Carbon Monoxide Poisoning

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Endorsements

This educational module has been endorsed by the International Association of Firefighters (IAFF).

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Carbon monoxide is the most frequent cause of poisonings in industrialized countries.

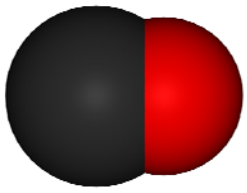
CHEMISTRY

Chemistry of Carbon Monoxide

- Gas:
  - Colorless
  - Odorless
  - Tasteless
  - Nonirritating
- Results from the incomplete combustion of carbon-containing fuels.
- Abbreviated "CO"

Chemistry of Carbon Monoxide

- Molecule consists of one carbon atom joined to one oxygen atom by a triple bond.
- Extremely stable molecule.



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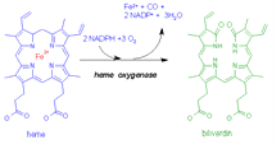
SOURCES

Sources of Carbon Dioxide

- Endogenous
- Exogenous
- Methylene chloride

Sources of Carbon Monoxide

- **Endogenous:**
  - Normal heme catabolism (breakdown):
    - Only biochemical reaction in the body known to produce CO.
  - Levels increased in:
    - Hemolytic anemia.
    - Sepsis

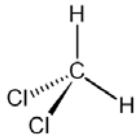


Sources of Carbon Monoxide

- **Exogenous:**
  - House fires.
  - Gas –powered electrical generators.
  - Automobile exhaust.
  - Propane-powered vehicles.
  - Heaters.
  - Camp stoves.
  - Boat exhaust.
  - Cigarette smoke.

Sources of Carbon Monoxide

- **Methylene chloride:**
  - Paint and adhesive remover.
  - Converted to CO in the liver after inhalation.



INCIDENCE

Incidence

- CO is leading cause of poisoning deaths.
- CO may be responsible for half of all poisonings worldwide.
- ~5,000–6,000 people die annually in the United States as a result of CO poisoning.
- ~40,000–50,000 emergency department visits annually result from CO poisoning.

Incidence

- Accidental CO poisoning deaths declining:
  - Improved motor vehicle emission policies.
  - Use of catalytic converters.

Incidence

- **Most accidental deaths are due to:**
  - House fires.
  - Automobile exhaust.
  - Indoor-heating systems.
  - Stoves and other appliances.
  - Gas-powered electrical generators
  - Charcoal grills.
  - Camp stoves.
  - Water heaters.
  - Boat exhausts.

Incidence

- **Increased accidental CO deaths:**
  - Patient > 65 years of age.
  - Male
  - Ethanol intoxication.
- **Accidental deaths peak in winter:**
  - Use of heating systems.
  - Closed windows.

Incidence

- **Significant increase in CO poisoning seen following disasters.**
- **Primarily relates to loss of utilities and reliance on gasoline-powered generators and use of fuel-powered heaters.**

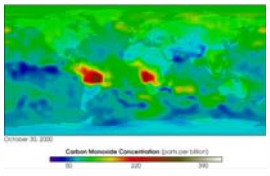
Incidence

- Fetal hemoglobin has a much greater affinity for CO than adult hemoglobin.
- Pregnant mothers may exhibit mild to moderate symptoms, yet the fetus may have devastating outcomes.

EXPOSURE

Environmental CO Exposure

- Environmental exposure typically <0.001% (10 ppm).
- Higher in urban areas.
- Sources:
  - Volcanic gasses
  - Bush fires
  - Human pollution



CO Exposure

Source	Exposure (ppm)
Fresh Air	0.06-0.5
Urban Air	1-30
Smoke-filled Room	2-16
Cooking on Gas Stove	100
Actively Smoking a Cigarette	400-500
Automobile Exhaust	100,000

CO Exposure

- **CO absorption by the body is dependent upon:**
  - **Minute ventilation (V_{min}).**
  - **Duration of exposure.**
  - **Concentration of CO in the environment.**
  - **Concentration of O_2 in the environment.**

Exposure Limits

- **OSHA:**
  - **50 ppm (as an 8-hour time-weighted average).**
- **NIOSH:**
  - **35 ppm (as an 8-hour time-weighted average).**

Firefighter Risks

- CO is a significant and deadly occupational risk factor for firefighters.
- Sources:
  - Structure fires.
  - Apparatus fumes.
  - Portable equipment fumes.
  - Underground utility fires.
  - Closed-space rescue situations.
- CO is heavier than air and accumulates in lower regions.

