MEDICAL UNIVERSITY – PLEVEN
FACULTY OF PUBLIC HEALTH
CENTER FOR DISTANCE LEARNING

TOXICOLOGY OF ANTICHOLINESTERASE COMPOUNDS (ANTICHOLINESTERASE PESTICIDES)

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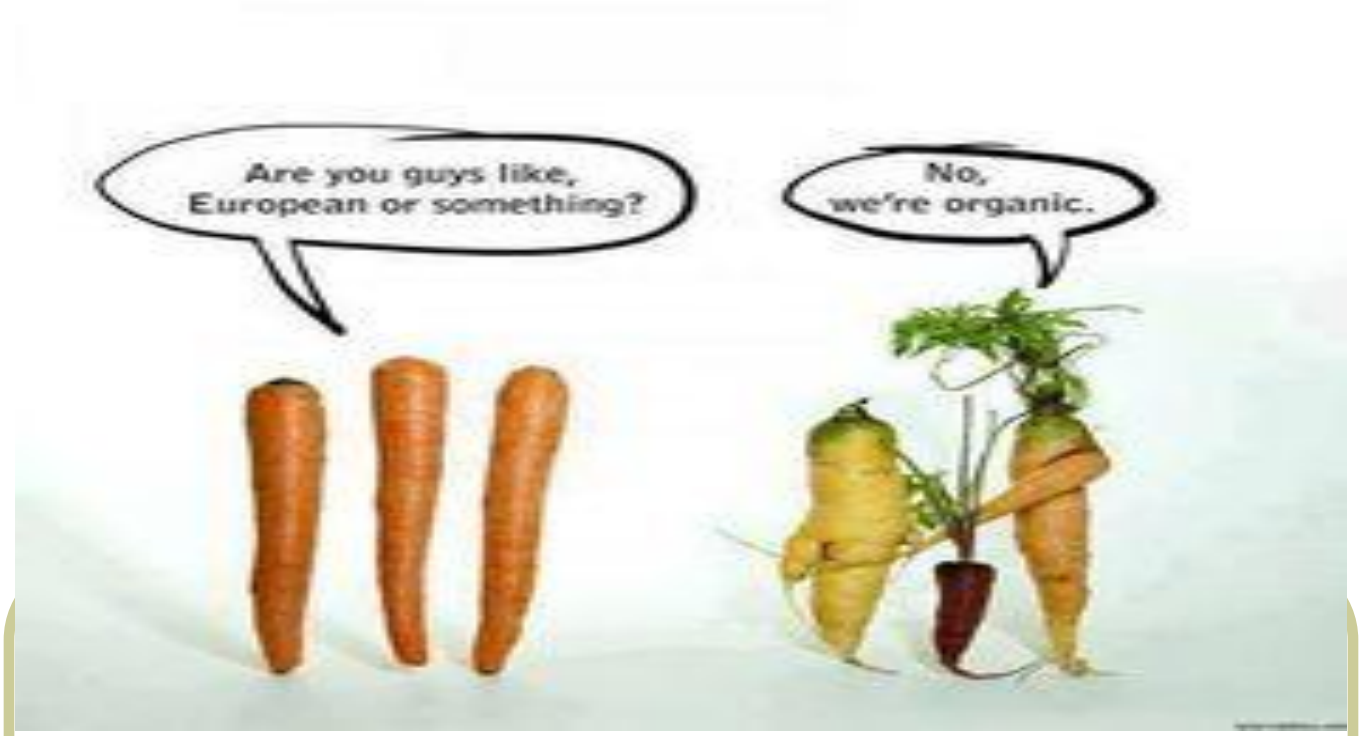
- **The pesticides** are any **substances or mixture** of substances intended **for preventing, destroying or mitigating any pest**.
- The pesticides are usually more specifically classified on the basis of **their use** and **organism killed**:
  - **insecticides**
  - **herbicides**
  - **fungicides**
  - **acaricides**
  - **rodenticides**
  - **defoliants etc.**

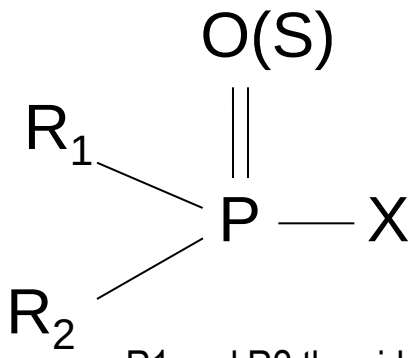
Classes Of Pesticides

- **Insecticides (kill insects)**
  - Organochlorines
  - Organophosphates
  - Carbamates
  - Synthetic Pyrethroids
- **Herbicides (kill plants)**
- **Rodenticides (kill rodents)**
- **Fungicides (kill fungus)**
- **Fumigants (kill whatever)**



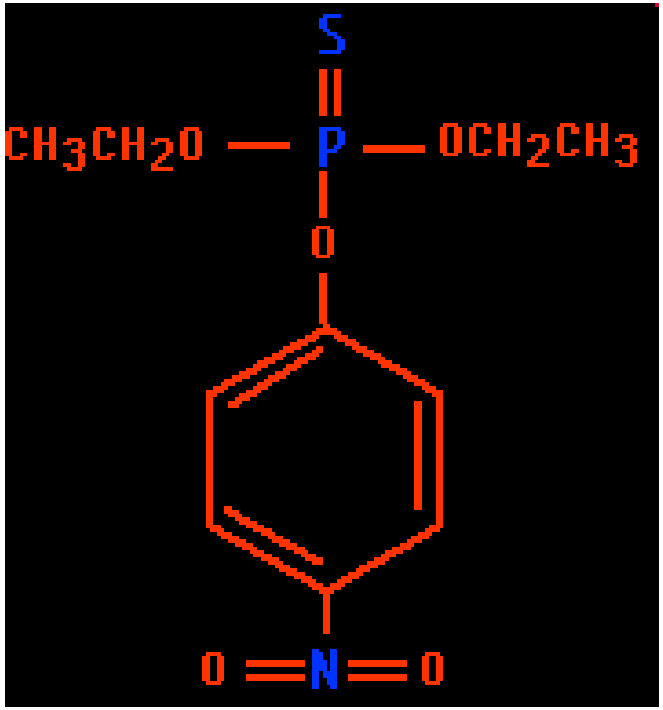
ANTICHOLINESTERASE PESTICIDES

Anticholinesterase pesticides have **a common mechanism** of action, but arise **from two distinctly different chemical classes - the esters of phosphoric or phosphorothionic acid** and those of **carbamic acid**.

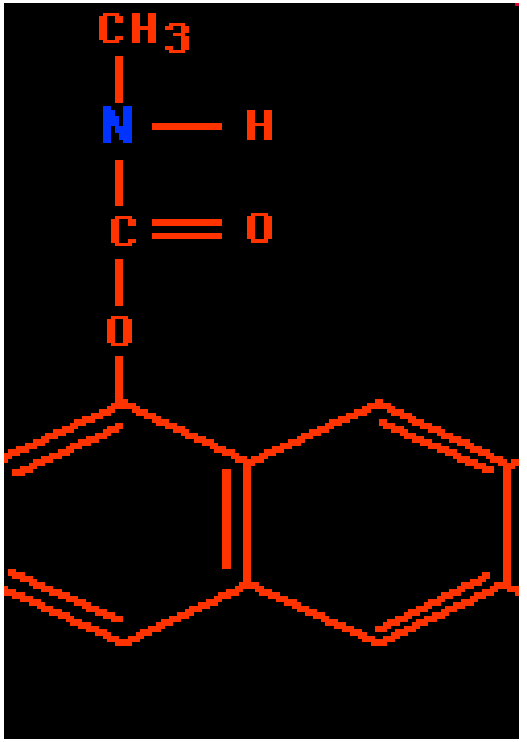


X represents the leaving group, R1 and R2 the side groups, usually alkoxy groups.
In very toxic agents the leaving group contains fluorine (F), which has high tendency to hydrolysis and thus extremely high AcHE inhibition. In less toxic OPs the leaving group usually contains alkyl or aryl groups. The majority of novel OP pesticides possess the thion, P=S.

Pesticides
OPs and Carbamates



Parathion



Carbaryl

Toxicokinetics

- **Absorption** can occur from all body surfaces and especially the **gastrointestinal tract, skin, lungs, and eyes**.
- **Distribution is rapid**, but organophosporus and carbamate products **do not accumulate in the fat depots**.
- It is important to note that:
- **Conditions that promote phase I or mixed function oxydase activity are likely to increase the toxicity of organophosphates** by converting them to the corresponding oxygen analog.
- **Hydrolysis of the ester linkage in organophosphates or carbamates markedly decreases toxicity**.

Mechanism of toxic action

Although the anticholinesteraste type insecticides have a **common mode of action**, there are **significant differences between organophosphorus and carbamate esters**.

There are **two kinds** of **AchE** in the human body.

True cholinesterase is found primarily in the **nervous system** and **red blood cells**.

Butyrylcholinesterase **(BuChE)** or **pseudocholinesterase** is found **in the plasma and liver**. OP insecticides also inhibit its activity. BuChE is not subject to substrate inhibition, because BuChE is an enzyme present at the synaptic cleft that has a less specific activity than AchE

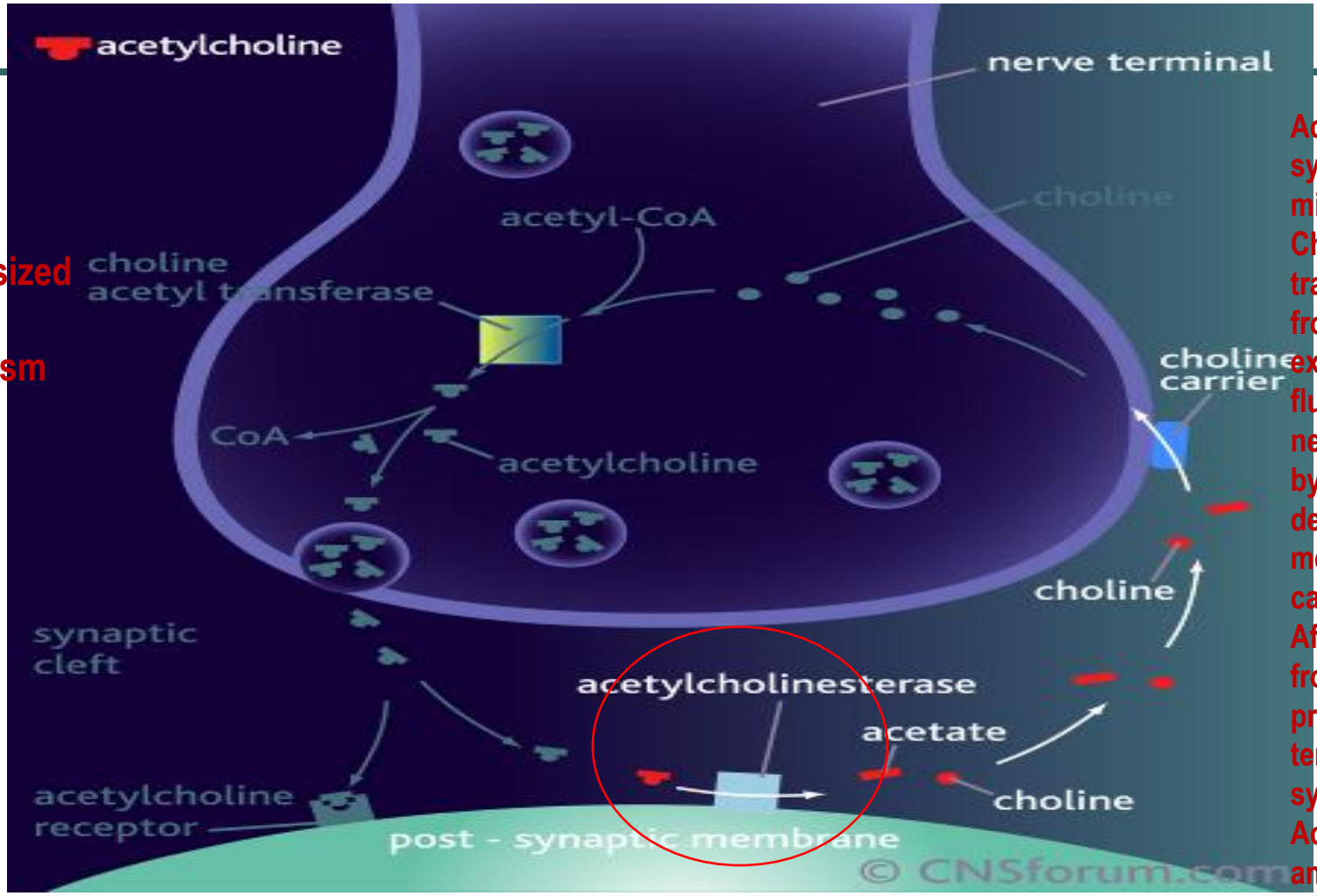
Acetylcholine (Ach) is involved in **neurotransmission** at **motor, autonomic** and **central synapses**.

