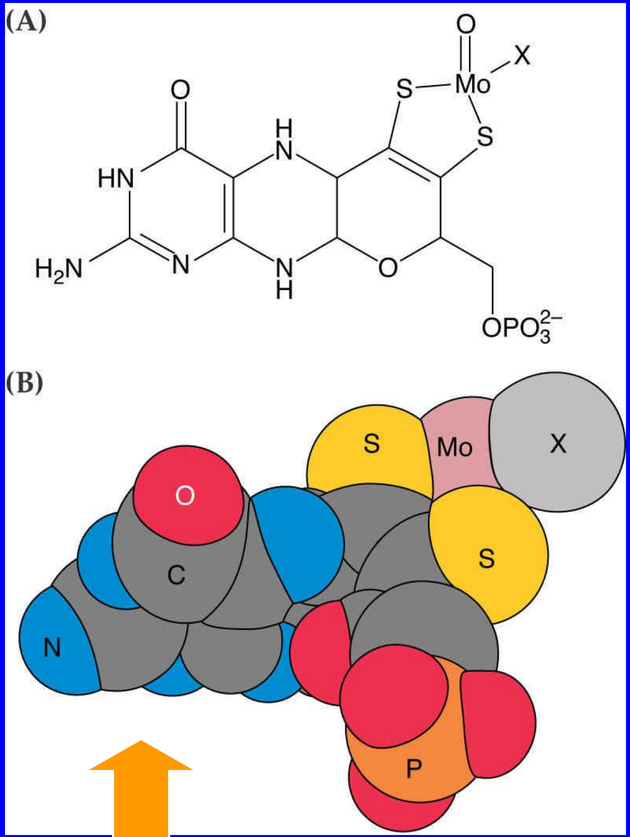
Regulation of nitrate reductase gene expression. (A) Stimulation of NR activity follows the induction of NR mRNA in shoots and roots of barley. (B) In plants grown in the presence of nitrate, NR mRNA concentrations demonstrate a diurnal cycle.

Domain structure of nitrate reductase.





Ribbon diagram of nitrate reductase. The heme prosthetic group is shown in purple, FAD in blue, and MoCo in black.



Molybdenum cofactor of NR. (A) Chemical structure. (B) Space-filling model.

Crystal structure of FAD domain of NR.

2. Nitrite is reduced to ammonia (chloroplast)

① Overall reaction

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

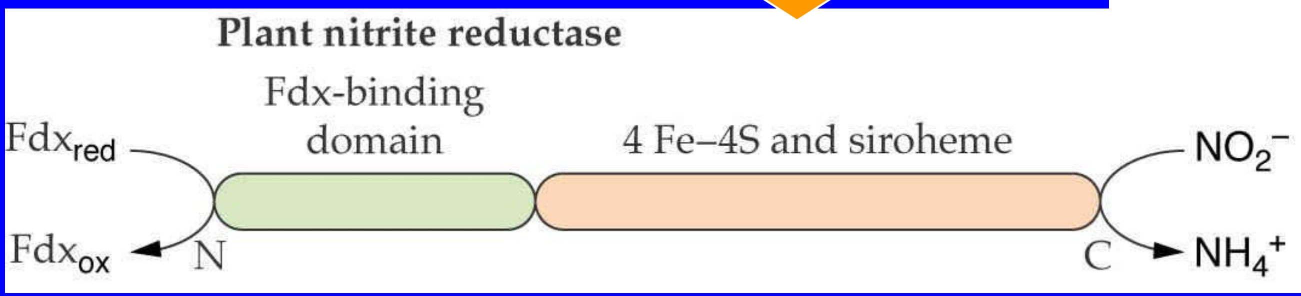
② Nitrite reductase

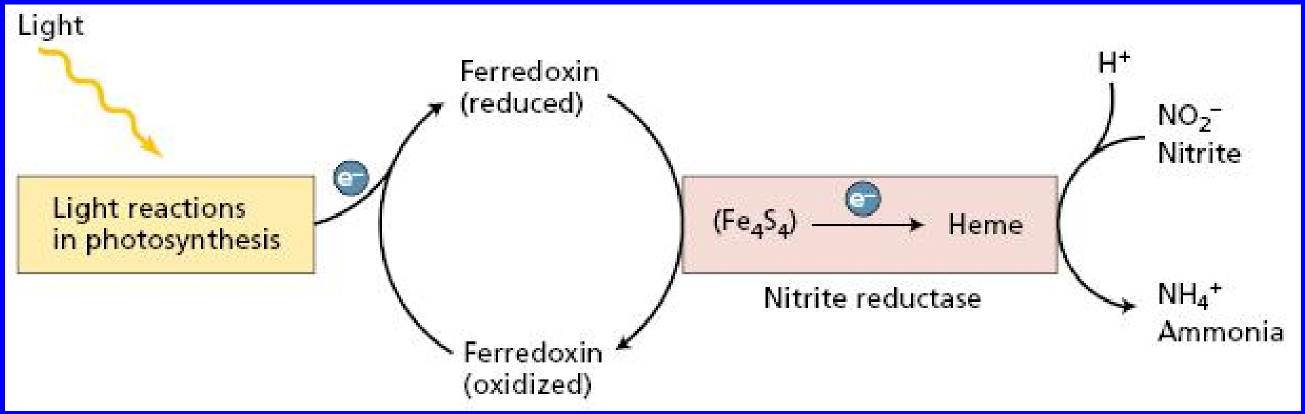
Relative molecular weight: 6.0×10^4-7.0×10^4

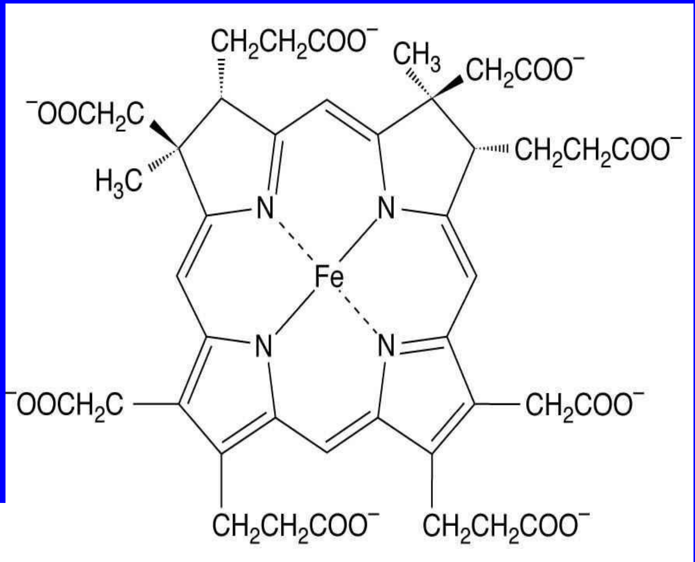
2 subgroups

2 prothetic groups: siroheme - tetrahydroferric porphyrin; iron-sulfur protein Fe_4-S_4 cluster

Structure of nitrite reductase from plants. The N-terminal region oxidizes ferredoxin. The C-terminal region, which binds a 4Fe-4S center and a siroheme group, reduces nitrite to ammonium.