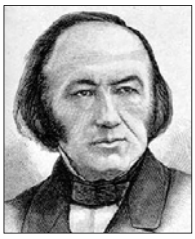
Firefighter Risks

- SCBA extremely important in CO prevention.
- CO often encountered during overhaul operations.

CO POISONING PATHOPHYSIOLOGY

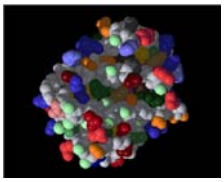
Pathophysiology

- Pathophysiology of CO poisoning first described by French physician Claude Bernard in 1857.



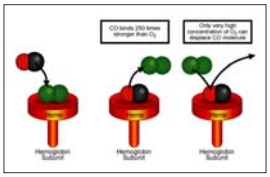
Pathophysiology

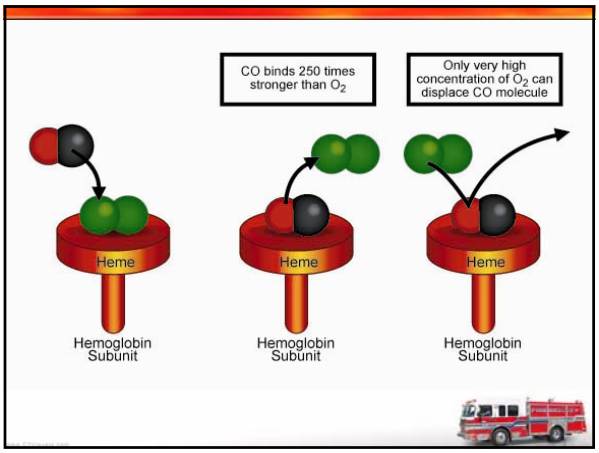
- CO poisoning actually very complex.
- CO binds to hemoglobin with an affinity – 250 times that of oxygen.
- The combination of CO and hemoglobin is called carboxyhemoglobin (COHb).



Pathophysiology

- CO displaces O_2 from the hemoglobin binding sites.
- CO prevents O_2 from binding.
- COHb does not carry O_2.
- COHb causes premature release of remaining O_2 into the tissues.





Pathophysiology

- COHb ultimately removed from the circulation and destroyed.
- Half-life:
  - Room air: 240-360 minutes
  - O_2 (100%): 80 minutes
  - Hyperbaric O_2: 22 minutes

Pathophysiology

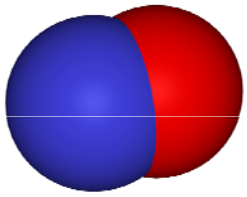
- CO also binds to other iron-containing proteins:
  - Myoglobin
  - Cytochrome
- Binding to myoglobin reduces O_2 available in the heart:
  - Ischemia
  - Dysrhythmias
  - Cardiac dysfunction

Normal COHb Levels

Source	COHb (%)
Endogenous	0.4-0.7
Tobacco Smokers:	
1 pack/day →	5-6
2-3 packs/day →	7-9
cigars →	Up to 20
Urban Commuter	5
Methylene chloride (100 ppm for 8 hours)	3-5

Pathophysiology

- **Nitric oxide (NO):**
  - Highly-reactive gas that participates in numerous biochemical reactions.
  - Oxygen free-radical
  - Levels increased with CO exposure.

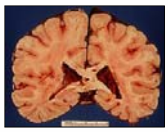


Pathophysiology

- **Nitric Oxide (NO):**
  - Causes cerebral vasodilation:
    - Syncope
    - Headache
  - May lead to oxidative damage to the brain:
    - Probable cause of syndrome of delayed neurologic sequelae (DNS).
    - Associated with reperfusion injury.