For **cholinergic neurotransmission to occur properly, acetylcholine must be inactivated rapidly by the enzyme acetylcholinesterase** (AchE).

This removal **prevents repeated stimulation** of the receptors.

Mechanism of OP's

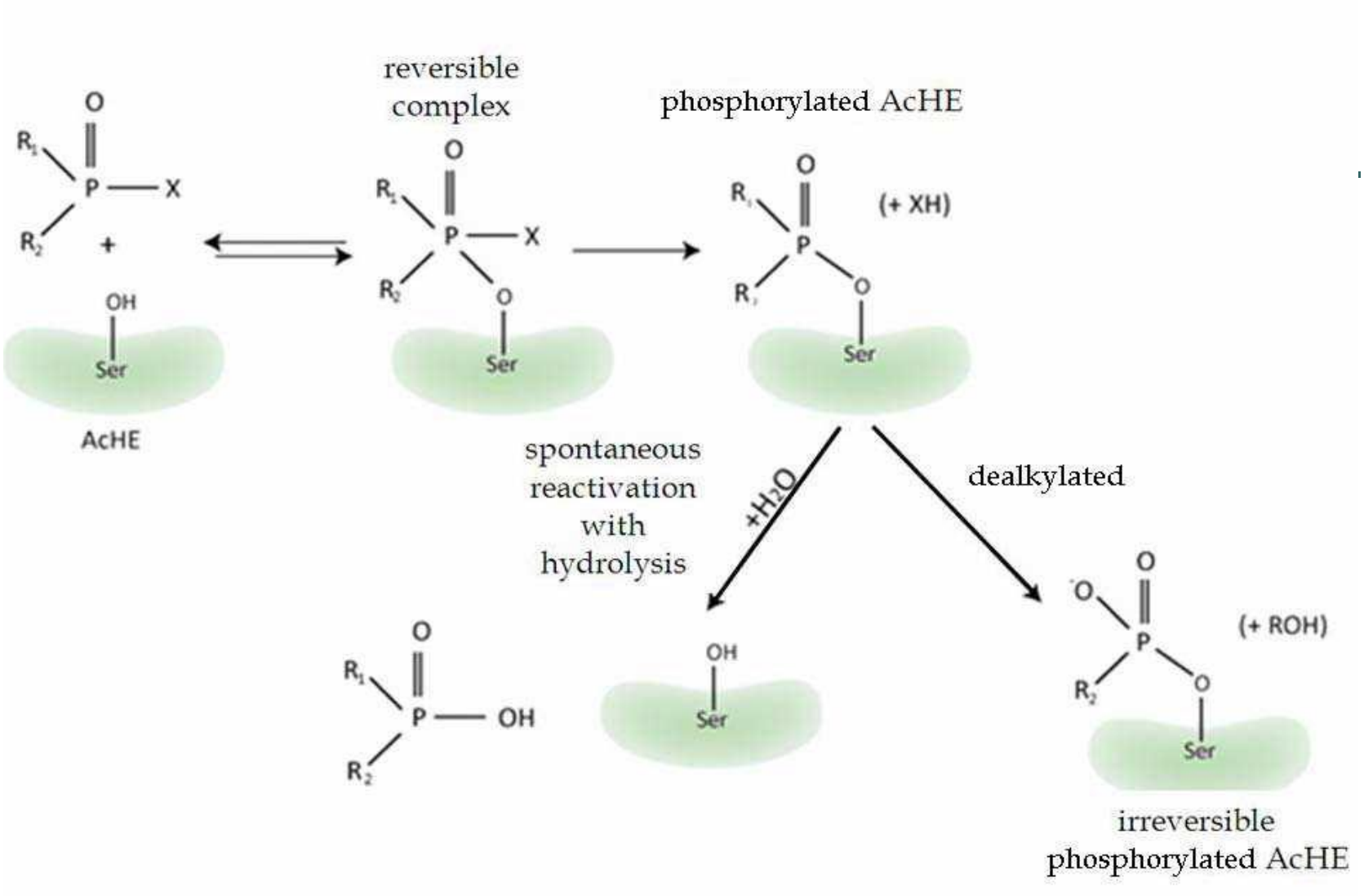
Ach synthesized in the cytoplasm

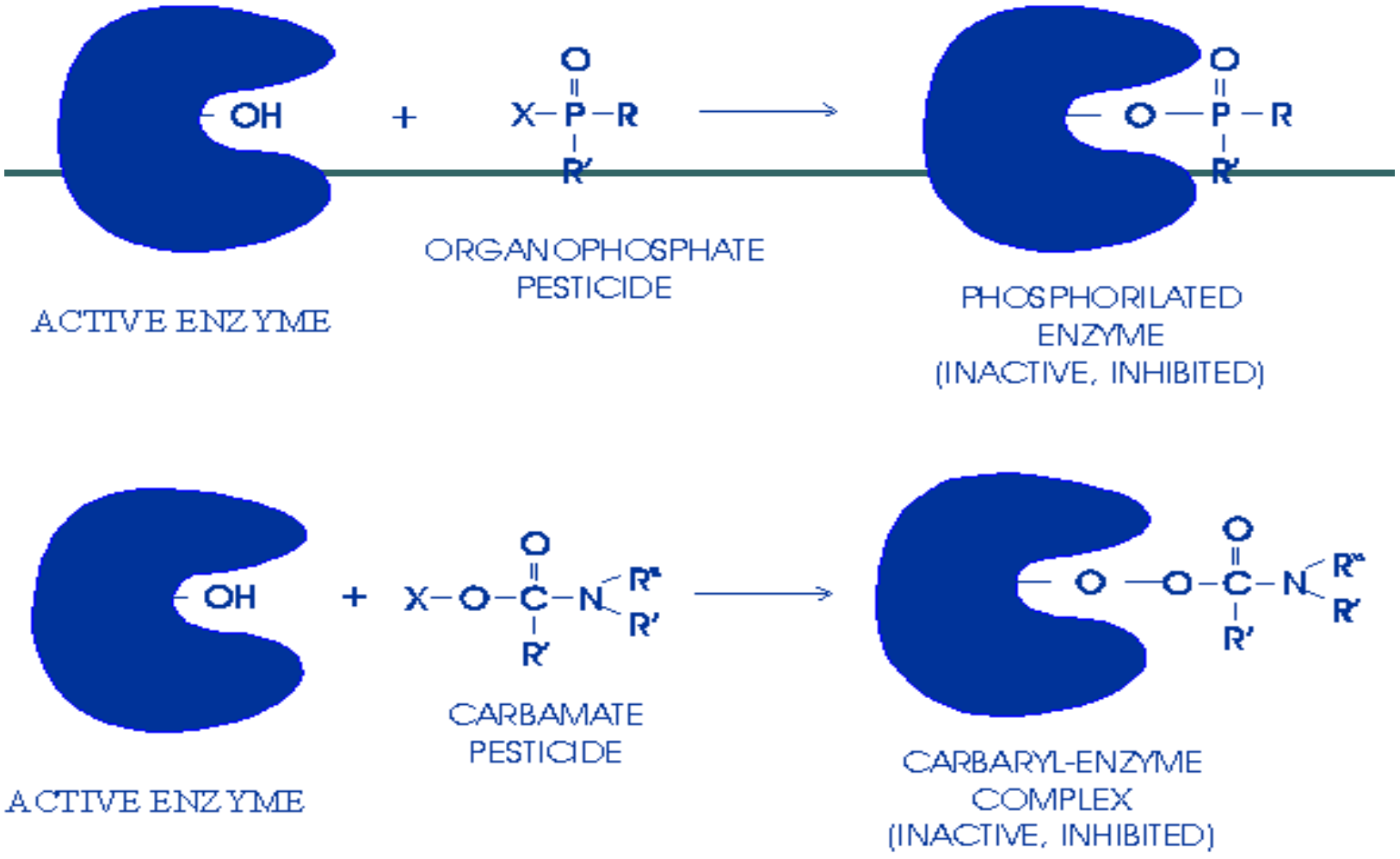


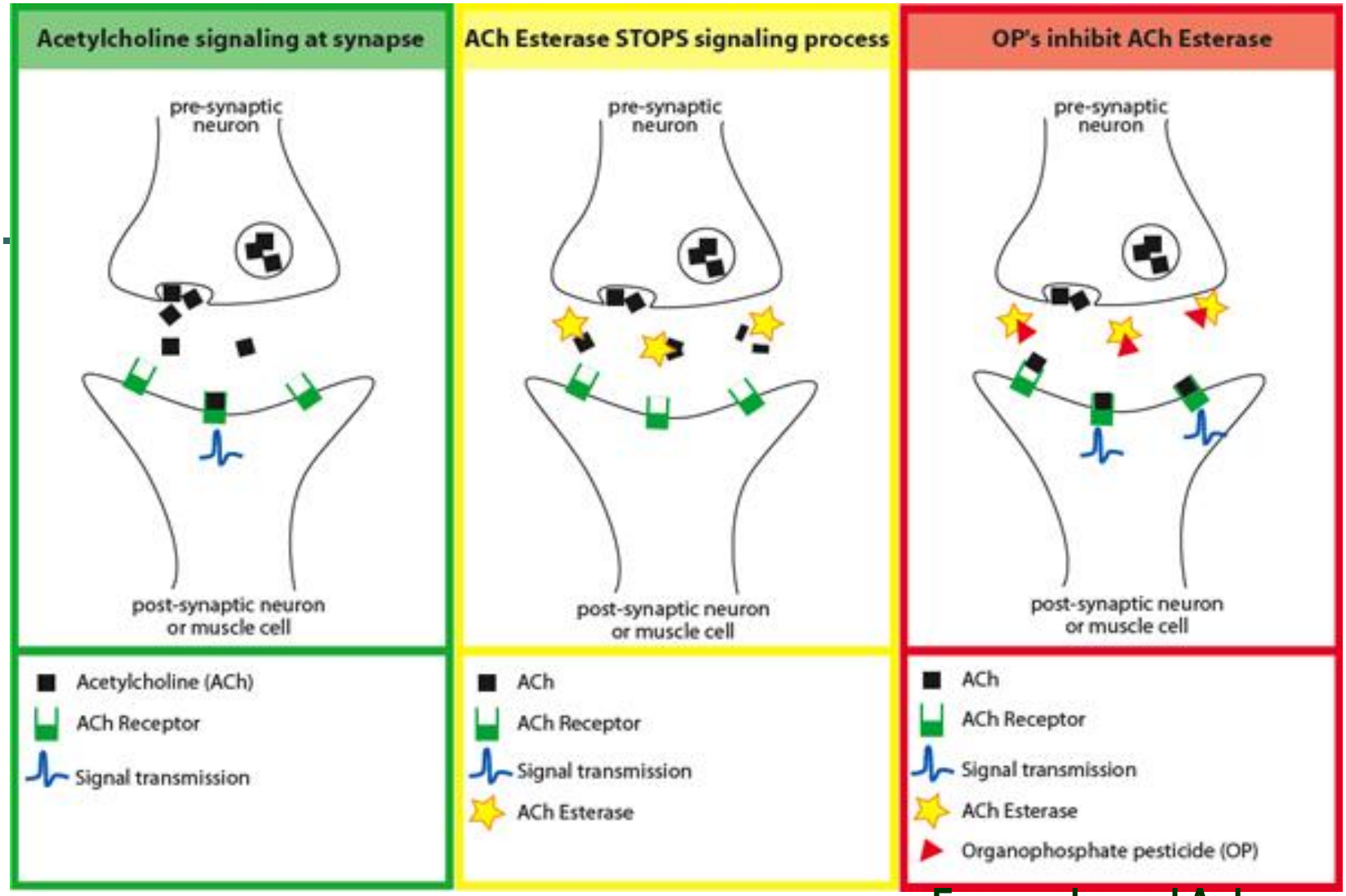
Acetyl-CoA synthesized in mitochondria. Choline is transported from the extracellular fluid into the neuron terminal by Na dependent membrane carrier. After release from the presynaptic terminal into the synaptic cleft Ach may bind to and activate Ach R