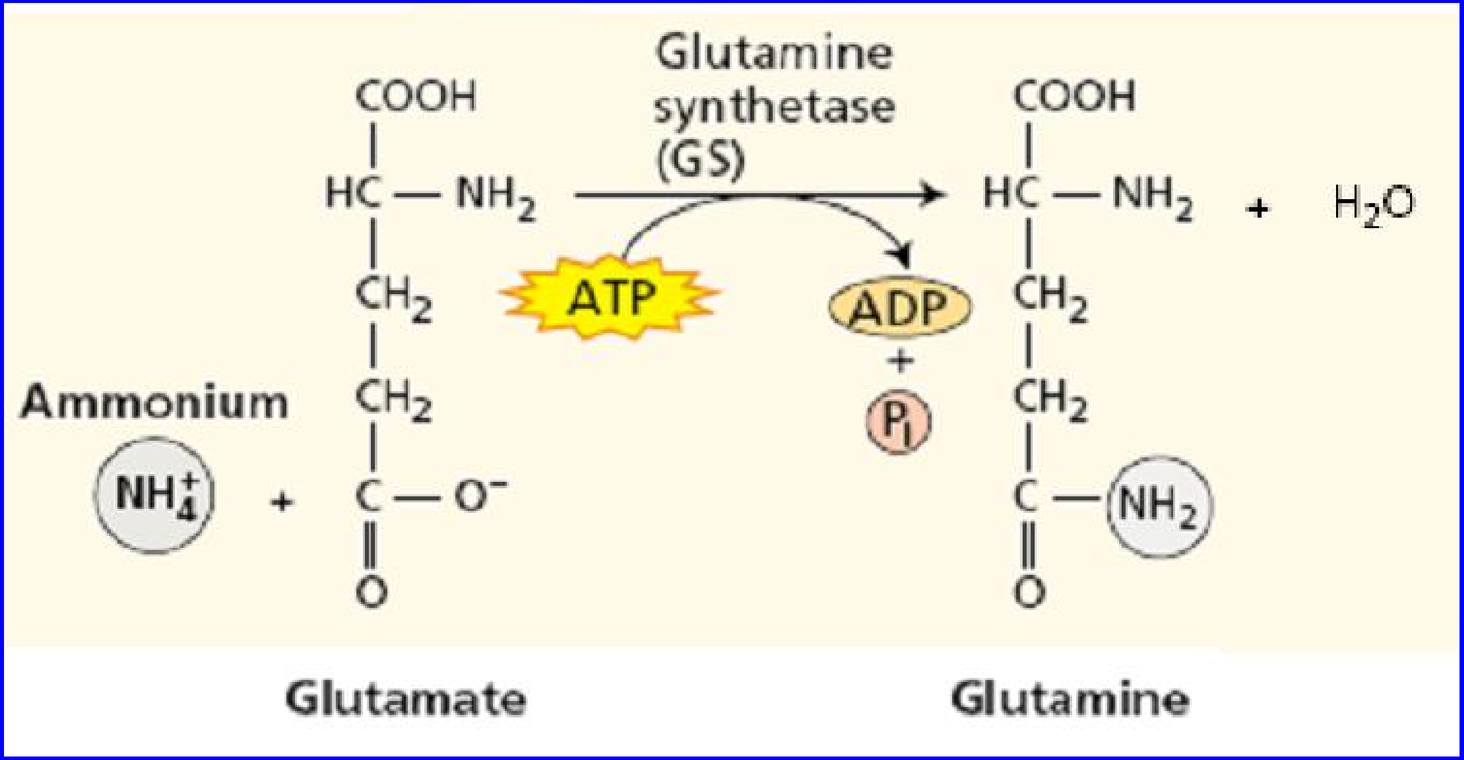


Siroheme

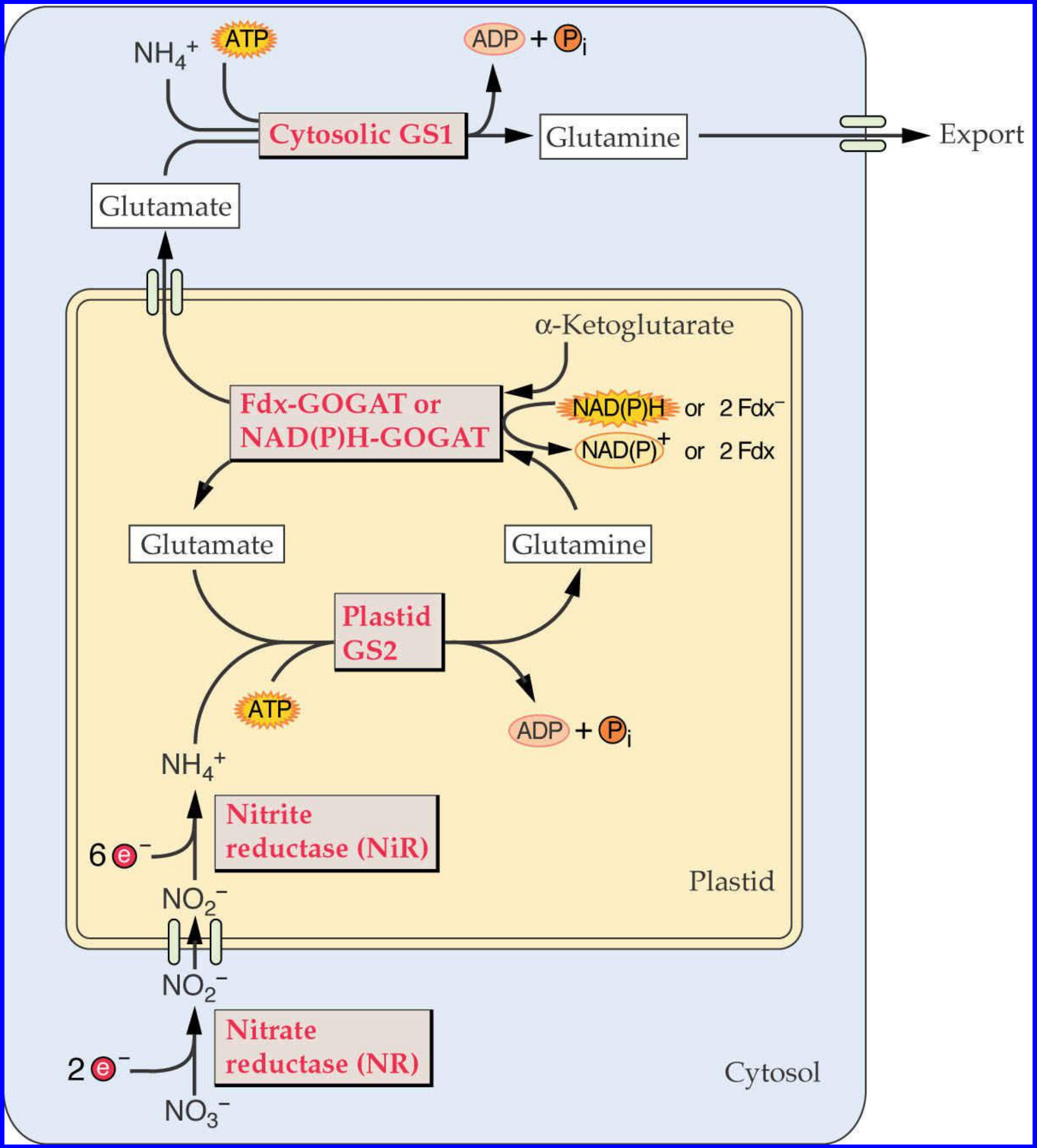
Structure of siroheme prosthetic group.

(II) Assimilation of ammonia

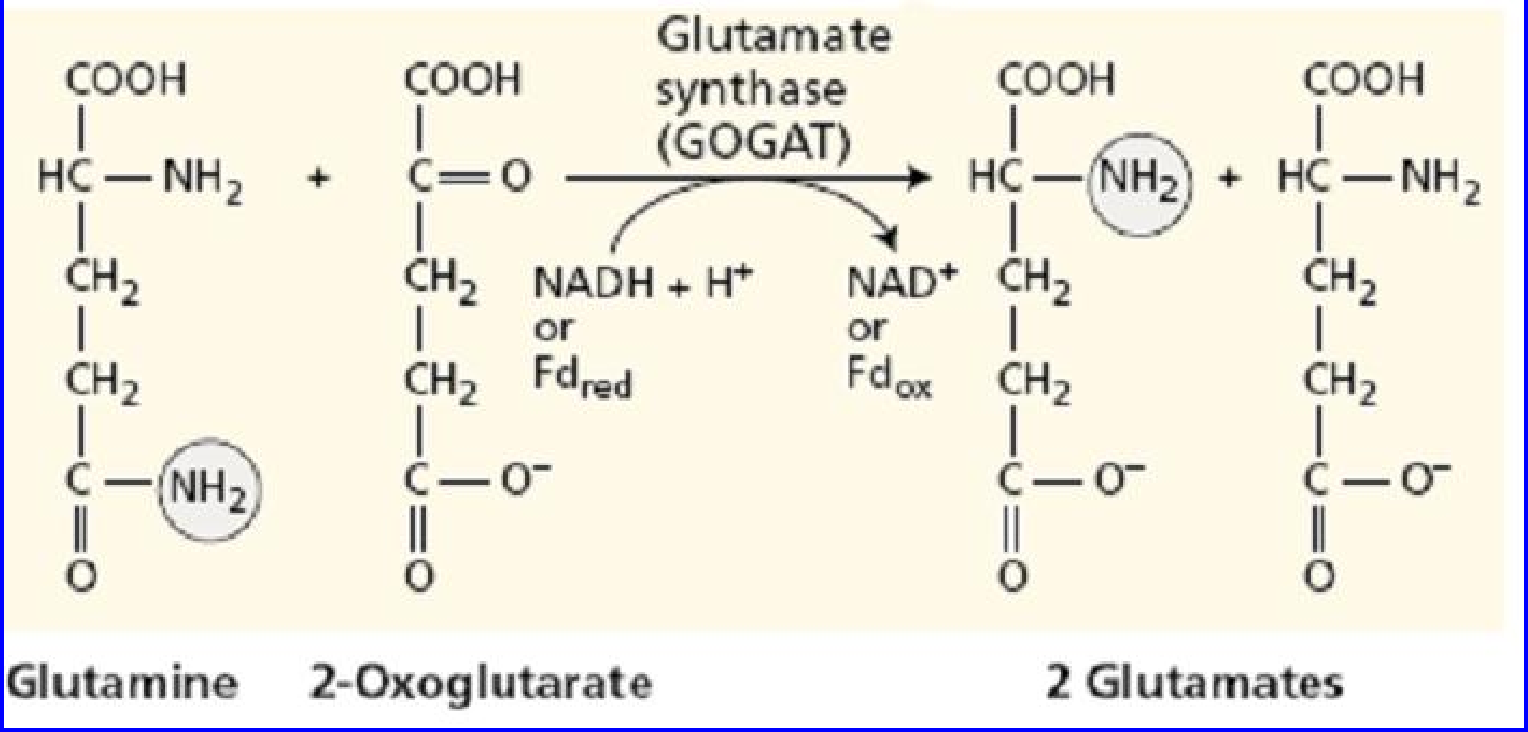
1. Glutamine synthetase : With Mg^{2+}, Mn^{2+} or Co^{2+} as a cofactor, it makes ammonium bound with glutamate to form glutamine. This process is conducted in cytoplasm, root cell plasmid or leaf cell chloroplast.