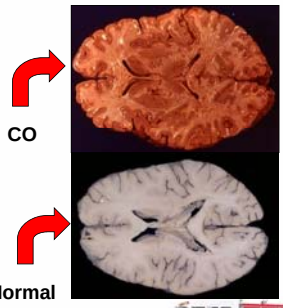
Pathophysiology

- Impact of CO on major body systems:
  - Neurologic:
    - CNS depression resulting in impairment:
      - Headache
      - Dizziness
      - Confusion
      - Seizures
      - Coma
    - Long-term effects:
      - Cognitive and psychiatric problems



Pathophysiology

- 46-year-old woman with chronic exposure to CO from old car.
- COHb = 46%
- Autopsy:
  - Cherry-red tissues
  - Cerebral edema
- Immediate cause of death: ventricular fibrillation due to CO poisoning.



Pathophysiology

- Impact of CO on major body systems:
  - Cardiac:
    - Decreased myocardial function:
      - Hypotension with tachycardia.
      - Chest pain.
      - Dysrhythmias.
      - Myocardial ischemia.
      - Most CO deaths are from ventricular fibrillation.
    - Long-term effects:
      - Increased risk of premature cardiac death.

Pathophysiology

- **Impact of CO on major body systems:**
  - **Metabolic:**
    - Respiratory alkalosis (from hyperventilation).
    - Metabolic acidosis with severe exposures.
  - **Respiratory:**
    - Pulmonary edema (10-30%)
      - Direct effect on alveolar membrane.
      - Left-ventricular failure.
      - Aspiration.
      - Neurogenic pulmonary edema.

Pathophysiology

- **Impact of CO on major body systems:**
  - **Multiple Organ Dysfunction Syndrome (MODS):**
    - Occurs at high-levels of exposure.
    - Associated with a high mortality rate.

Pathophysiology Summary

- **Limits O_2 transport:**
  - CO more readily binds to Hb forming COHb.
- **Inhibits O_2 transfer:**
  - CO changes structure of Hb causing premature release of O_2 into the tissues.
- **Tissue Inflammation:**
  - Poor perfusion initiates an inflammatory response.

Pathophysiology Summary

- **Poor cardiac function:**
  - ↓ O_2 delivery can cause dysrhythmias and myocardial dysfunction.
  - Long-term cardiac damage reported after single CO exposure.
- **Increased activation of nitric oxide (NO):**
  - Peripheral vasodilation.
  - Inflammatory response.

Pathophysiology Summary

- **Vasodilation:**
  - Results from NO increase.
  - Cerebral vasodilation and systemic hypotension causes reduced cerebral blood flow.
  - NO is largely converted to methemoglobin.
- **Free radical formation:**
  - NO accelerates free radical formation.
  - Endothelial and oxidative brain damage.

Patient Groups at Risk

- Children.
- Elderly.
- Persons with heart disease.
- Pregnant women.
- Patients with increased oxygen demand.
- Patients with decreased oxygen-carrying capacity (i.e., anemias, blood cancers).
- Patients with chronic respiratory insufficiency.

CO POISONING SIGNS & SYMPTOMS

CO Poisoning

- Signs and symptoms usually vague and non-specific.

You must ALWAYS maintain a high index of suspicion for CO poisoning!

CO Poisoning

- Signs and symptoms closely resemble those of other diseases.
- Often misdiagnosed as:
  - Viral illness (e.g., the "flu")
  - Acute coronary syndrome
  - Migraine
- Estimated that misdiagnosis may occur in up to 30-50% of CO-exposed patients presenting to the ED.

Signs and Symptoms

Carbon Monoxide
The
Great Imitator†

† - *So is:*
- *Syphilis*
- *Lyme disease*
- *Fibromyalgia*
- *Lupus erythematosis*
- *Multiple sclerosis*

CO Poisoning

- **Classifications:**
  - Acute
    - Results from short exposure to a high level of CO.
  - Chronic:
    - Results from long exposure to a low level of CO.