Mechanism of toxic action

- The organophosphorus pesticides **phosphorylate** and **inactivate** the enzyme.
- The reaction between the organophosphorus ester and **the active site in acetylcholinesterase protein (a serine hydroxyl group)** results in the formation of **a transient intermediate complex**.
- This complex **partially hydrolyses** leaving **a stable, phosphorylated and largely unreactive**, **inhibited enzyme**.
- Under normal circumstances the enzyme can be reactivated **very slow**.
- So, with many organophosphorus ester insecticides, an **irreversibly inhibited enzyme is formed**, and **the signs and symptoms** of intoxication are **prolonged** and **persistent**.


reversible
complex
phosphorylated AcHE
(+ XH)
AcHE
spontaneous
reactivation
with
hydrolysis
+H2O
dealkylated
(+ ROH)
irreversible
phosphorylated AcHE

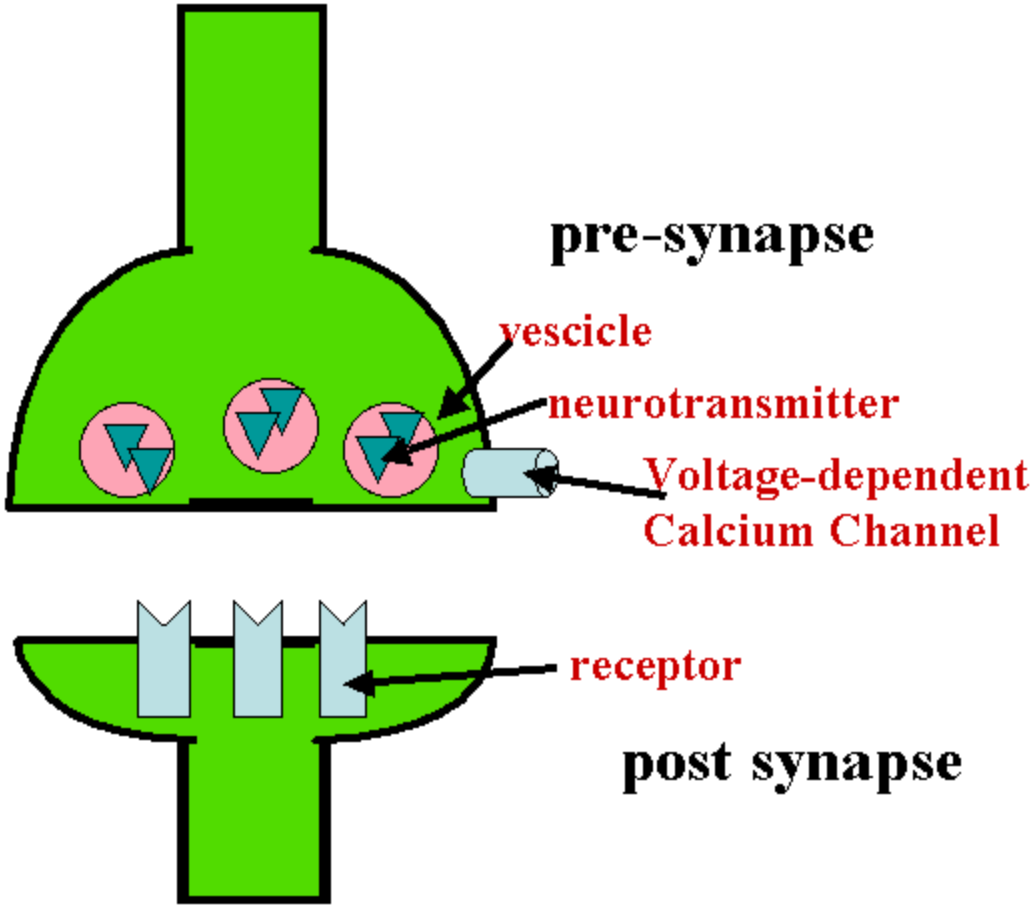

OH
+
X–P(=O)(R)–R′
O
P
R
R′
ACTIVE ENZYME
ORGANOPHOSPHATE PESTICIDE
PHOSPHORILATED ENZYME (INACTIVE, INHIBITED)
OH
+
X–O–C(=O)–N(R″)–R′
R′
ACTIVE ENZYME
CARBAMATE PESTICIDE
CARBARYL-ENZYME COMPLEX (INACTIVE, INHIBITED)



Ach → Choline + Acetate

Free, unbound Ach, continual stimulation of electrical activity

chemical transmission

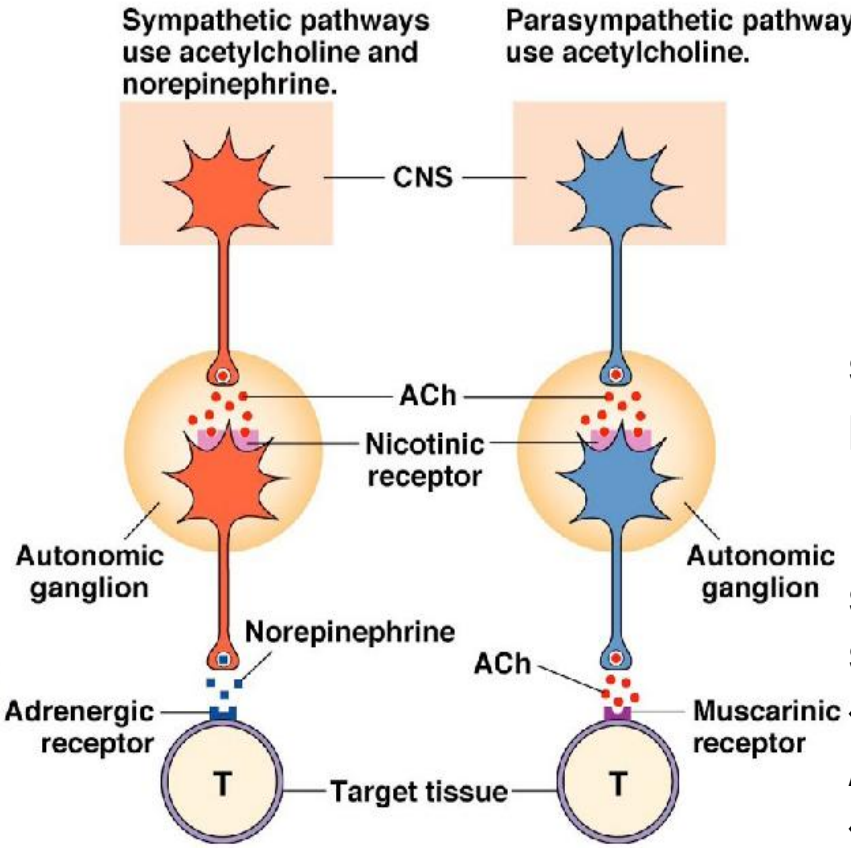


Mechanism of toxic action

- Without intervention, the toxicity will persist until sufficient quantities of **"new" acetylcholinesterase** are synthesized **in 20 to 30 days to destroy** efficiently the excess of acethylcholine.

- In contrast, **carbamic acid** esters attaching to **the reactive site** of the **acetylcholinestarase** undergo **hydrolysis** very quickly and the enzyme activity **is recovered** soon.
- So, the **only distinctive difference** between the two anticholinesterase - type insecticides lies **in the rate** at which the **dephosphorylation** or **decarbamylation takes place**.
- **The rate is exceedingly slow for organophosphorus esters and sufficiently rapid for the carbamic esters.**
- The **adverse effect** of organophosphorus insecticides and **carbamate ester** insecticides are the result of **accumulation of acetylcholine** at the neuromuscular junctions, which causes muscular fasciculations and ultimately **paralysis**.
- The e**xcessive acetylcholine** also causes **excessive stimulation** of the **autonomic nervous system** and changes the **function of the lung, cardiovascular system, gastrointestinal tract**, etc.