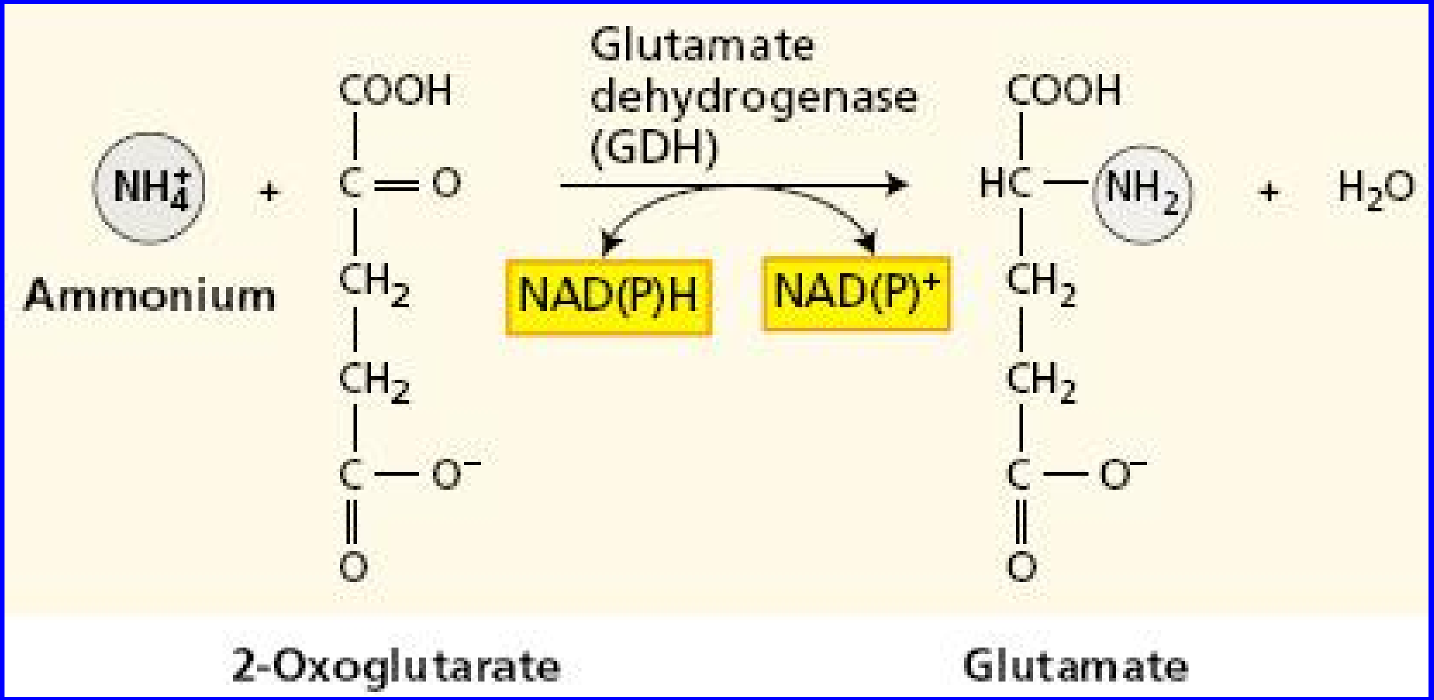
Isoenzymes of glutamine synthetase (GS) are present in both the plastids (GS2) and the cytoplasm (GS1).

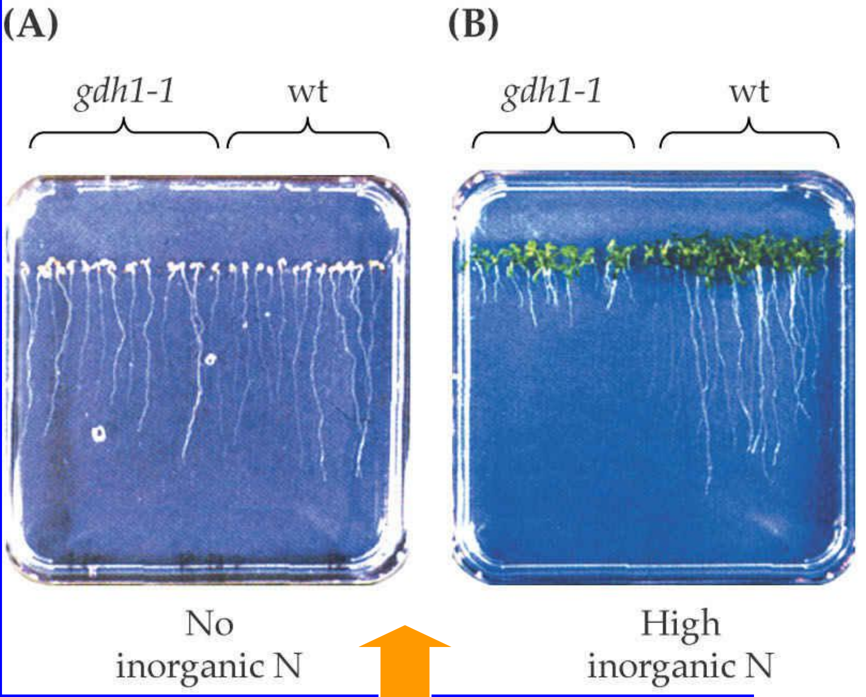


2. Glutamate synthase: This enzyme is also called glutamine -α-oxoglutarate aminotransferase (GOGAT), has two types: NADH and Fdx. and exists in plasmids of root cells, or leaf vascular bundles that are being developed, and chloroplast of leaf cells.



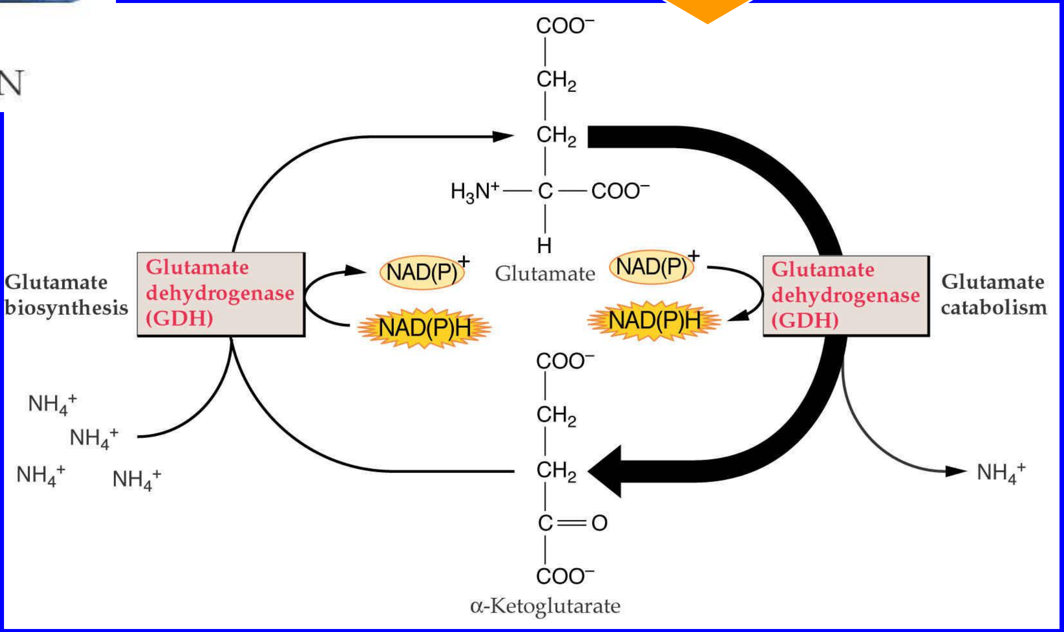
3. Glutamate dehydrogenase: It has low affinity to NH_3 and takes effect only when the concentration of NH_3 is high. It exists in mitochondria and chloroplast.





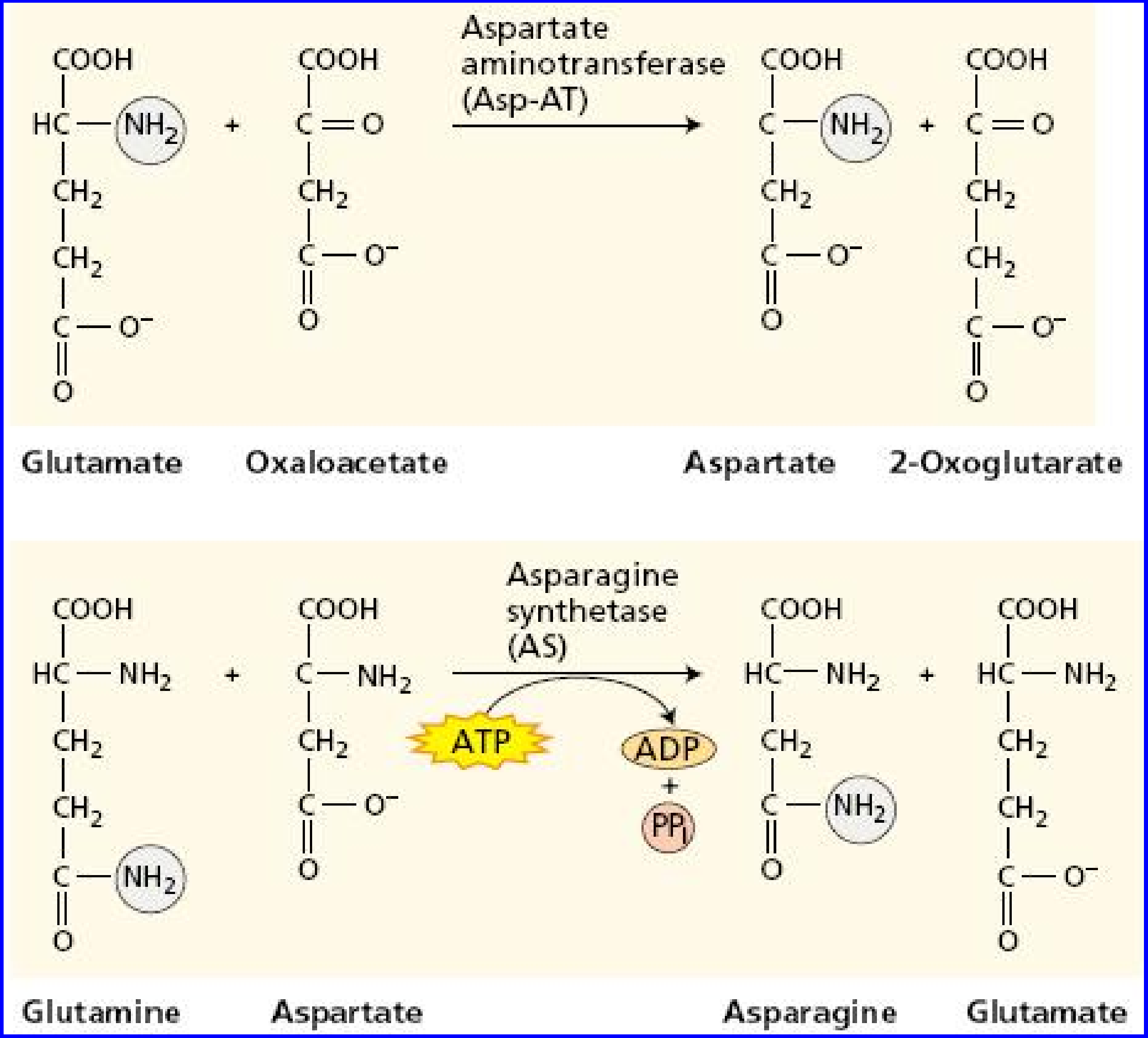
GDH is thought to function primarily in glutamate catabolism but can also assimilate inorganic nitrogen into glutamate when ammonium concentrations are high.