Signs and Symptoms (Acute)

- Malaise
- Flu-like symptoms
- Fatigue
- Dyspnea on exertion
- Chest pain
- Palpitations
- Lethargy
- Confusion
- Depression
- Impulsiveness
- Distractibility
- Hallucination
- Confabulation
- Agitation
- Nausea
- Vomiting
- Diarrhea
- Abdominal pain

Signs and Symptoms (Acute)

- Headache
- Drowsiness
- Dizziness
- Weakness
- Confusion
- Visual disturbances
- Syncope
- Seizures
- Fecal incontinence
- Urinary incontinence
- Memory disturbances
- Gait disturbances
- Bizarre neurologic symptoms
- Coma
- Death

Firefighter Headaches

- While CO should always be considered a possible cause of headaches in working firefighters, there are more common causes:
  - Tight helmet ratchet.
  - Too heavy a helmet (especially leather).
  - Dehydration.

Signs and Symptoms (Chronic)

- Signs and symptoms the same as with acute CO poisoning except that onset and severity may be extremely varied.

Cherry red skin color is not always present and, when present, is often a late finding.

COHb levels do not always correlate with symptoms nor predict sequelae.

nptoms

		adac rred nfusi spnea hypr pitat ypoter cardiac pulmon
Fatal	> 60%	Death

CO ppm	Duration	Symptoms
50	8 hours	OSHA minimum
200	2-3 hours	Mild headache, fatigue, nausea, dizziness
400	1-2 hours	Serious headache—other symptoms intensify. Life-threatening > 3 hours
800	45 minutes	Dizziness, nausea and convulsions. Unconscious within 2 hours. Death within 2-3 hours.
1,600	20 minutes	Headache, dizziness and nausea. Death within 1 hour.
3,200	5-10 minutes	Headache, dizziness and nausea. Death within 1 hour.
6,400	1-2 minutes	Headache, dizziness and nausea. Death within 25-30 minutes.
12,800	1-3 minutes	Death

Signs and Symptoms

- CO may be the cause of the phenomena associated with haunted houses:
  - Strange visions.
  - Strange sounds.
  - Feelings of dread.
  - Hallucinations.
  - Inexplicable deaths.

Long-Term Complications

- **Delayed Neurologic Syndrome (DNS):**
  - Recovery seemingly apparent.
  - Behavioral and neurological deterioration 2-40 days later.
  - True prevalence uncertain (estimate range from 1-47% after CO poisoning).
  - Patients more symptomatic initially appear more apt to develop DNS.
  - More common when there is a loss of consciousness in the acute poisoning.

Delayed Neurologic Syndrome

- **Signs and Symptoms:**
  - Memory loss
  - Confusion
  - Ataxia
  - Seizures
  - Urinary incontinence
  - Fecal incontinence
  - Emotional lability
- **Signs and Symptoms:**
  - Disorientation
  - Hallucinations
  - Parkinsonism
  - Mutism
  - Cortical blindness
  - Psychosis
  - Gait disturbances
  - Other motor disturbances

Long-Term Complications

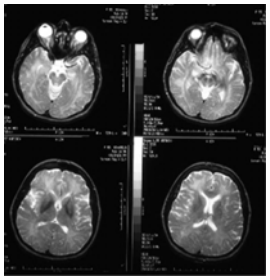
- **Cardiac Complications:**
  - 230 sequential patients with moderate to severe CO poisoning treated with HBO.

CO Myocardial Injury	Patients (n)	Died (%)	5-year Survival (%)
Myocardial injury from CO	85	37.6	71.6
No Myocardial injury from CO	145	15.2	88.3

Henry CR, Satran D, Lindgren B, et al. Myocardial injury and long-term mortality following moderate to severe carbon monoxide poisoning. *JAMA*. 2006;295:398-402

Long-Term Complications

- Depression and anxiety can exist up to 12 months following CO exposure.
- Higher at 6 weeks in patients who attempted suicide by CO.
- No differences in rates between accidental and suicide-attempt at 12 months.