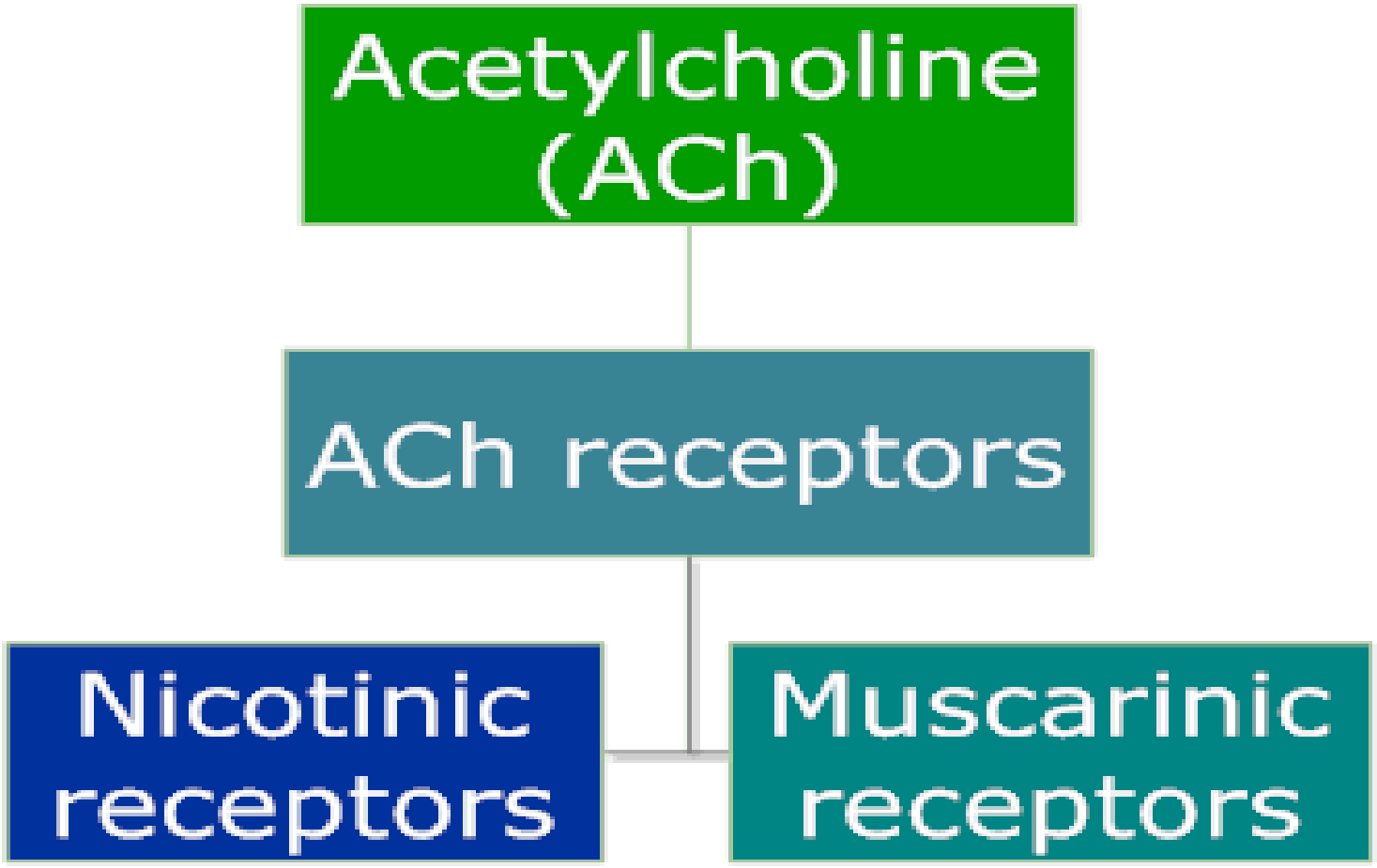
The Autonomic Nervous System

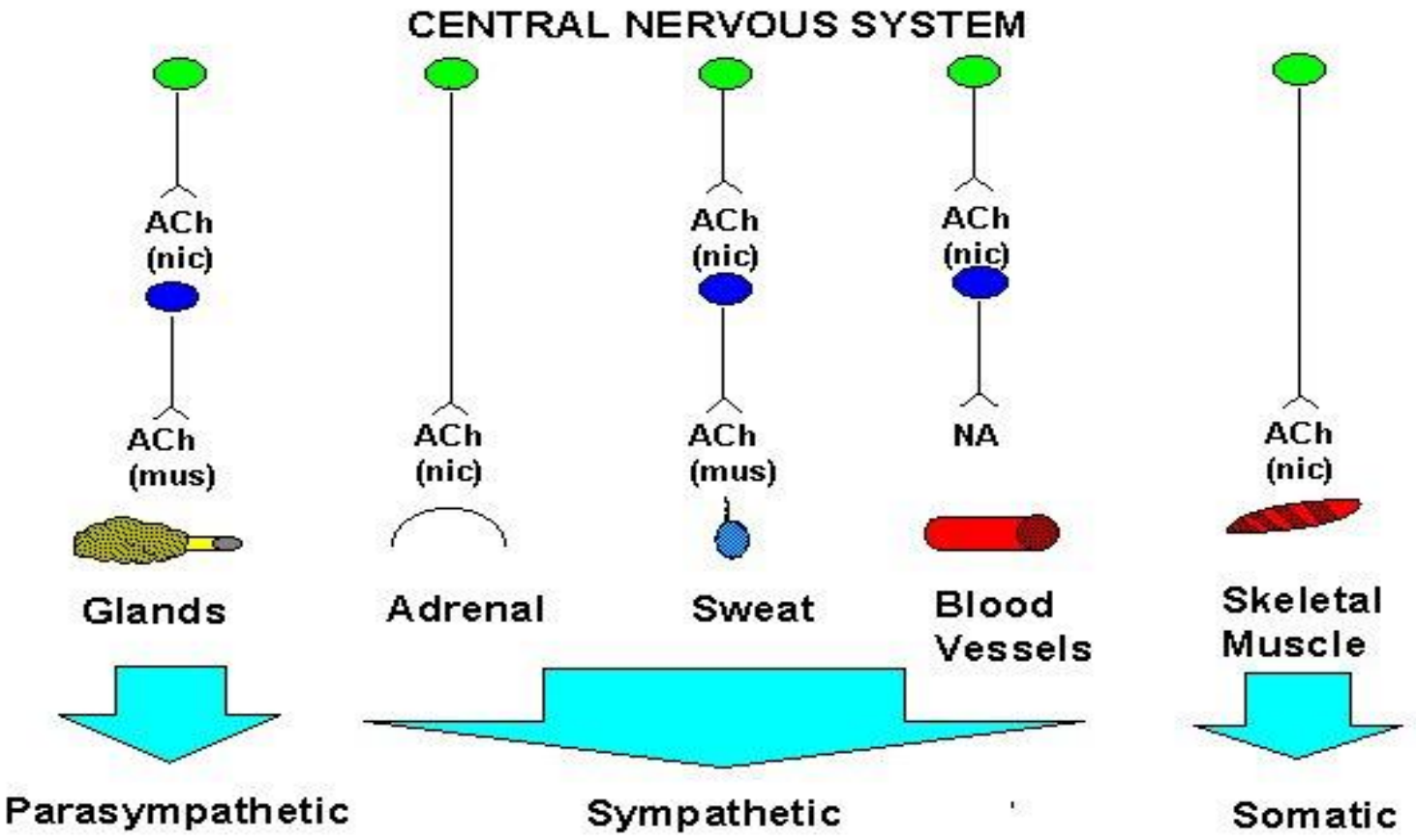


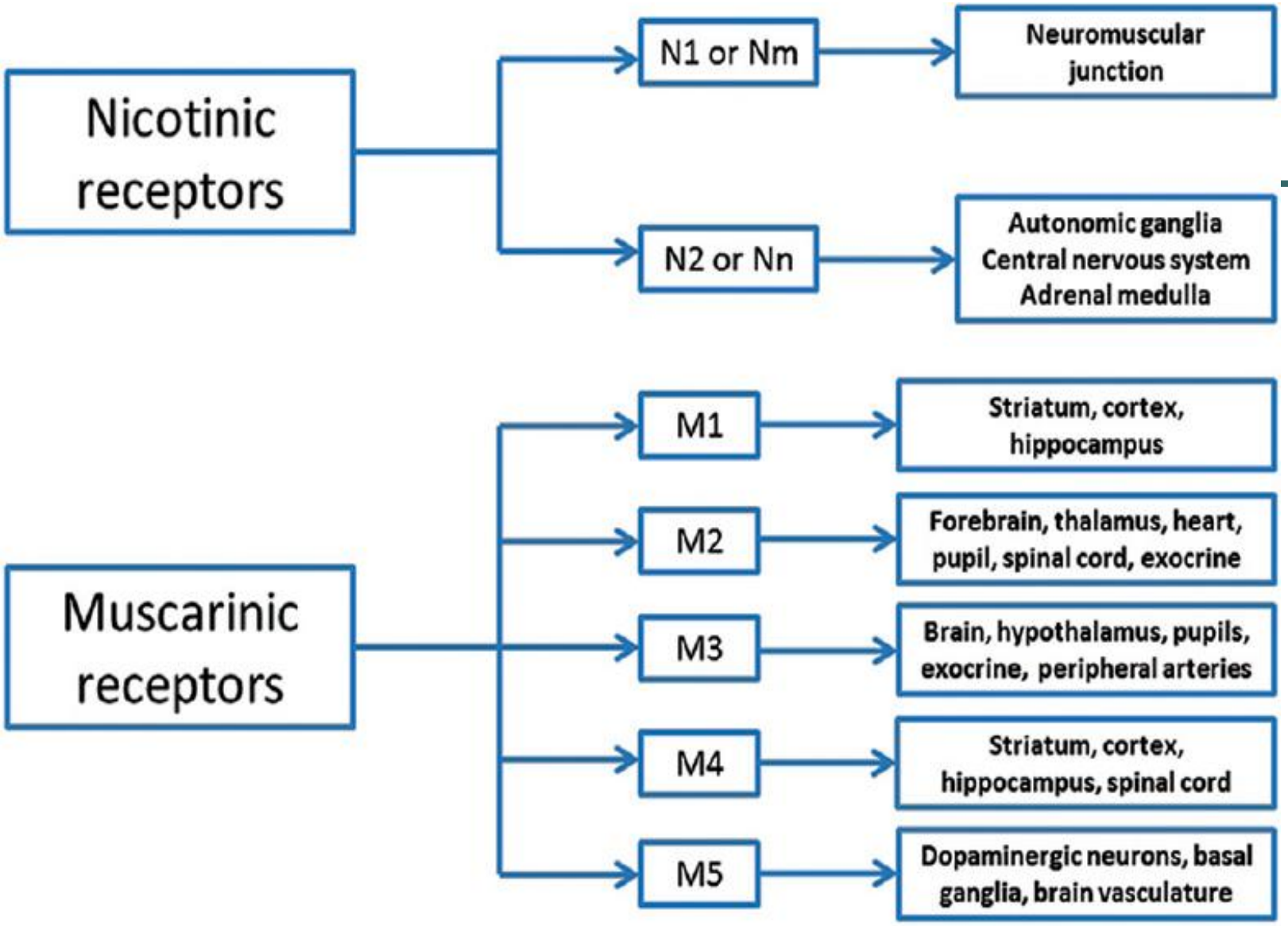
- at the ganglionic synapses in both the parasymp. and the symp. NS, the NT is Ach
- at the postganglionic synapses, the two systems are differ:

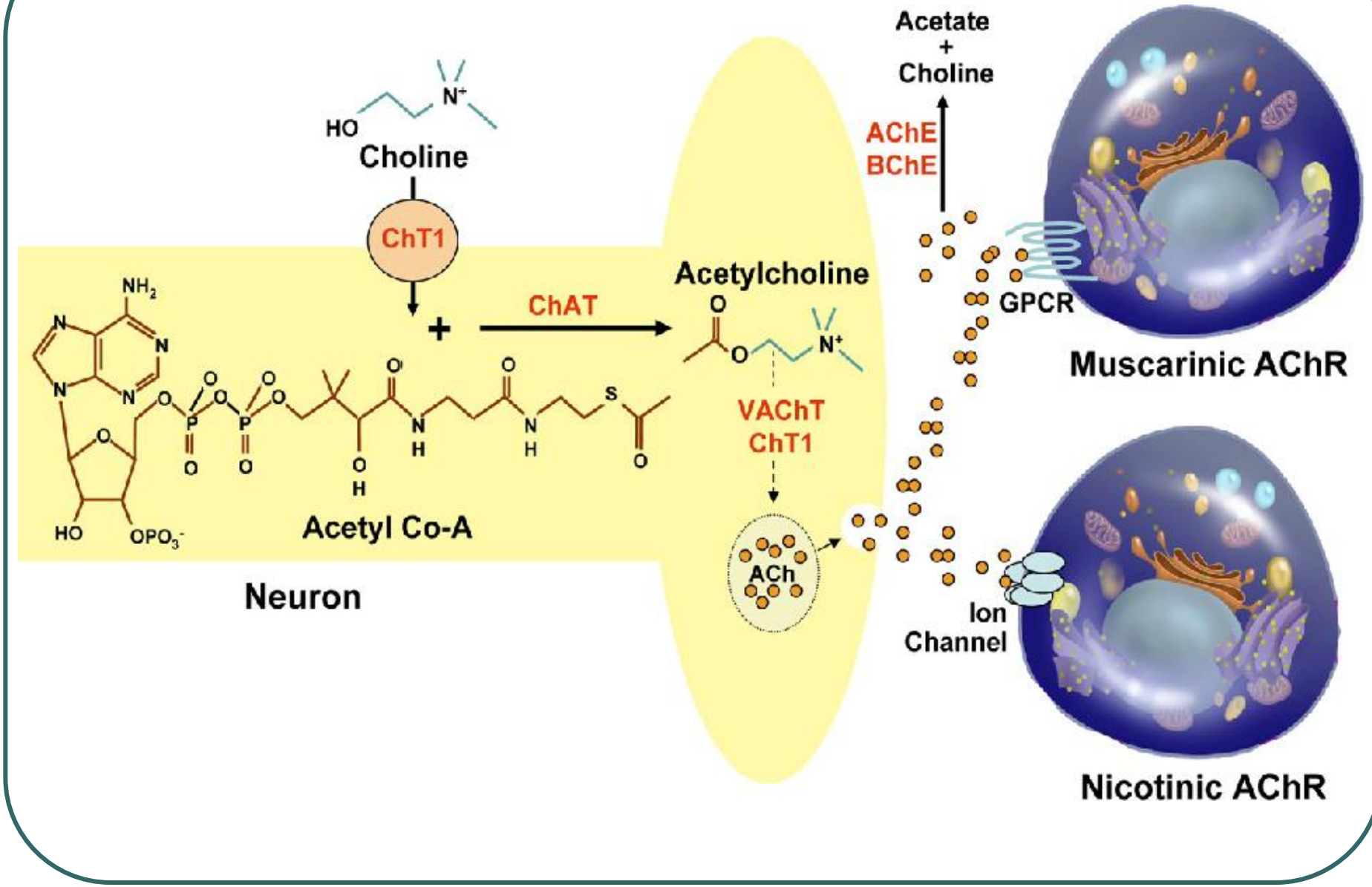
♦ the parasymp. NT is Ach

♦the symp. NT is norepinephrine, but at sweat glands it is ACh


Acetylcholine (ACh)
ACh receptors
Nicotinic receptors
Muscarinic receptors


CENTRAL NERVOUS SYSTEM
ACh (nic)
ACh (mus)
Glands
Parasympathetic
ACh (nic)
Adrenal
ACh (nic)
ACh (mus)
Sweat
ACh (nic)
NA
Blood Vessels
Sympathetic
ACh (nic)
Skeletal Muscle
Somatic