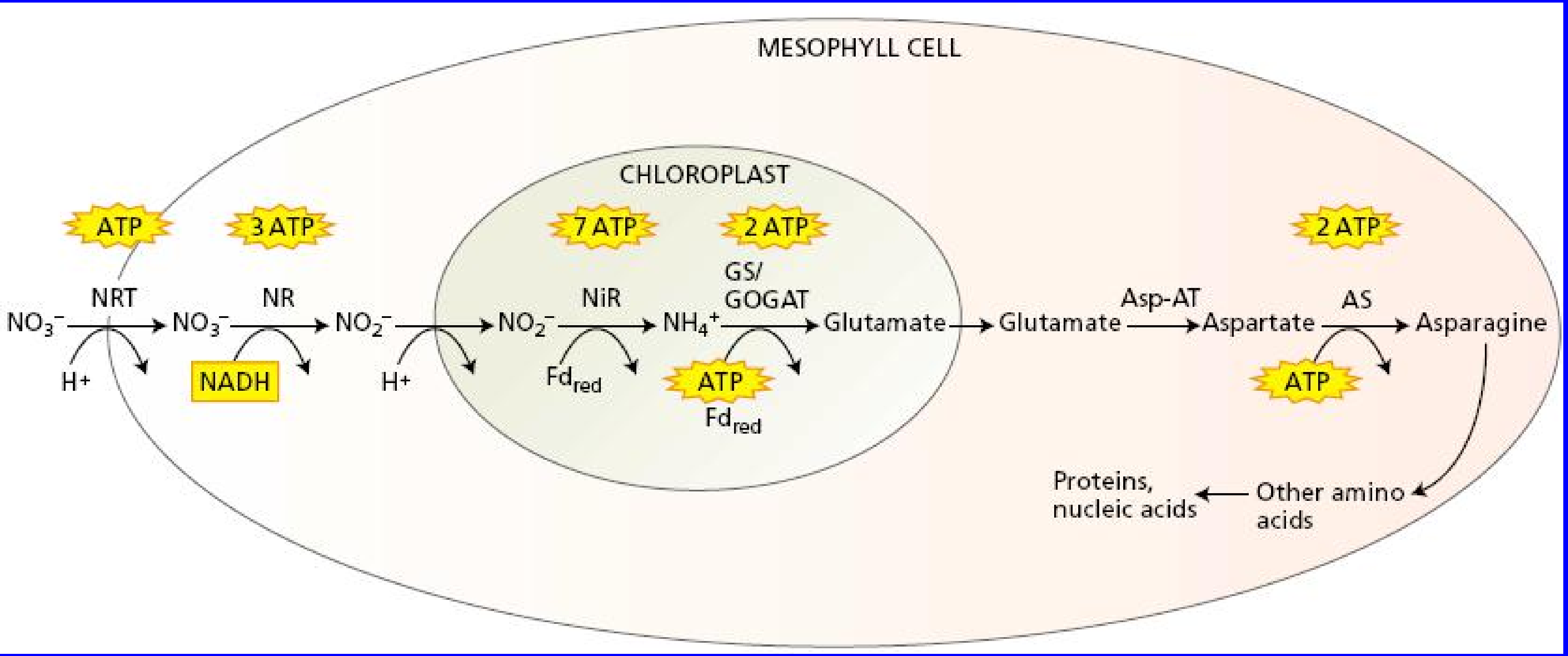
***gdh1*-1 mutant seedlings can grow in the absence of inorganic nitrogen (left), but their growth is inhibited (right) by high nitrogen concentrations.**



4. Transamination

Glu and Gln form other amino acids or amides in cytoplasm, chloroplast, mitochondria, glegoxysome and peroxisome through transamination. Pyridoxal phosphate needs to be used as a coenzyme.





Summary of the processes involved in the assimilation of mineral nitrogen in the leaf. Nitrate translocated from the roots through the xylem is absorbed by a mesophyll cell via one of the nitrate-proton symporters (NRT) into the cytoplasm. There it is reduced to nitrite via nitrate reductase (NR). Nitrite is translocated into the stroma of the chloroplast along with a proton. In the stroma, nitrite is reduced to ammonium via nitrite reductase (NiR) and this ammonium is converted into glutamate via the sequential action of glutamine synthetase (GS) and glutamate synthase (GOGAT). Once again in the cytoplasm, the glutamate is transaminated to aspartate via aspartate aminotransferase (Asp-AT). Finally, asparagine synthetase (AS) converts aspartate into asparagine. The approximate amounts of ATP equivalents are given above each reaction.

(III) Biological nitrogen fixation

1. Concept: A process in which some microorganisms fix the nitrogen in the air and convert it into nitrogenous compounds.

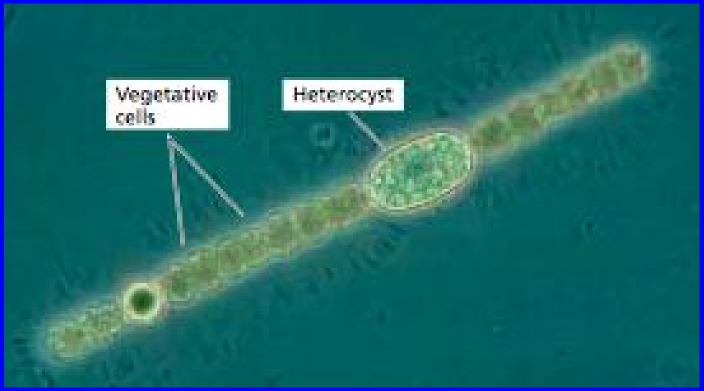
2. Nitrogen-fixing microorganisms :

① Asymbiotic microorganism :

Aerobic bacteria - azotobacter

Facultative anaerobe - Fusobacterium

Blue-green algae



② Symbiotic microorganism - rhizobium, actinomyces and blue-green algae

Photo of legume grown in N-deficient soil. (×3)

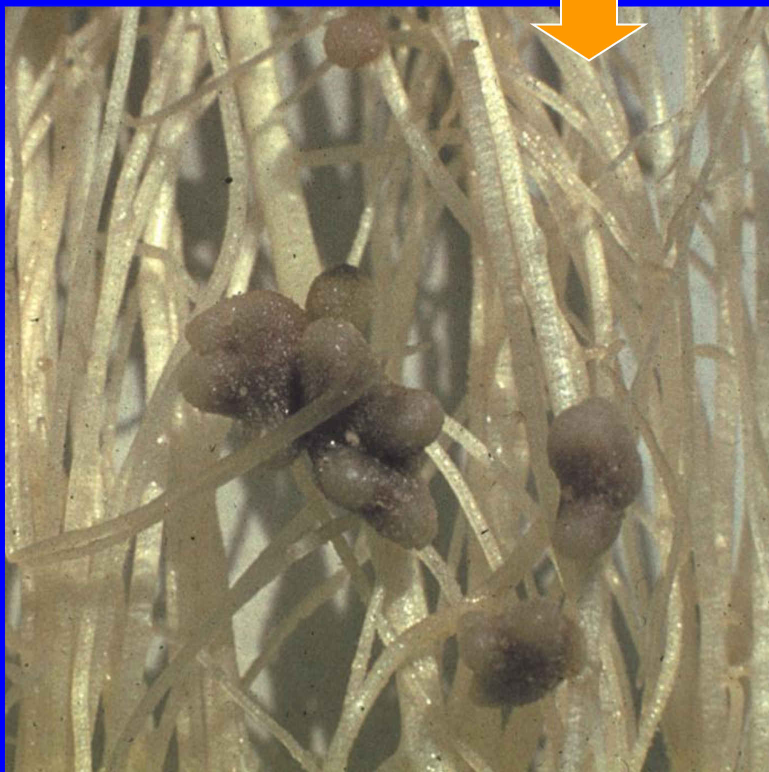


Photo of root nodules on pea. (×7.3)