CO DETECTION

Carbon Monoxide Detection

- CO detectors have been widely-available for over a decade.
- Still vastly underutilized.
- Underwriters Laboratories (UL) revised guidelines for CO detectors in 1998.
- Units manufactured before 1998 should be replaced.

Carbon Monoxide Detection

- Biological detection of CO limited:
  - Exhaled CO measurement.
  - Hospital-based carboxyhemoglobin levels (arterial or venous).

Carbon Monoxide Detection

- Technology now available to detect biological COHb levels in the prehospital and ED setting.
- Referred to as CO-oximetry

Carbon Monoxide Detection

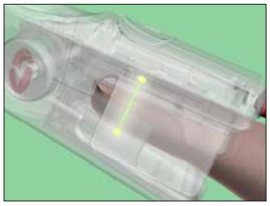
- Hand-held devices now available to assess atmospheric levels of CO.
- Multi-gas detectors common in the fire service:
  - Combustible gasses
  - CO
  - O_2
  - H_2S

Carbon Monoxide Detection

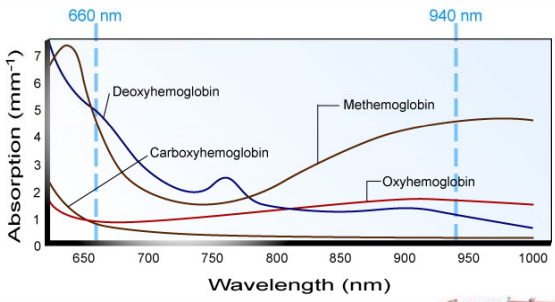
- New generation oximeter/CO-oximeter can detect 4 different hemoglobin forms.
  - Deoxyhemoglobin (Hb)
  - Oxyhemoglobin (O_2Hb)
  - Carboxyhemoglobin (COHb)
  - Methemoglobin (METHb)
- Provides:
  - SpO_2
  - SpCO
  - SpMET
  - Pulse rate

CO-Oximetry

- Uses finger probe similar to that used in pulse oximetry.
- Uses 8 different wavelengths of light (instead of 2 for pulse oximetry).
- Readings very closely correlate with COHb levels measured in-hospital.



CO-Oximetry



CO-Oximetry

- CO evaluation should be routine at all levels of EMS and the fire service.
- All field personnel should be educated in use of the oxmeter and CO-oximeter.

Missed CO poisoning is a significant area of legal liability for EMS and fire personnel.

CO POISONING TREATMENT

Diagnostic Criteria

- Biologic:
  - COHb > 5% in nonsmokers.
  - COHb > 10% in smokers.
- Environmental:
  - No confirmatory test.

Diagnostic Criteria

- **Suspected:**
  - Potentially-exposed person, but no credible threat exists.
- **Probable:**
  - Clinically-compatible case where credible threat exists.
- **Confirmed:**
  - Clinically-compatible case where biological tests have confirmed exposure.

Treatment

- Treatment is based on the severity of symptoms.
- Treatment generally indicated with SpCO > 10-12%.
- Be prepared to treat complications (i.e., seizures, dysrhythmias, cardiac ischemia).

Treatment

- Administer high-concentration oxygen.
- Maximizes hemoglobin oxygen saturation.
- Can displace some CO from hemoglobin.
- Associated with improvements in neurological and cardiac complications.

The importance of early administration of high-concentration oxygen CANNOT be overemphasized!

Treatment

- Prehospital CPAP can maximally saturate hemoglobin and increase oxygen solubility.
- *Strongly suggested* for moderate to severe poisonings.

Treatment Algorithm

Treatment

- Efficacy of hyperbaric oxygen therapy (HBO) is a matter of conjecture although still commonly practiced.
- Generally reserved for severe poisonings.
- May aid in alleviating tissue hypoxia.
- Significantly decreases half-life of COHb.