Nicotinic receptors
N1 or Nm
Neuromuscular junction
N2 or Nn
Autonomic ganglia
Central nervous system
Adrenal medulla
Muscarinic receptors
M1
Striatum, cortex, hippocampus
M2
Forebrain, thalamus, heart, pupil, spinal cord, exocrine
M3
Brain, hypothalamus, pupils, exocrine, peripheral arteries
M4
Striatum, cortex, hippocampus, spinal cord
M5
Dopaminergic neurons, basal ganglia, brain vasculature


Choline
ChT1
Acetyl Co-A
ChAT
Acetylcholine
Neuron
VAChT
ChT1
ACh
Acetate
+
Choline
AChE
BChE
GPCR
Muscarinic AChR
Ion
Channel
Nicotinic AChR

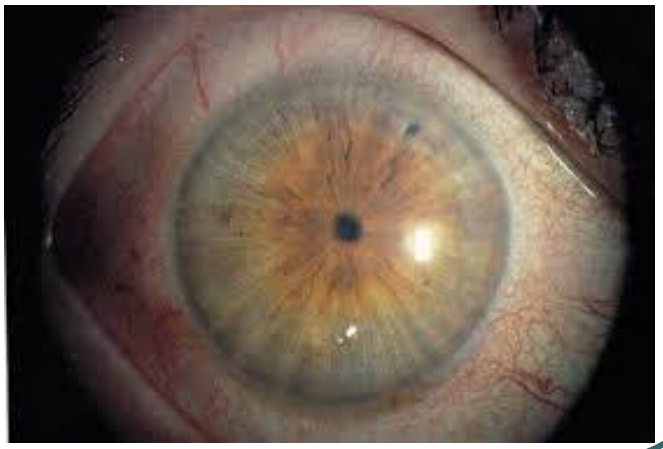
Signs and Syptoms of poisoning

A. Acute form of poisoning

Muscarinic syndrome

The signs of toxicity include those resulting from s**timulation** of the **muscarinic receptors** of the **parasympathic** autonomic nervous system:

- **increased secretions (hypersalivation**, **lacrimation**)
- **bronchoconstriction** (dyspnea), **bronchorrhea**
- **miosis**
- **gastrointestinal cramps**
- **diarrhea**
- **vomiting**
- **urination**
- **bradicardia, hypotension**



Toxidromes – M syndrome

Various mnemonics have been used to describe the **muscarinic** signs of OP poisoning:

S Salivation
L Lacrimation
U Urine incontinence
D Diarrhea
G GIT cramps
E Emesis

D Diarrhea
Diaphoresis
U Urination
M Miosis
B Bronchospasm
Bronchorrhea
Bradycardia
E Emesis
L Lacrimation
S Salivation

Signs and Syptoms of poisonings

- The sings resulting from the **stimulation** and subsequent **blockade** of **nicotinic receptors**, including the **ganglia** of the **sympathetic** and **parasympathetic nervous** system as well as the **junction** between **nerves** and **muscles form the *nicotinic syndrome*:**
  - **tachicardia**
  - **hypertension**
  - **muscle fasciculations (myofibrilations)**
  - **tremor**
  - **muscle weakness**
  - **convulsions (tonic-clonic seizures)**

Toxidromes – N syndrome

M **M**uscle weakness and fasciculations

A **A**drenal medulla activity ↑

T **T**achycardia

C **C**ramping of skeletal muscle

H **H**ypertension

- The signs caused by the effects on **CNS** ***form CNS syndrome*****:**
  - **restlessness**
  - **emotional lability**
  - **ataxia**
  - **lethargy**
  - **mental confusion**
  - **loss of memory**
  - **coma**

B) Delayed neurotoxicity

- In the **recent years** are **recognized additional and persistent signs of neurotoxocity** not previously associated with the organophosphorus pesticides.
- First and frequently associated with exposure to high concentration of these compounds are effects that may persist **for several months following** exposure and involve **neurobehavioral, cognitive and neuromuscular functions, lowered vitality, cephalgia, gastrointestinal and cardiovascular symptoms, premature decline in potency and libido, premature aging, amnestic or demential effects.**

C) Organophosphate-induced delayed Neurotoxicity (OPIDN)

This syndrome was known as "**ginger jake paralysis**" or "**jake led".**

Symptoms: initial flaccidity and muscle weakness in the arm and legs giving rise to:

- **a clumsy**
- **shuffling gait**
- **spasticity**
- **hyperreflexia and abnormal reflexes**
- **clonus**

They indicate the damage of the pyramidal tract.

D) Carbamate pesticides

- **The signs and symptoms** of acute intoxication by **carbamate insecticides** are **quite similar** to those described above for organophosphorus compounds, **differing** only in the **duration** and **intensity of the toxicity**.
- **- The most** apparent **reason** for the relatively short duration and the mild severity of signs of carbamate insecticides are that:
- they are **reversible inhibitors** of nervous tissue acetylcholinesterase;
- they are **rapidly biotransformed**;

Diagnosis

- Diagnosis is based **on the history** and **clinical picture**.
- The examination of the **acetylcholinesterase activity** is very important for the diagnosis.
- A **20% to 50% reduction** in an **individual baseline cholinesterase level indicates excessive exposure**.

Mild form – **50-60%**, moderate form – **30-40%**, severe form – **10-20% - 0%**

- Signs and **symptoms may not appear in some individuals** until the cholinesterase level has **declined by 80%.**
- **Measuring the RBC cholinesterase level** is **more reliable** for the diagnosis of the organophosphorus poisonings, but in the health practice **the serum or plasma cholinesterase** is preferred to be defined.

DD: Amanita muscaria (fly agaric, fly mushroom)

Treatment

Treatment

The priorities in management are to:

- **Resuscitation**
- **Atropinization of symptomatic patients**
- **Decontamination**
- **Other Treatments - Oximes**

Treatment

- **All cases** of **anticholinesterase poisoning** should be treated as **serious medical emergencies.**
- **Careful washing of the entire** body
- **Remove all contaminated clothing**.
- The status of the patient **should be monitored** by repeated analysis **of the plasma (serum) cholinesterase** and the **erythrocyte cholinesterase**.
- The **life threatening signs** (respiratory depression, bronchospasm, bronchial secretion, pulmonary edema, muscular weakness) require unmediate **artificial respiration** and **suctioning via an endotracheal tube** to maintain a patient airway.
- **Arterial blood gases** and **cardiac function** should be monitored.

GIT Decontamination

- **Gastric lavage** and **activated charcoal** should be used if the patient presents within **4 hours after exposure**.
- **Ipecacuanha-induced emesis** should not be used in OP poisoning. Patients poisoned with organophosphorus can rapidly become unconscious, risking aspiration if ipecacuanha has been given.
- **Mechanically-induced emesis** with large quantities of water risks pushing fluid through the pylorus and into the small bowel, probably increasing the rate of absorption.

GIT Decontamination

- **Activated charcoal** binds organophosphorus in vitro. The absence of effect in patients might be due to rapid absorption of pesticides **into the blood**. No evidence suggests that patients with pesticide poisoning benefit from treatment with activated charcoal.
- **Magnesium sulphate** blocks ligand-gated calcium channels, resulting in **reduced acetylcholine release** from pre-synaptic terminals, thus improving function at neuromuscular junctions, and reduced CNS overstimulation (reduced mortality in people).

Antidotes

1. Cholinolitics

- **Atropine** is used to **counteract** the initial **muscarinic effects** of the **accumulating neurotransmitter acetylcholine.**
- **Small doses** of atropine (subcutaneously or intravenously) are indicated for mild signs and symptoms following **a brief, intensive exposure** (1 mg s.c. repeated after 30 min if necessary).
- Relatively **large**, **cumulative** doses of **atropine** up **to 50 mg daily** may be necessary to **control severe muscarinic symptoms**.
- This drug can be administered every 15 minutes.

Mild form	**1 mg s.c., repeated if necessary**
Moderate form	**2-4 mg i.v., every 15 min 1-2 mg → atropinization**
Severe form	**4-6 mg i.v., every 15 min 1-2 mg → atropinization**

Antidotes

Atropine - belongs to a class of compounds known as alkaloids. It is derived from **Levohyoscyamine** – a component of plants such as **Belladonna, henbane, thorn apple, scopolia**.

Specific effects of atropine include: **the arrest of secretion** of sweat, mucus and saliva; inhibition of the **vagus nerve**, which results in **an increased heart rate**, **dilation of the pupils** and paralysis of accommodation of the lens of the eye and **relaxation of bronchial, intestinal and other smooth muscles.** Central effects include **excitement and delirium** followed by **depression and paralysis of the medulla oblongata.**

Atropa belladonna

Henbane


UGA1353071

Torn apple

Treatment

Specific effects of atropine

- The status of the patient must be **monitored continuously** by examine **for disappearance of secretions** (dry **mouth and nose** and **sweating**), **facial flushing** and **mydriasis**, **tachycardia**.

Anticholinergic Agents:

Atropine, Scopolamine, Benztropine etc.

What if you give too much Atropine ?

- Anticholinergic Syndrome:
  - Hot as a hare/hell/
  - Blind as a bat
  - Red as a beet
  - Dry as a bone
  - Mad as a hatter

- A sensitive indicator for ingestion, but poor predictor for toxicity.
- Full syndrome is rare

Anticholinergic TOXIDROME

- Mad as a hatter
  - confusion/hallucinations/seizures/coma
- Blind as a bat
  - mydriasis
- Dry as a bone
  - dry skin, urinary retention
  - Red as a beet
  - Flushed skin
- Hot as a pistol (hare)
  - hyperthermia

Treatment

- **2. Oximes**

The oximes (pralidoxime or **2-PAM, toxogonin, obidoxime)**, administered **intravenously reactivate** the **inhibited nervous tissue AchE**.

The use of these agents are **not necessary** for **cases of mild Intoxication a**nd they should be used for **moderate to severe** poisonings.

Treatment by **slow intravenous infusion** of doses of **1 g Pralidoxime should** be initiated **as soon as possible**.

The clinical treatment of **carbamate toxicity is similar** to that for organophosphorus insecticides **intoxication with the exception** that the **use at oxymes** is **contraindicated**.