3. Overall reaction of nitrogen fixation:

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

4. Nitrogenase complex:

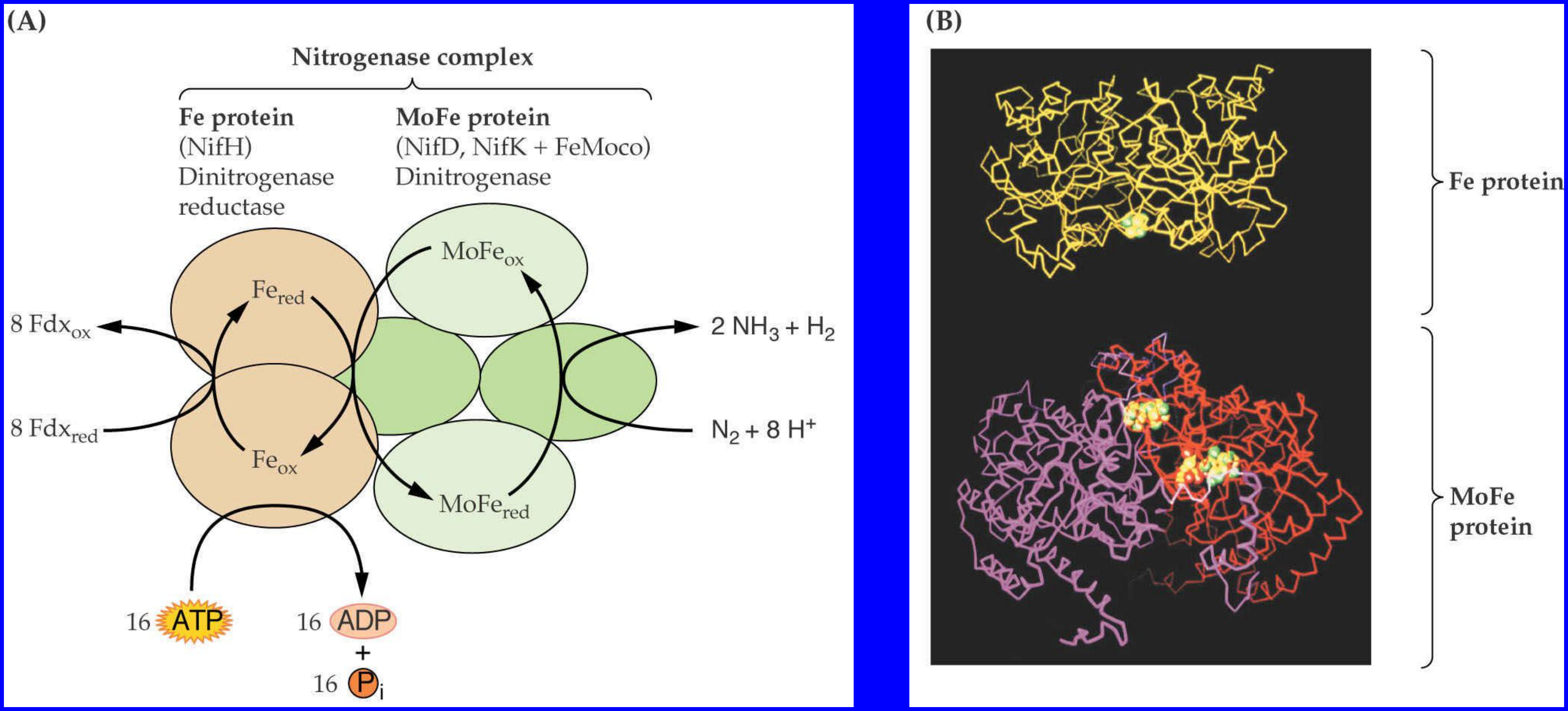
① Ferritin - 2 same subgroups, 3.0×10^4-7.2×10^4, a Fe_4-S_4 cluster, attend redox reaction, hydrolyze ATP, reduce molybdoiron protein and can be bound with two Mg·ATP.

② MoFe protein - 4 subgroups, 1.8×10^5-2.35×10^5, have FeMoco, are active catalytic sites and reduce N_2 to NH_3.

③ Activity appears only when the above two parts co-exist.

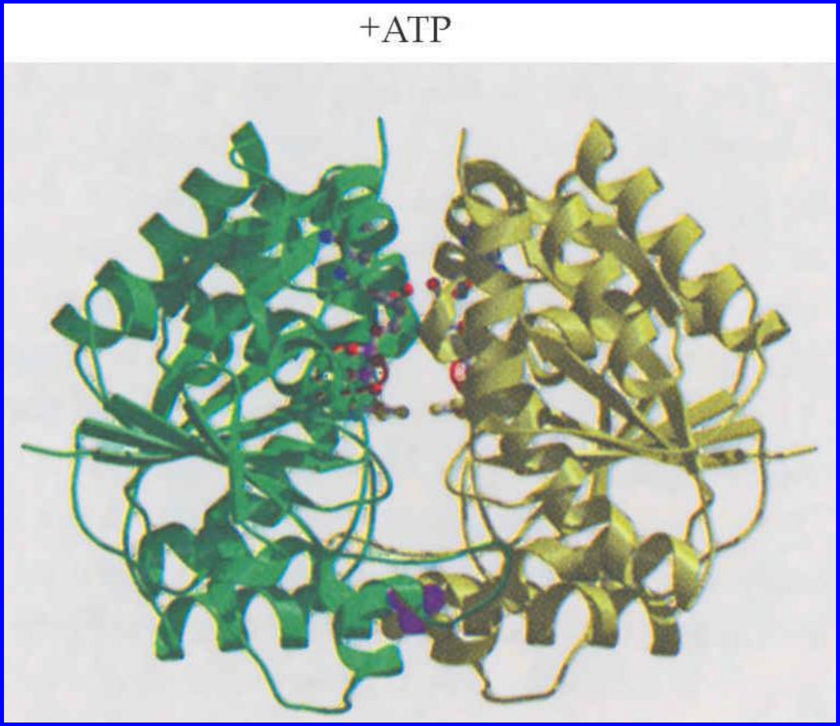
④ Nitrogenase complex will be soon inactivated after meeting O_2.

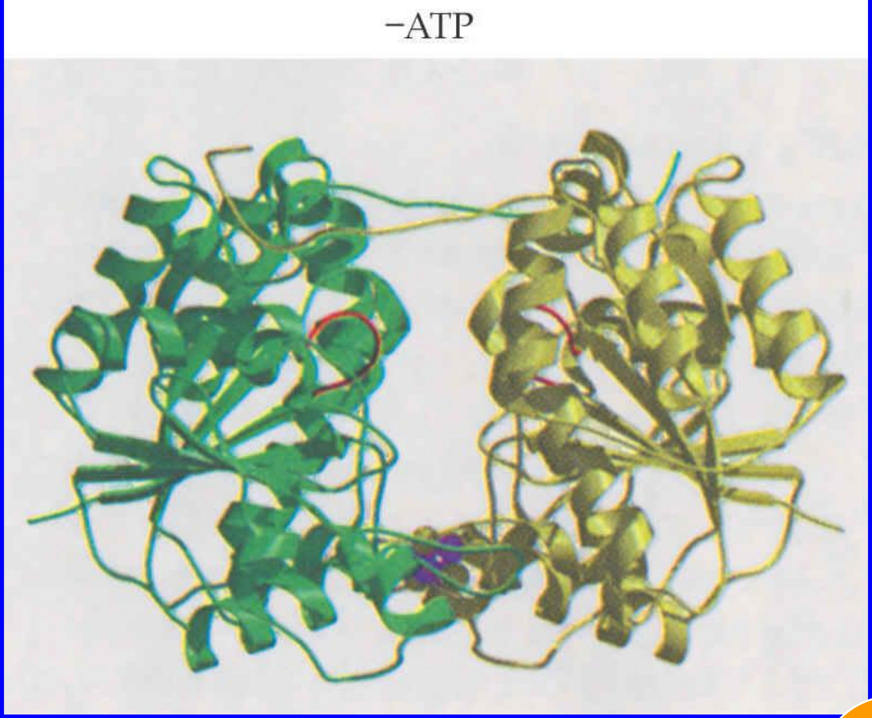
⑤ It may reduce H^+ to give out H_2. With the existence of hydrogenosome, H_2 may reduce Fdx to form circulation of electron transport.



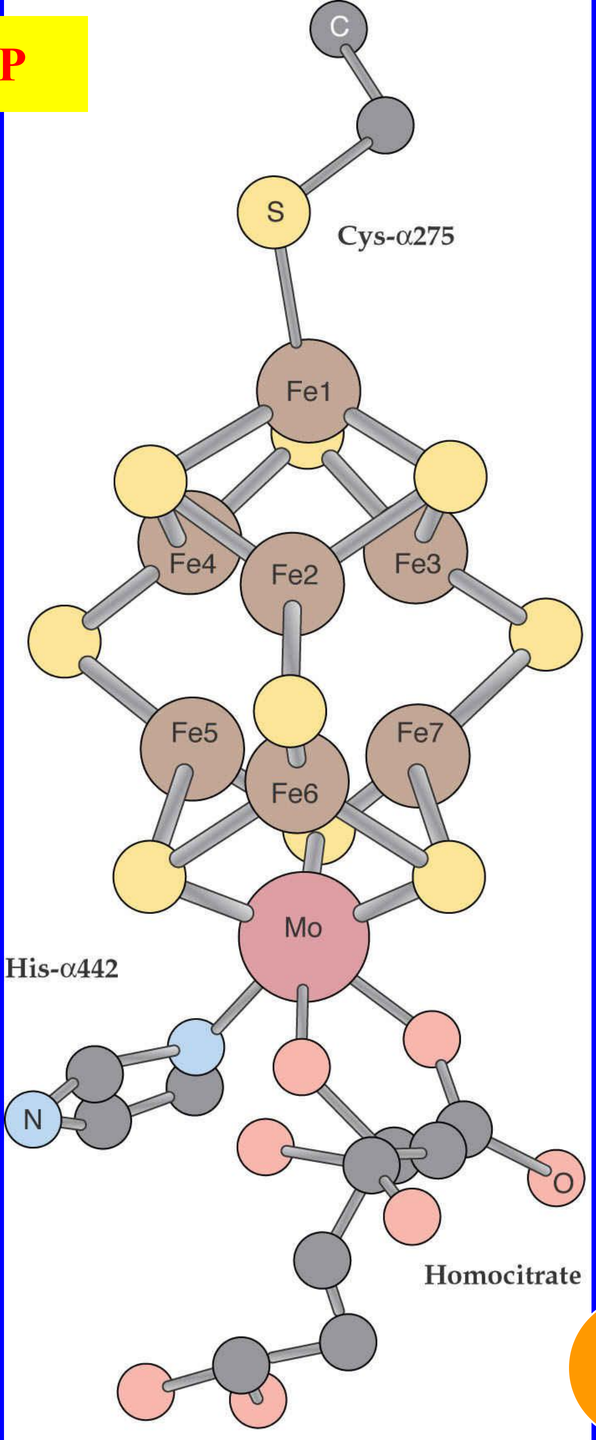
(A) Schematic diagram of the nitrogenase complex, showing the flow of reducing power and substrates in enzymatic nitrogen fixation. (B) Docking of the nitrogenase Fe protein dimer (yellow) with half of the nitrogenase MoFe protein (red, nifD; purple, nifH).