Indications for HBO Therapy

- **Strongly consider for:**
  - Altered mental status.
  - Coma.
  - Focal neurological deficits.
  - Seizures.
  - Pregnancy with COHb>15%.
  - History of LOC.

Indications for HBO Therapy

- **Possibly consider for:**
  - Cardiovascular compromise (e.g., ischemia, dysrhythmias).
  - Metabolic acidosis.
  - Extremes of age.

Treatment

- Continue to monitor SpO_2 and SpCO levels throughout treatment.
- Obtain 12-lead ECG (if ALS) and monitor ECG.
- Document findings and plot trends.

Treatment

- First-generation pulse oximeters may give falsely elevated SpO_2 levels in cases of carbon monoxide poisoning.
- Cannot distinguish between O_2Hb and COHb.

CO Poisoning

- Remember, CO poisoning is the great imitator.
- Missed CO exposure often leads to death and disability.
- CO is a particular risk for firefighters.

A simple COHb reading can save a life and possibly prevent long-term complications.

METHYLENE CHLORIDE

Methylene Chloride Exposure

- Methylene chloride slowly metabolized to CO.
- Victims do not pose contamination risks to rescuers.
- Victims with contaminated clothing or skin can secondarily contaminate response personnel by direct contact or through off-gassing vapor.
- Methylene chloride vapor may also off-gas from the toxic vomitus of victims who have ingested methylene chloride.

Methylene Chloride Exposure

- **Methylene chloride can cause:**
  - Acute CNS depression.
  - Respiratory depression.
  - Cardiac dysrhythmias.
  - Respiratory tract irritation (at high levels).
  - Non-cardiogenic pulmonary edema (at high levels).

Methylene Chloride Exposure

- **Treatment:**
  - No antidote for methylene chloride.
  - Support respiratory and cardiovascular functions.
  - Administer O_2 (O_2 is an antagonist of metabolically-produced carbon monoxide).

DOUBLE TROUBLE: CO and CYANIDE

Carbon Monoxide and Cyanide

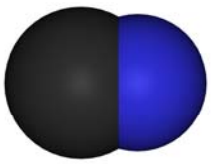
- Cyanide more often encountered in fires than once thought.
- The effects of CO and cyanide are cumulative.
- Symptoms of cyanide toxicity often attributed to CO because of lack of a high index of suspicion.

Chemistry of Cyanide

- **Gas:**
  - Colorless.
  - Faint bitter almond smell.
- Nearly 40% of the population cannot smell cyanide.
- Sodium cyanide (NaCN) and potassium cyanide (KCN) are both white powders.

Chemistry of Cyanide

- Molecule consists of one carbon atom joined to one nitrogen atom by a triple bond.
- Cyanide anion is extremely toxic.



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Cyanide

- Hydrogen cyanide is a product of combustion.
- High in:
  - Plastics.
  - Wool
  - Silk.
  - Synthetic rubber.
  - Polyurethane.
  - Asphalt.

Cyanide

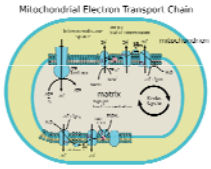
- Toxicity varies with chemical form.
- Hydrogen cyanide (HCN) gas at concentrations of 130 ppm can be fatal within an hour.
- OSHA permissible exposure levels are 10 ppm as an 8-hour time-weighted average.

Pathophysiology

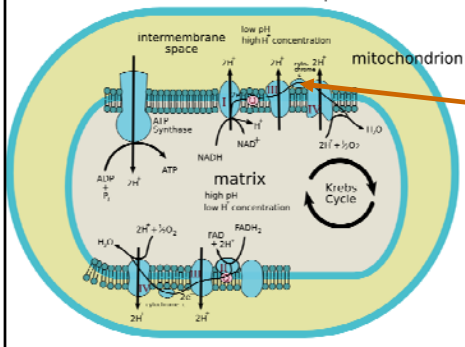
- Cyanide can be inhaled of ingested.
- Ingestion more common with suicide or murders.