Treatment

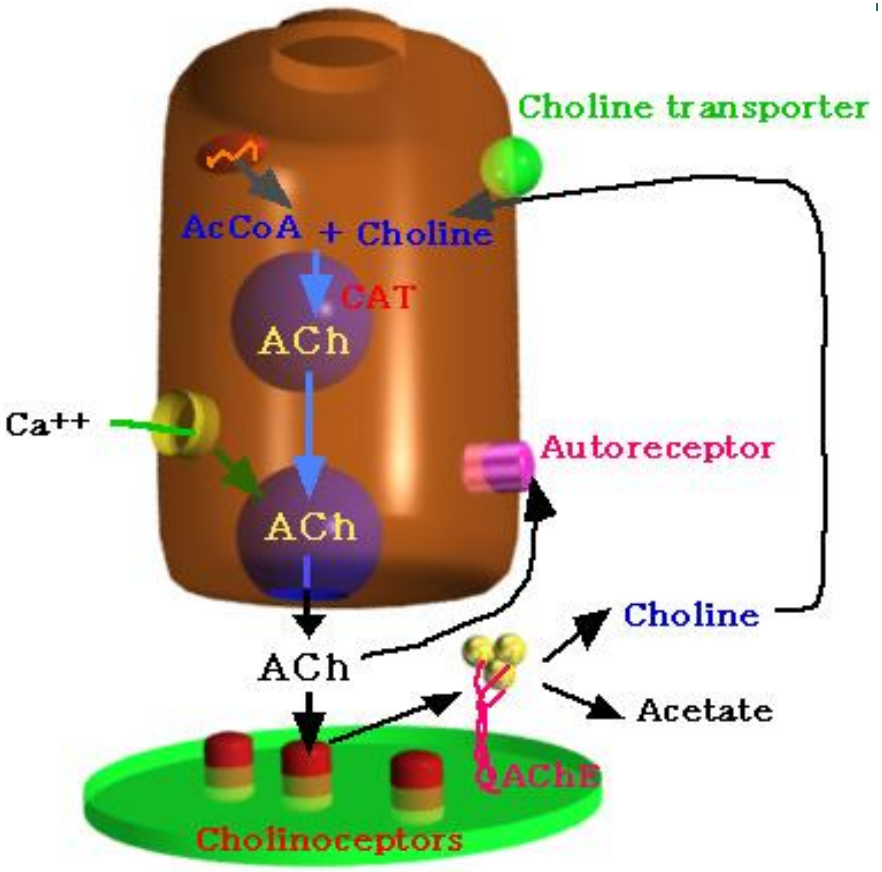
- **Diazepam**

This drug **counteracts** some aspects of the **CNS and neuromuscular signs** that are not affected by atropine. **Doses of 10 mg** (s.c. or i.v) are appropriate and may be repeated.

- **Other centrally acting drugs** that may **depress respiration** is **not recommended** in the absence of artificial respiration.

Alternate sites for antidotes

- Protect AChE
- Supply AChE
- Reduce ACh
- Protect ACh Receptor
- Reduce OP Load
- Multiple Mechanisms



New aspects of treatment

- The **alpha 2-adrenergic receptor agonist clonidine** also reduces acetylcholine synthesis and release from presynaptic terminals. Animal studies show benefit of clonidine treatment, especially in combination with atropine, but effects in human beings are unknown.
- **Sodium bicarbonate** is sometimes used for treatment of organophosphorus poisoning Increases in blood pH (up to 7.45–7.55) have been reported to improve outcome.

Enzymes

Butyrylcholinesterase scavenges organophosphorus in plasma, reducing the amount available to inhibit acetylcholinesterase in synapses. It has been cloned and military research now aims to inject soldiers with the enzyme before exposure to organophosphorus nerve gases. Such a prophylactic approach is not practical for self-poisoning with organophosphorus because we cannot predict when a person is going to ingest the pesticide. Some researchers have reported the use of **butyrylcholinesterase in fresh frozen plasma** to treat poisoned patients.

Enzymes

- A better approach than use of butyrylcholinesterase might be to give **recombinant bacterial phosphotriesterases, or hydrolases**. These proteins break down organophosphorus pesticides **enzymatically.**

TOXICOLOGY OF CHEMICAL WARFARE AGENTS

Classification of chemical warfare agents, so-called "medical classification“

I. Agents liable to be met in warfare

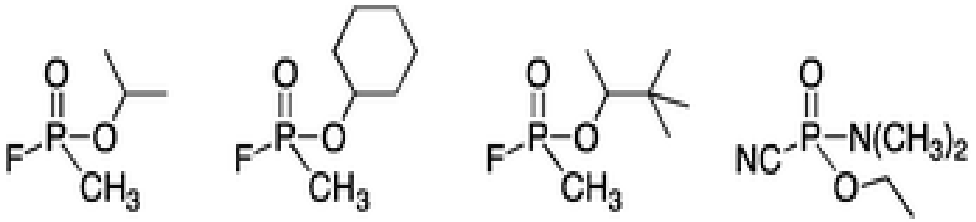
Nerve agents (**G and V gases, sarin, tabun, soman**)
Lung-damaging (**phosgene and chlorine**) **agents**
Vesicant agents (**sulphur mustard, lewisite**, etc.)
Psychotomimetic agents (**LSD, BZ,** etc.)
Heterogenous (other) agents
a) Cyanide
b) Arsine

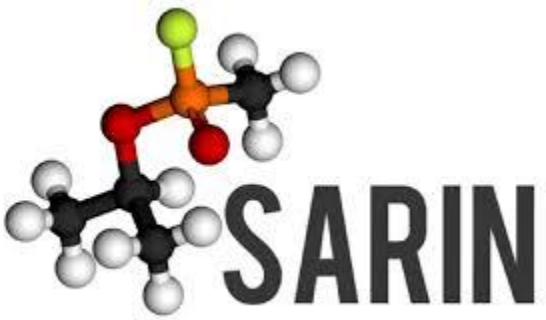
II. Agents liable to be met in riot control/or war

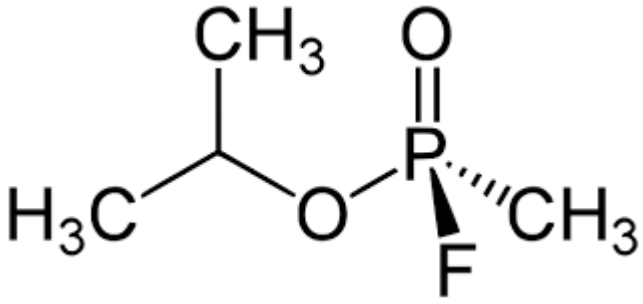
1. **1. Sensory irritants** (**CS, CN, CR**, etc.)
2. **2. Vomiting agents**