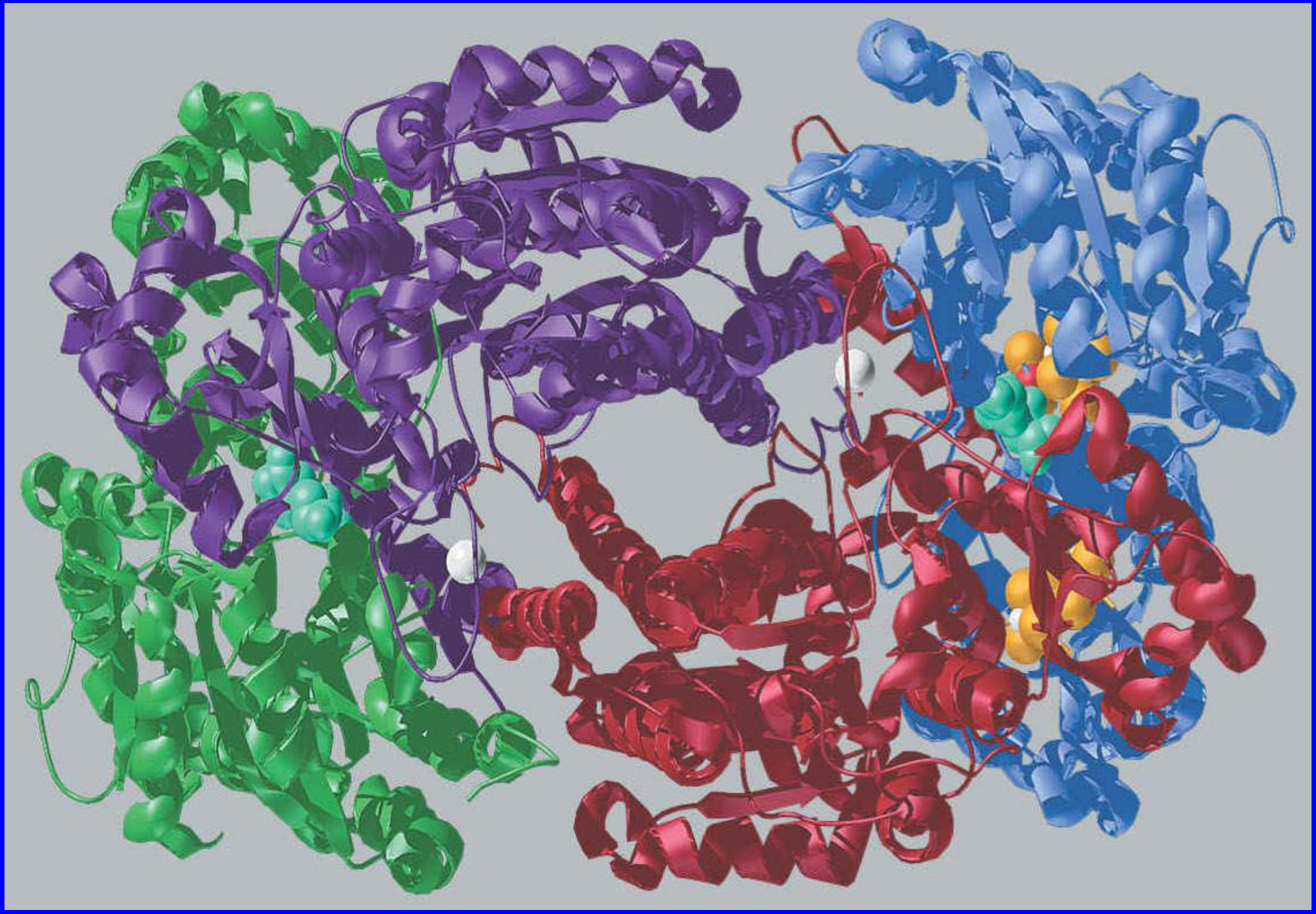
Binding of ATP changes the conformation of nitrogenase Fe protein from *Azotobacter vinelandii*. (4Fe-4S cluster, purple)





Molecular model of molybdenum iron cofactor (FeMoCo). The MoFe type of nitrogenase is present in all symbiotic bacteria, including *Rhizobium* and *Bradyrhizobium*.





Ribbon structure of dinitrogenase (MoFe-protein). The two *nif*K protein subunits (green, blue) in dinitrogenase associate with each other through the interaction of *nif*D protein subunit (red, purple).

Substrates and products of nitrogenase.

Substrate	Common name	Product(s)
N_2	Dinitrogen	NH_3 (ammonia)
H^+	Hydrogen ion	H_2 (hydrogen gas)
N_2O	Nitrous oxide	N_2, H_2O
CN^-	Cyanide	NH_3, CH_4 (methane)
CH_3NC	Methyl isocyanide	CH_3NH_2 (methylamine), CH_4
N_3^-	Azide	N_2, NH_3
C_2H_2	Acetylene	C_2H_4 (ethylene), C_2H_6 (ethane)
H_2NCN	Cyanamide	NH_3, CH_3NH_2
C_3H_4	Cyclopropene	C_3H_6 (cyclopropane)
CH_2N_2	Dazirine	NH_3, CH_3NH_2

II. Assimilation of S

1. Location of assimilation: Root and aerial part
2. Overall reaction:

   $SO_4^{2-}+ATP+8e^-+8H^+ \rightarrow S^{2-}+ADP+4H_2O$

3. Activation of SO_4^{2-}: APS (a product of sulfate reduction), PAPS (a form of activated sulfate in cells)
4. APS is reduced to S^{2-}:

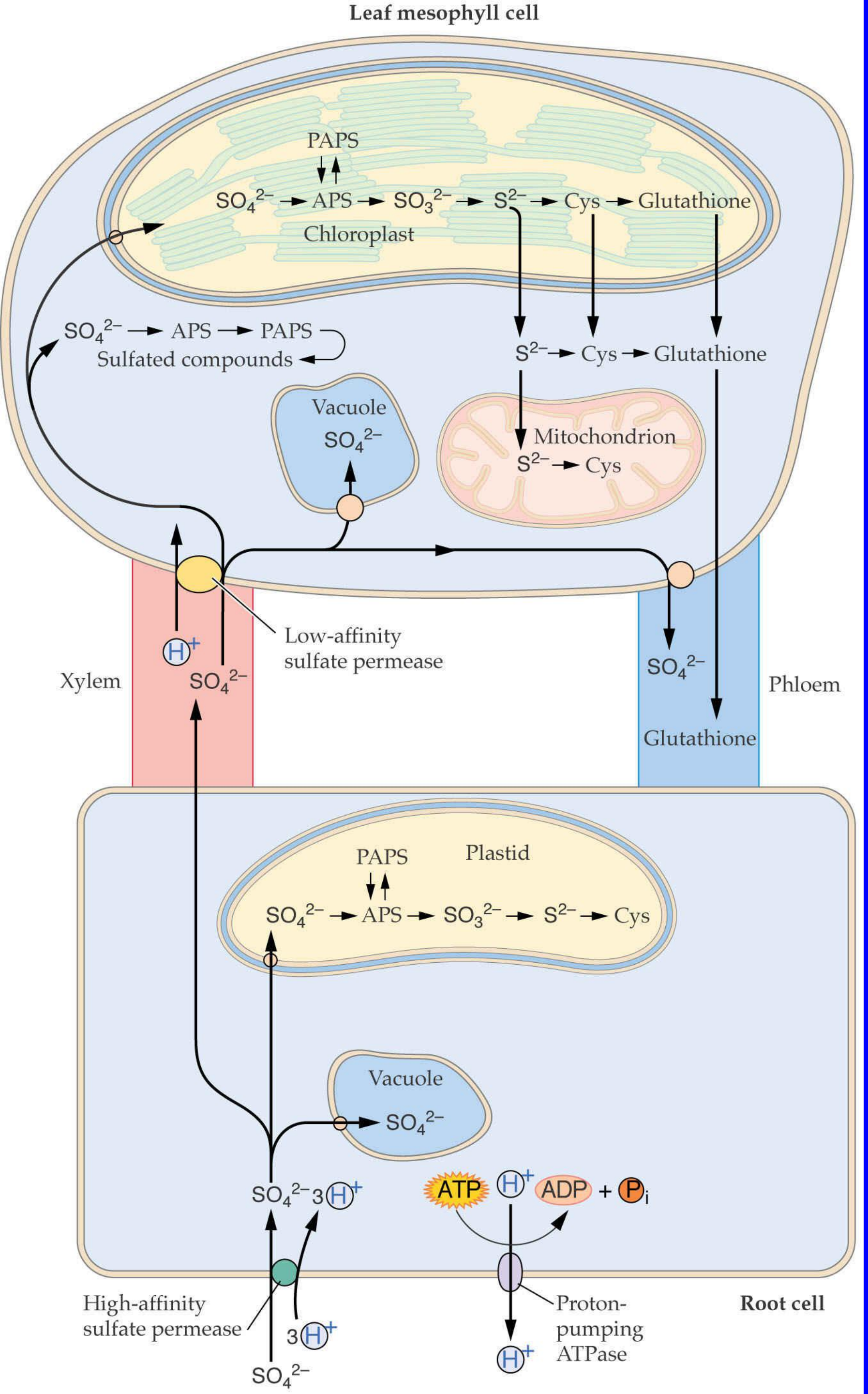
   $APS+2GSH \Rightarrow SO_3^{2-}+2H^++GSSG+AMP$