Pathophysiology

- Cyanide is an irreversible enzyme inhibitor:
  - Cytochrome c oxidase (aa_3).
  - Part of the 4th complex of the electron transport chain.
  - Found in the shelves (cristae) of the mitochondria in the cells.



Mitochondrial Electron Transport Chain



Pathophysiology

- Cyanide stops the e
  and stops energy pr
  cell.
- Tissues that primari
  respiration are parti
  - Heart
  - Central nervous sys

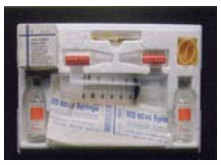
Cyanide and CO both primarily affect the heart and CNS thus multiplying the ill-effects!

Cyanide Treatment

- Antidotes available:
  - Cyanide Antidote Kit:
    - Amyl nitrite.
    - Sodium nitrite.
    - Sodium thiosulfate.
  - Hydroxocobalamin.

Cyanide Poisoning

- Amyl nitrite is administered via inhalation or ventilation.
- Sodium nitrite is administered intravenously.
- Sodium thiosulfate is administered intravenously.



Cyanide Treatment

- The nitrites promote the formation of methemoglobin.
- Cyanide has a greater affinity for methemoglobin (METHb) than the cytochrome oxidase enzyme.
- The binding of cyanide to METHb frees cytochrome oxidase so that energy production is resumed.

Cyanide Treatment

- Sodium thiosulfate binds to cyanide and forms thiocyanate.
- Thiocyanate much less toxic than cyanide anion and excreted through the kidneys.

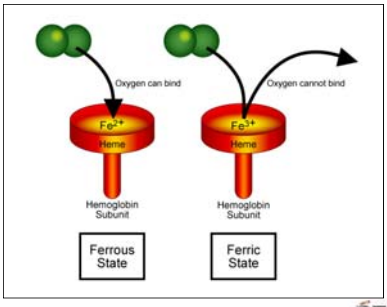
Cyanide Treatment

- Hydroxocobalamin
  - Precursor to cyanocobalamin (Vitamin B_{12}).
  - Hydroxocobalamin combines with cyanide to form cyanocobalamin which is excreted through the kidneys.
  - FDA approval in US obtained in December 2006.
  - Marketed as Cyanokit™.

Cyanide Treatment

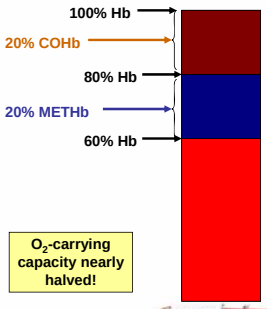
- Problems (related to nitrites):
  - METHb does not transport O_2.
  - The conversion of HB to METHb changes the state of the heme molecule where O_2 binds.
  - METHb has heme in the ferric (Fe^{3+}) state and not the ferrous state (Fe^{2+}).
  - O_2 can only bind to heme when in the Fe^{2+} state.

Cyanide Treatment



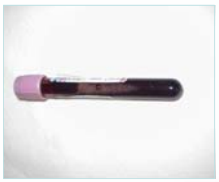
Cyanide Treatment

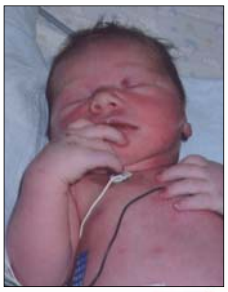
- Concomitant CO and cyanide poisoning can significantly decrease the O_2-carrying capacity of the blood.
- Combination of COHb and METHB can significantly reduce the O_2-carrying capacity of the blood.



Cyanide Treatment

- Children are particularly at risk for hypotension and adverse effects from methemoglobinemia.





CO and Cyanide

- Parts of cyanide antidot… nitrite) induce methemo…
- Cyanide antidotes and … elevated COHb and ME… reducing O_2 capacity of…
- Sodium nitrite should b… combination cyanide/C… >10%.
- Hydroxocobalamin con… cyanocobalamin (Vitamin B_{12}) which is renally-cleared.

Hydroxocobalamin is the cyanide antidote of choice for mixed cyanide and *CO* poisonings.

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