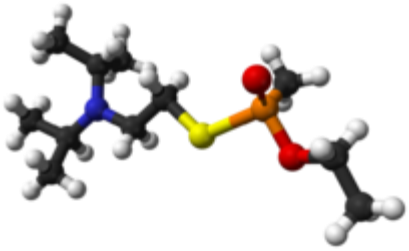
ROUTES OF ENTRY

- Ingestion
- Eyes
- Respiratory Tract
- Injection
- Skin

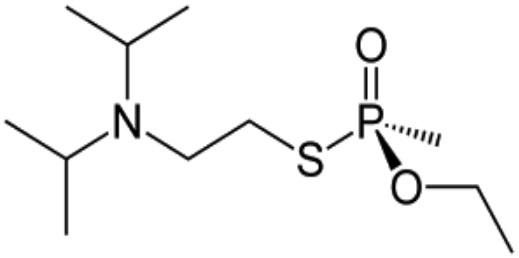


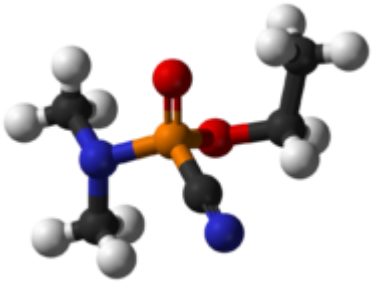






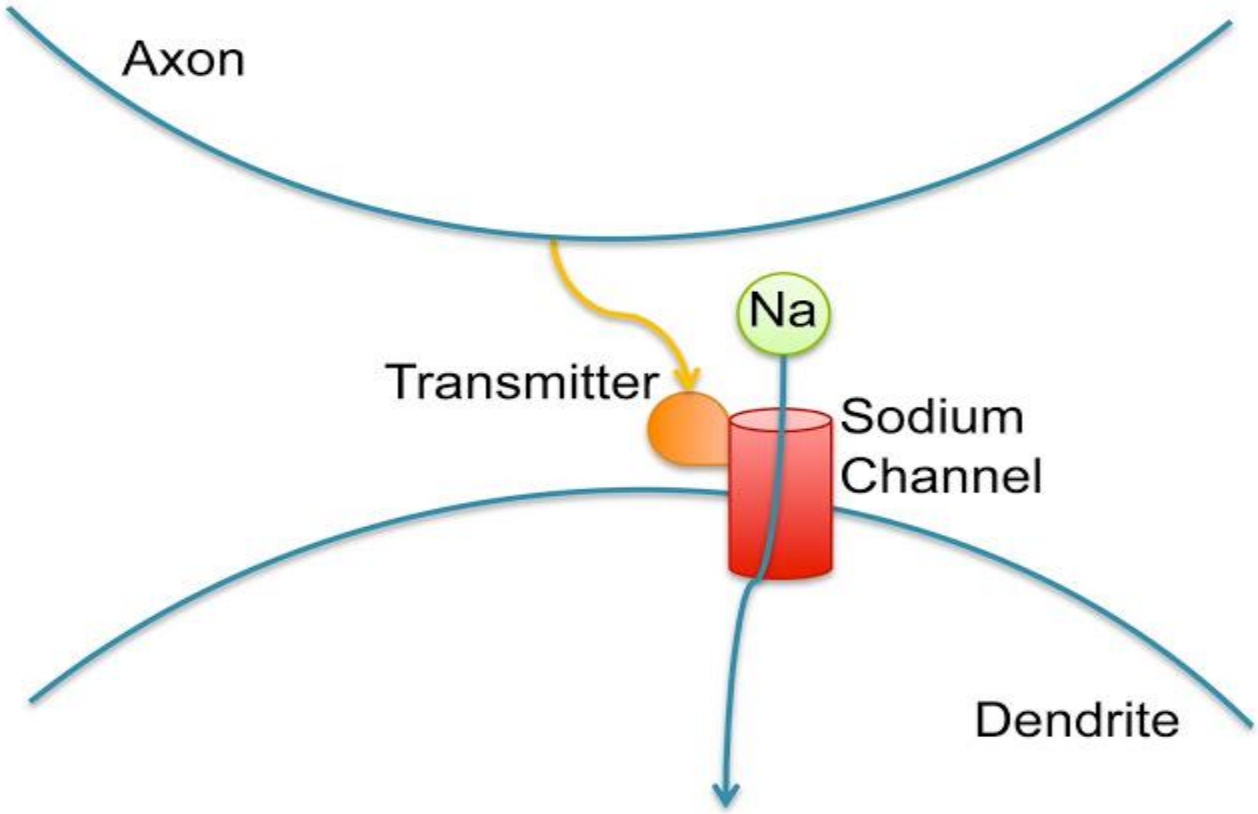
Vx gases

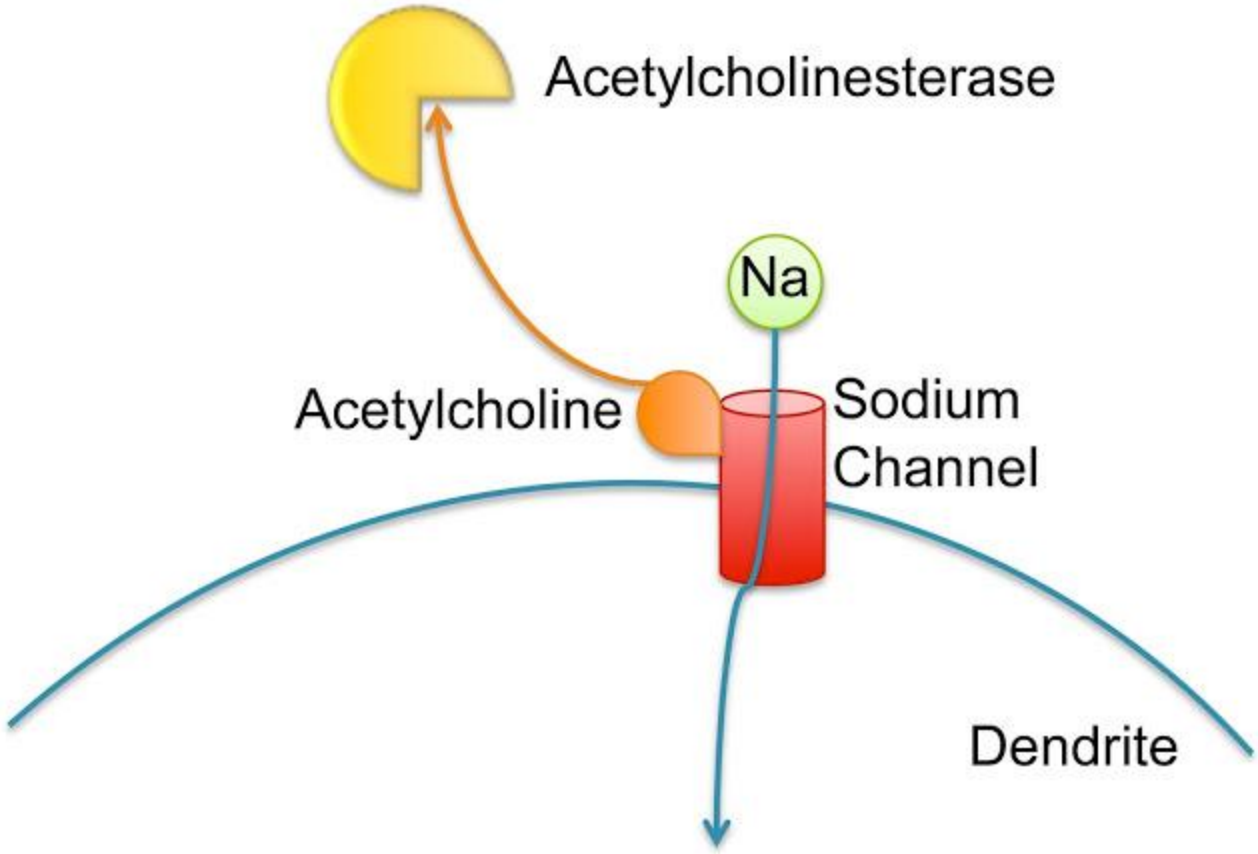


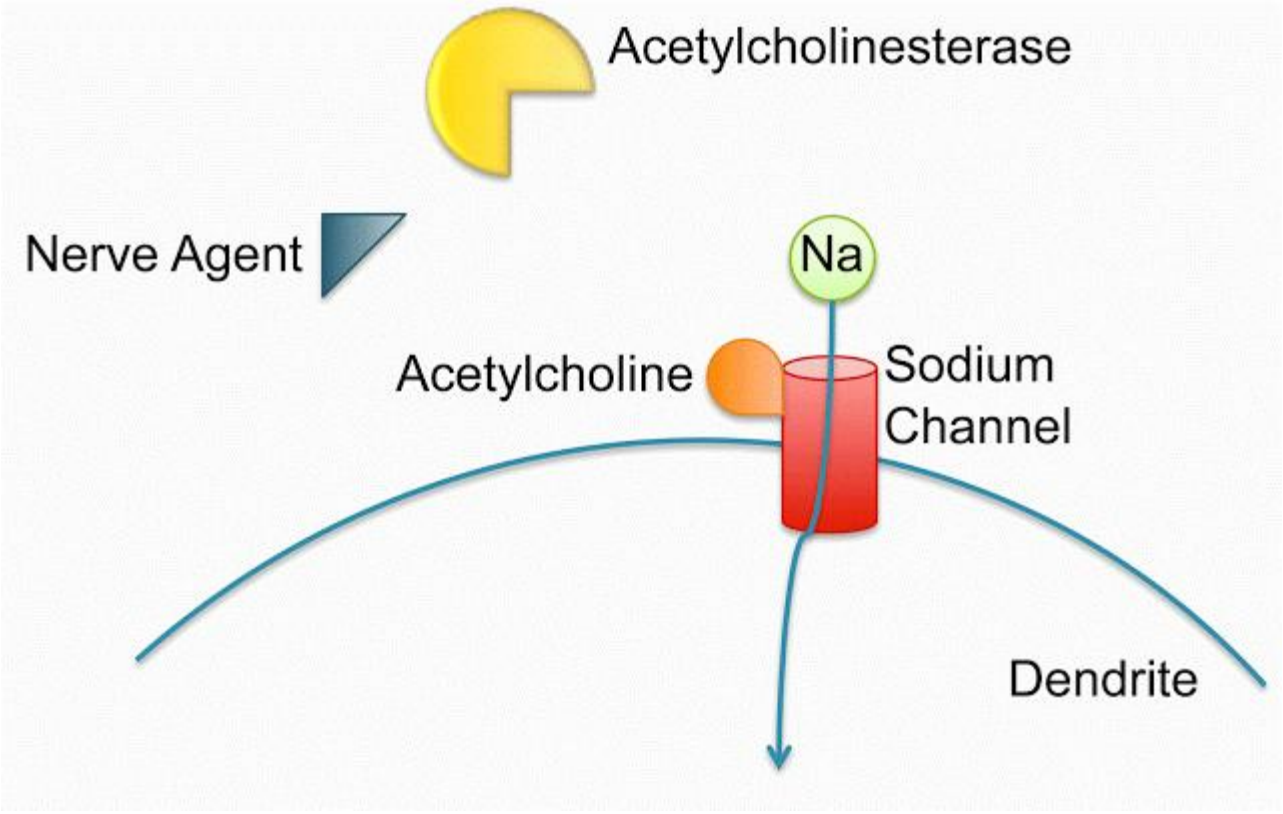


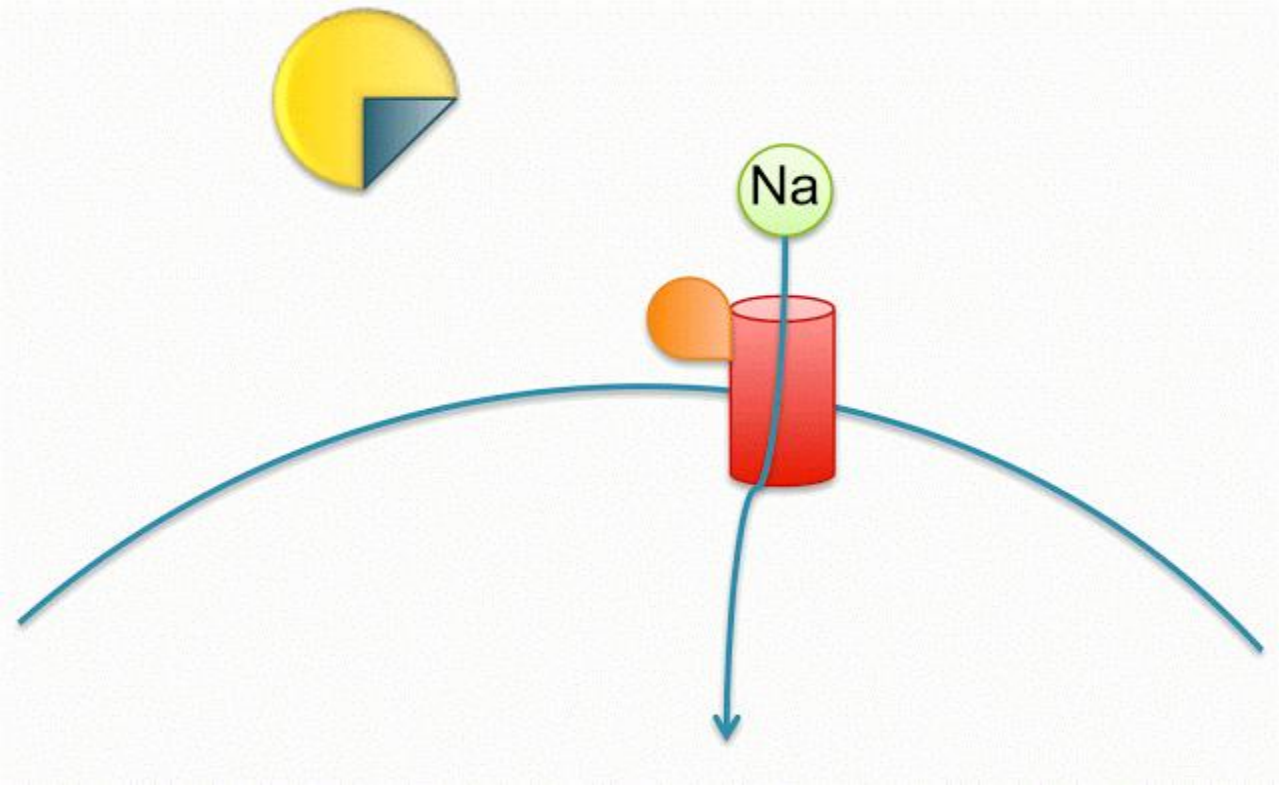
tabun


Cell
Axon
Dendrite


Axon
Na
Transmitter
Sodium
Channel
Dendrite


Acetylcholinesterase
Na
Acetylcholine
Sodium
Channel
Dendrite


Acetylcholinesterase
Nerve Agent
Na
Acetylcholine
Sodium
Channel
Dendrite


Na

Sarin

- 100mg can kill a person in a few minutes
- 500x toxic as cyanide

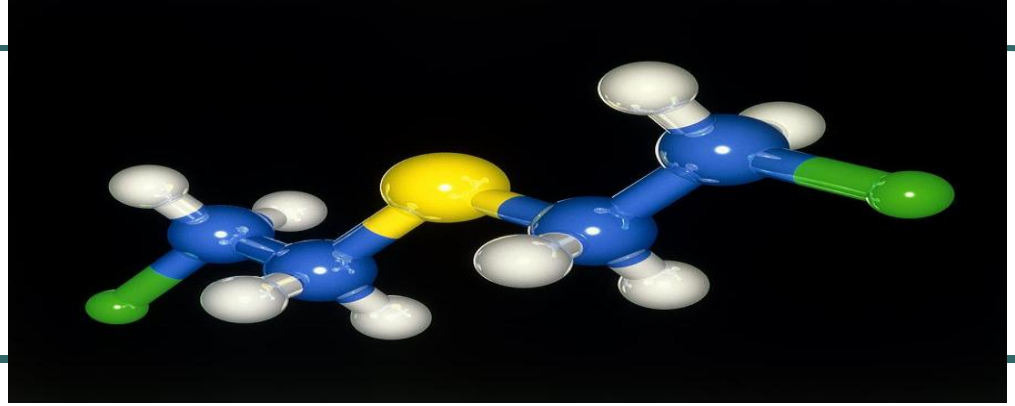
V_x Nerve Gases

Deadliest nerve agent

Fraction of a drop absorbed through the skin is deadly 100 x more deadly than sarin gas when absorbed, 2 x if inhaled.