   $SO_3^{2-}+6Fdx_{red} \Rightarrow S^{2-}+6Fdx_{ox}$

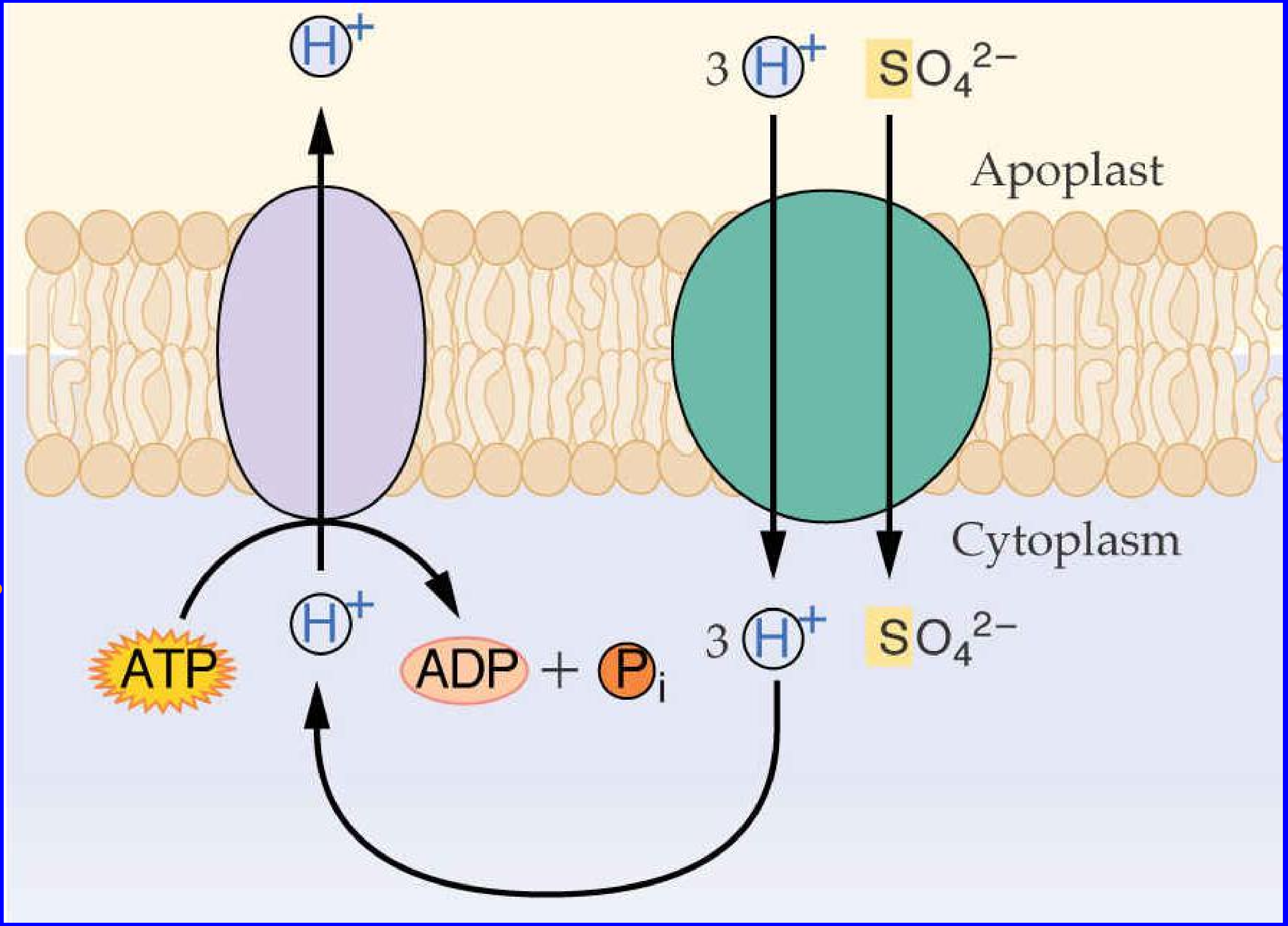
5. S^{2-} synthesizes Cys: $Ser+acetyl\text{-}CoA \Rightarrow OAS+CoA$

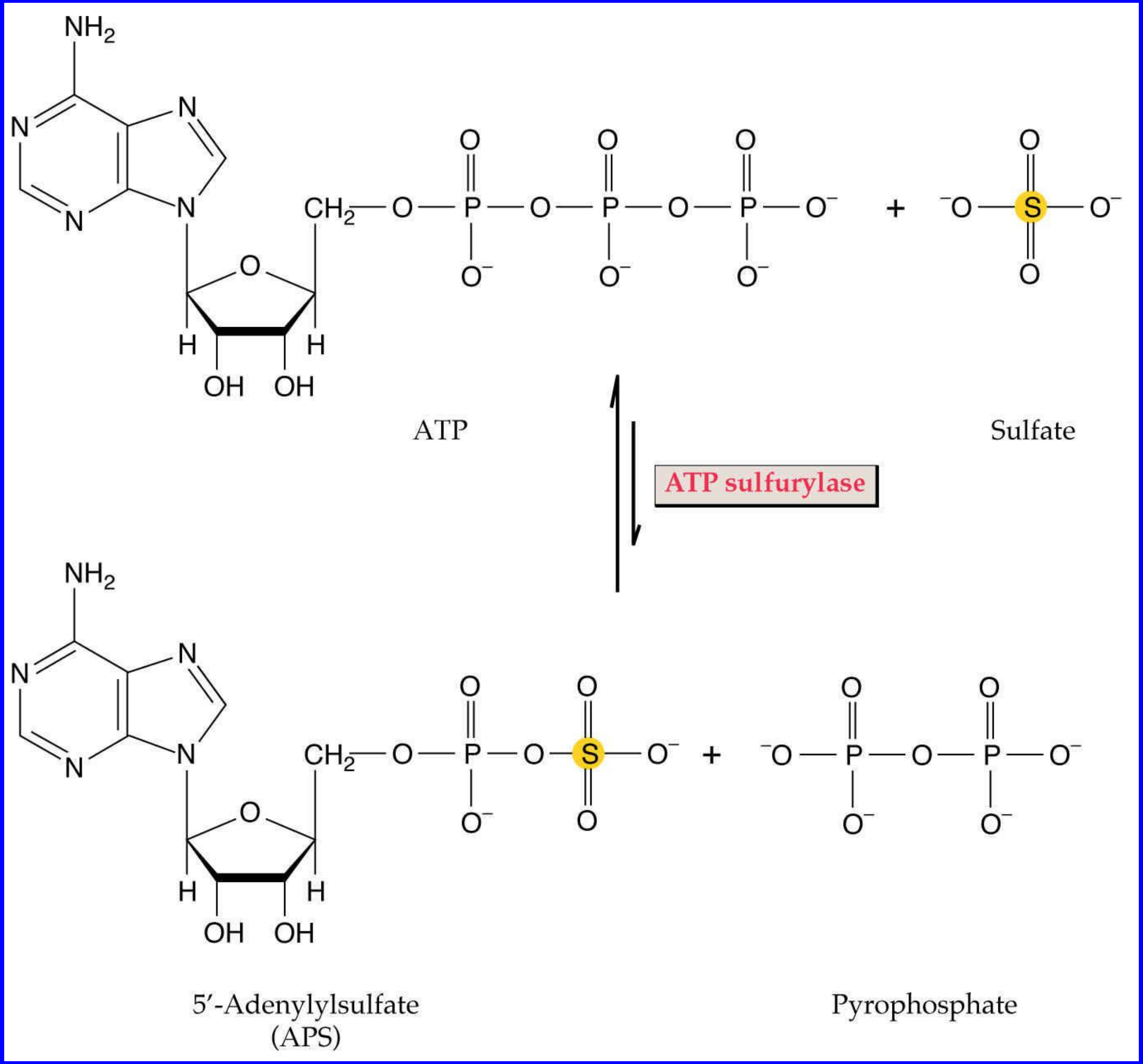
   $OAS+S^{2-} \Rightarrow Cys+Acetate$

Overview of sulfur uptake, reduction, and transport in plants.

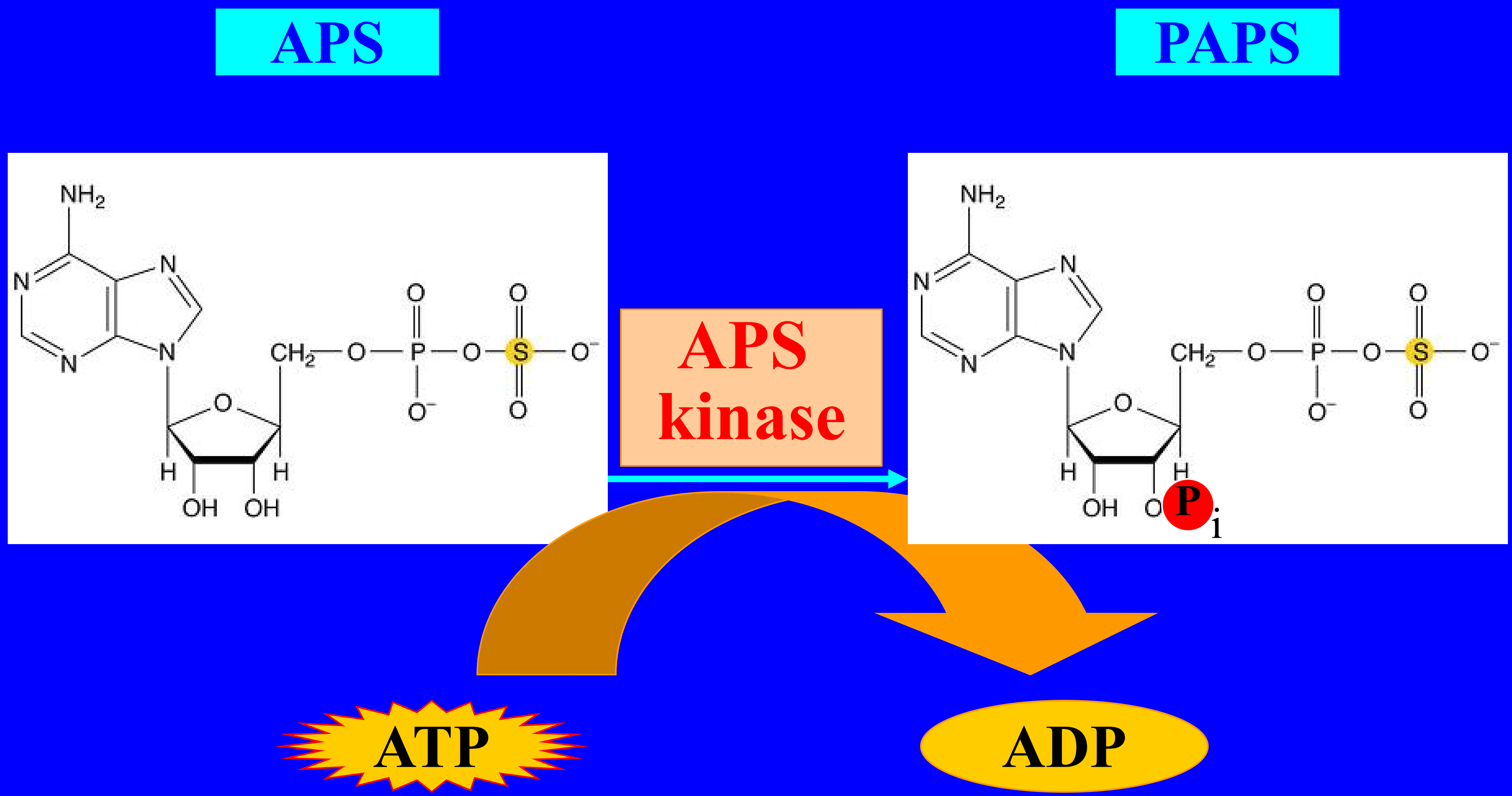


Model for sulfate transport across the plasma membrane.