VESICANT COMPOUNDS

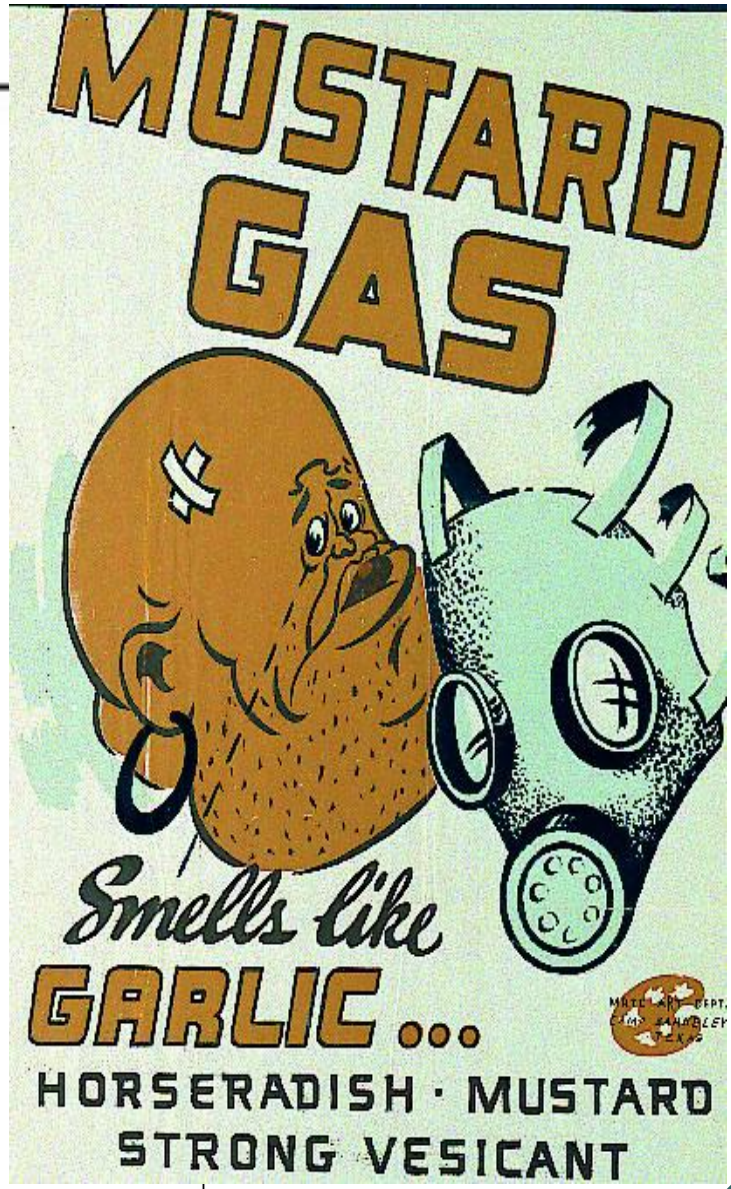
(Blister agents)



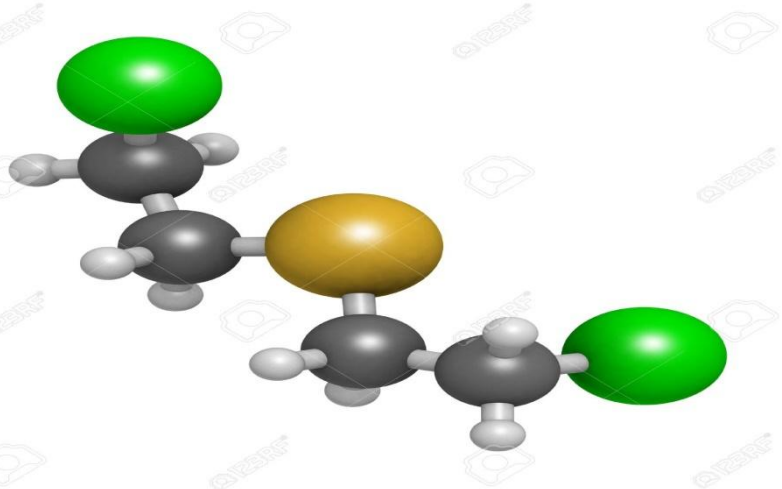
- **Vesicant compounds** were introduced **as chemical warfare agents** on 12 July 1917 (I World War) when **German forces** used sulphur mustard **at the river Ypres**, **in Belge**.
- The most important agents of this group are **sulphur mustards** and **nitrogen mustards**
  - Mustards got their name from their pungent **mustard - garlic odor**. **Sulphur mustard** vapours pass quickly **through clothing**. It is **lipid soluble and is absorbed across the skin**.
  - The majority of inhaled sulphur mustards is absorbed in the **upper airways**.

Mustard gas (sulphur mustard)

Nitrogen Mustard



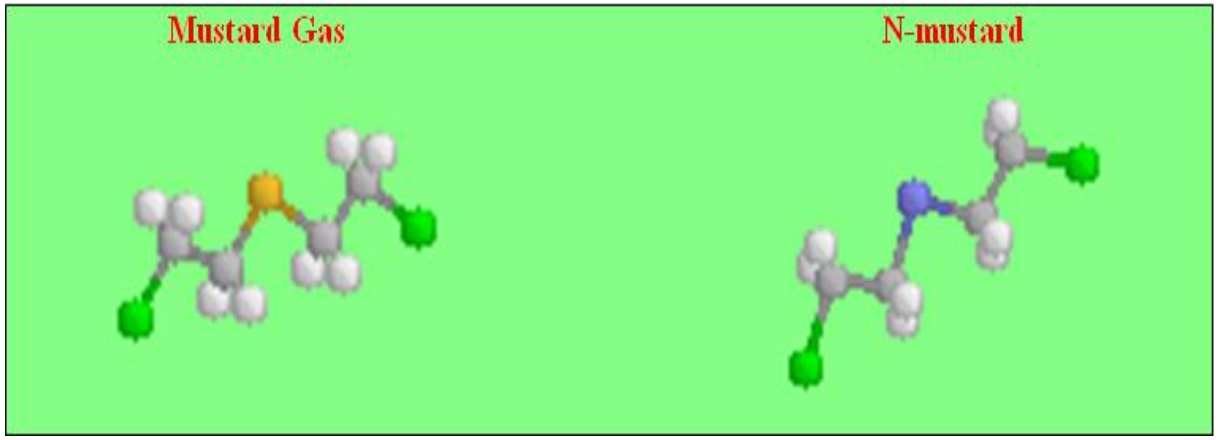
Mechanism of action



- Mustard gases (**Iperite**) are powerful **alkylating agents** and react with **amino, thiol, carboxyl, hydroxyl**, and primary **phosphate groups**.
- As a result of its alkylating and electrophylic properties, mustard gas is able to change the structure of **nucleic acids, cellular membranes, and proteins**.

Clinical presentation

- Mustard gas (either vapor or liquid) causes damage to the **skin, eyes, respiratory system, and gastrointestinal tract**.



Eyes Clinical presentation

- **After 20 - 60 min** of the contact with the poison is observed: **nausea, retching and eye smarting**. It is followed by **a latent period** of up **an hour**.
- **Later (2 - 6 h.):**
  - **inflammation of the eyes**
  - intense **eye pain**
  - **lacrimation**
  - **blepharospasm**
  - **photophobia**
  - **rhinorrhea**

Skin

- **Blisters** develop between **6 - 24 hours**. They **are not painful**, but pain may be produced on moving. Blisters heal **slowly** and healing areas of skin are **sensitive**. Reddening of exposed skin.
- **Darkening of the skin**, due to an increase of **melanin** in the skin and areas of brown or black **hyperpigmentation** are produced.

Respiratory system

- After a delay of 24 hours, **inhalation of the gas** produces initially **hoarseness**, which may progress to **loss of voice**.
- A **cough** (worse at night) appears early and later becomes productive. **Fever, dispnea, and moist rhonchi and rales may develop**.
- **Bronchopneumonia** frequently intervenes develops.
- Symptoms may **persist for 1 or more years**.

Gastrointestinal tract

- **Ingestion of food or water contaminated by liquid mustard produces:**
- **nausea**
- **vomiting**
- **pain bleeding diarrhea**
- **dehydration**
- **prostration**

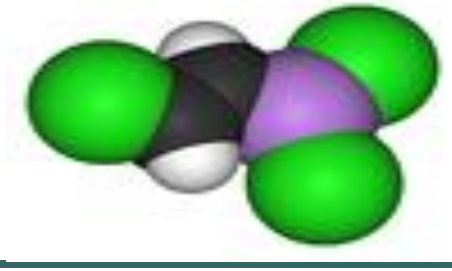
Treatment - the main treatment is to relieve symptoms

Management of eye lesions - early decontamination of liquid splashes in the eye is essential. It is necessary also:

- **daily saline irrigations**;
- **chloramphenicol eye drops** to prevent infection;
- **mydriatics** (e.g. hyoscine drops) to prevent iridolenticular adhesion;
- **dark glasses**;

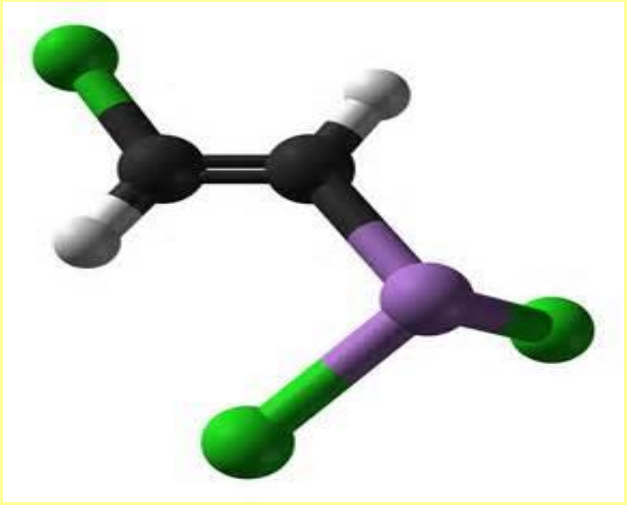
Management of lesions of respiratory tract includes:

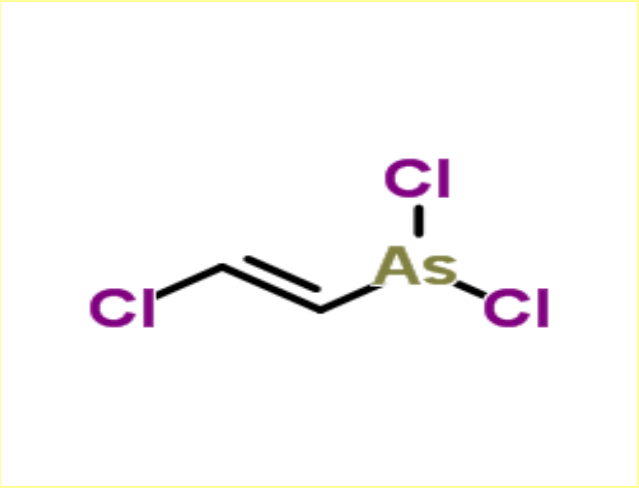
- **antibiotic cover** is recommended if the respiratory effects are more than very mild;
- **mucolitics**, including acetyl cysteine;
- **intensive care** in case of very severe damage of respiratory tract;



Lewisite

- Lewisite, developed as a chemical warfare agent in 1918 by Lee Lewis, has never been used in war. Despite this it has acquired a reputation as an agent of likely great effectiveness and lethality.





The toxicology of the Lewisite is very similar to this one of the sulphur mustard. However, certain differences exist:

- Exposure to the eyes to Lewisite vapor is immediately painful and the damage produced is more severe than that produced by mustard gas vapor.
- Skin blisters produced by Lewisite appear more quickly post-exposure than those produced by mustard gas.
- The inflammatory response associated with Lewisite lesions is more severe than that associated with mustard lesions.
- Healing of Lewisite - induced skin lesions is more rapid than of those occurring as a result of exposure to sulphur mustard.

Treatment

- A specific, antidotal therapy is available for treatment of Lewisite poisoning.
- **Dimercaprol (BAL)** binds the arsenical groups of Lewisite and produces a harmless complex. BAL competes avidly with binding sites in the body for arsenic and removes arsenic from them. BAL is used also in the treatment of poisoning by a range of heavy metal compounds.