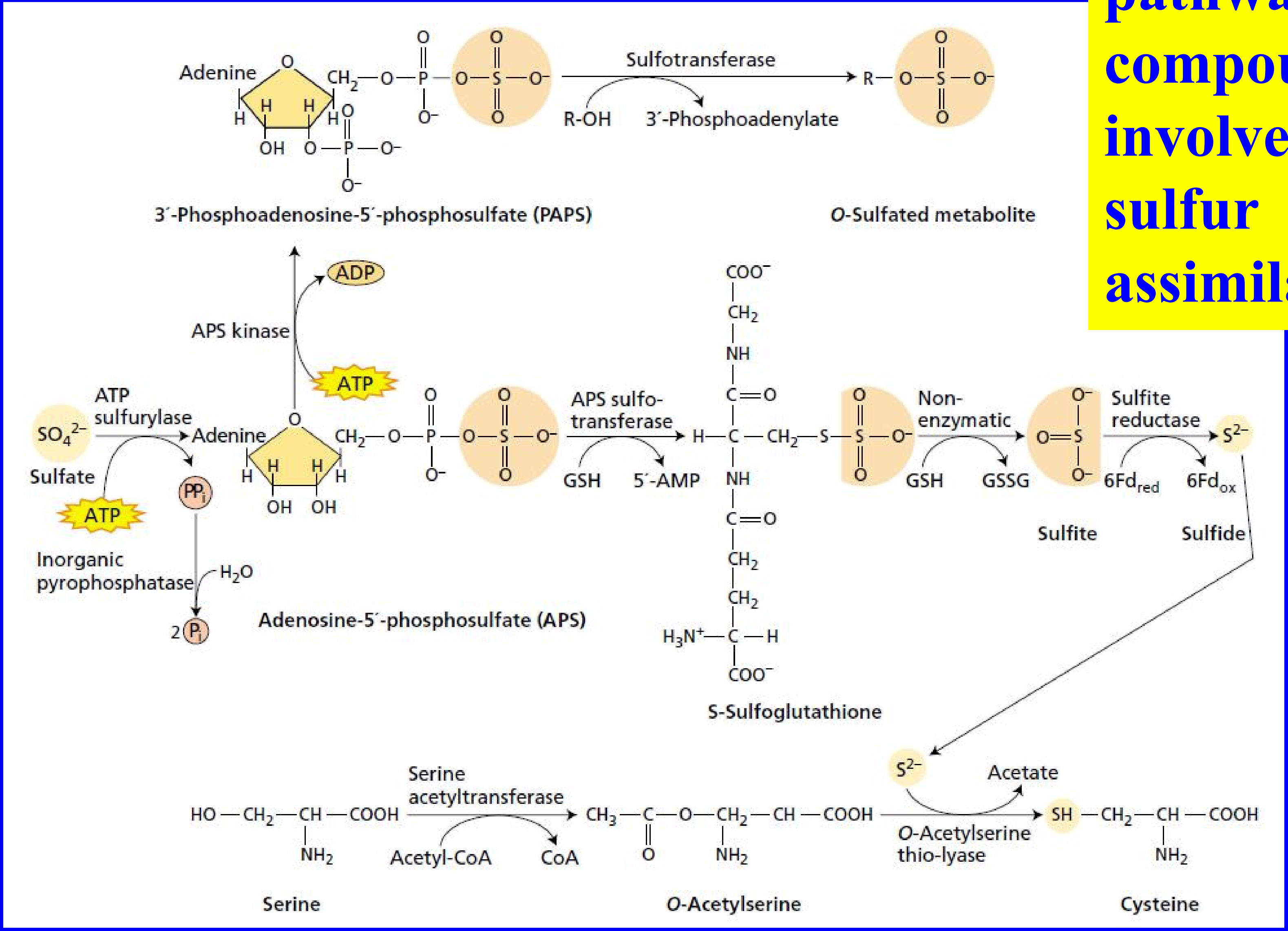




The reaction catalyzed by ATP sulfurylase.


APS
PAPS
NH2
N
N
N
N
O
CH2
O
P
O
S
O⁻
H
H
OH
OH
APS kinase
P
i
ATP
ADP

Structure and pathways of compounds involved in sulfur assimilation.



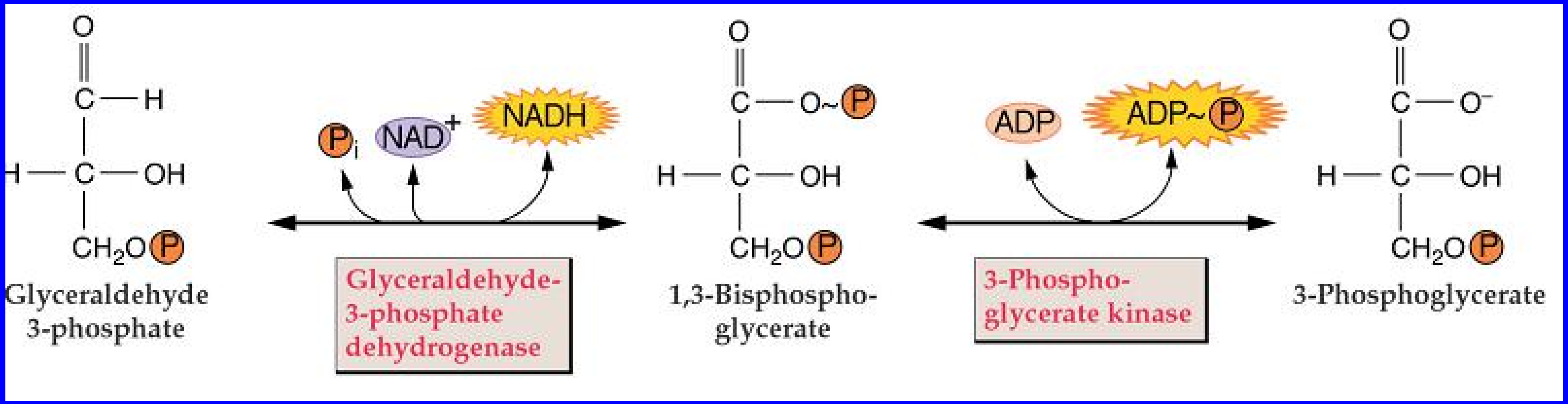
III. Assimilation of Phosphate

1. Location of assimilation: Root and aerial part. Mostly assimilated into organics: Phosphosaccharide, phospholipid and nucleotide
2. A minority of ions are assimilated into ATP: ADP+P_i→ATP+H_2O

① Oxidative phosphorylation (mitochondria)

② Photosynthetic phosphorylation (chloroplast)

③ Substrate level prosphorylation (cytoplasm)



I. Fertilizer Demand Rule of Crops

1. Different crops show different requirements for absolute amount and relative ratio of N, P and K elements.
2. Different edible parts of crops have different relative needed amount for elements (cereal - P; tuber - K; leaf vegetable - N)
3. For a same crop, the contents of the three elements also vary with variety, soil and culture conditions.
4. In different growing stages, a same crop absorbs mineral elements differently and has a significant difference in fertilization effect.

II. Indicators of Reasonable Top Dressing

(I) Morphological indicators of top dressing

External shape reflecting fertilizer demand condition of plants

1. Appearance: When nitrogen fertilizer is sufficient, the plants grow fast, the leaves are long and soft and the plant shape is loose; when nitrogen fertilizer is insufficient, the plants grow slowly, the leaves are short and straight and the plant shape is compact.
2. Leaf color: Dark leaf color means high nitrogen and chlorophyll; light leaf color means low nitrogen and chlorophyll

(II) Physiological indicators of top dressing

Physiological and biochemical changes reflecting fertilizer demand condition of plants

1. Nutrient elements

① When the nutrient elements for leaves are in serious shortage, the yield will be very low; when nutrition is appropriate, the yield is the highest; when nutrition is further increased, the yield will not increase, wasting fertilizer; when nutrition is further added, it will be harmful and cause reduction of yield.

② Different crops, different growing stages and different elements have different critical concentrations (minimum nutrient concentration for maximum yield)

③ Fertilizer formula after soil testing: It is recommended to combine leaf analysis with soil analysis.

2. Amide

The excessive part of N absorbed by crop will be stored in form of amide. The content of Asn in plants or apical leaves is often used as an indicator.

3. Enzymatic activity

The activity of nitrate reductase and glutamate dehydrogenase is used as an indicator.

III. Measures for Giving Scope to Fertilizer Effect

1. Appropriate irrigation

Water is a solvent; also a transport medium; influences crop growth

2. Appropriate deep plowing

Make the soil hold more water and fertilizer; promote development of the root system

3. Improve fertilizer application methods

Deep (5-10 cm) fertilizer application; sufficient base fertilizer, staged top dressing