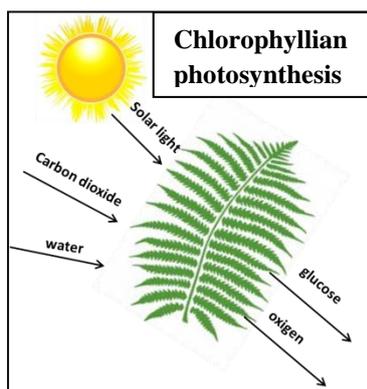


The Silent Assassin: Sources and Toxicity of Carbon Monoxide

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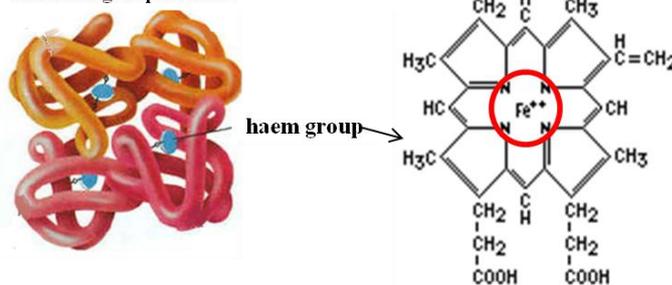
To appreciate the problem caused to humans by carbon monoxide (CO) it is first necessary to understand the importance that oxygen (O₂) has assumed. Although we are still unclear exactly how life on earth began some 4 x 10⁹ years ago, it is generally agreed that the subsequent evolution of living systems has resulted from the increasing sophistication of their chemistry in an attempt to improve the capacity for survival. This is particularly well illustrated in the case of oxygen. The oxygen rich atmosphere that we live in today is very different from that which originally existed on earth and life initially evolved in an environment in which oxygen was not available. Only much later, following the onset of photosynthesis, did O₂ start to accumulate in the atmosphere. The build-up was very gradual which was just as well, as the presence of the reactive chemical, O₂, had enormous consequences for early life and mass extinctions clearly occurred in this period. Survival of an organism, at this time, depended on the ability to select habitat to avoid the toxic gas oxygen altogether, or on the development of cellular devices to protect against its toxic effects. Over time these protective molecular devices were able to develop further to generate novel functions and uses which would eventually allow new species to emerge.



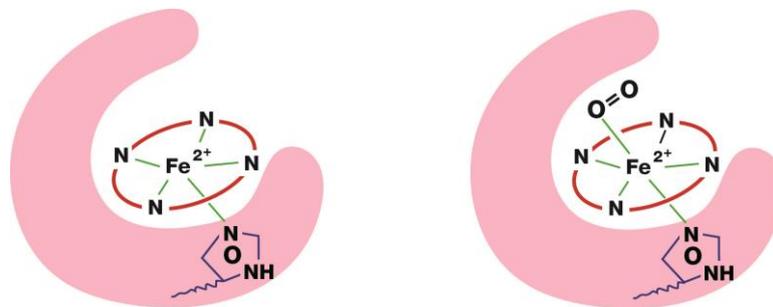
Despite the enormous problems posed to life by exposure to O₂, the opportunity to move from anaerobic to the much more efficient aerobic respiration provided great advantages that have undoubtedly led to the evolution of the higher organisms that we find on earth today. The requirement for O₂ by higher organisms has now become so important; that to deal with the problems of supplying it to enclosed tissues and to overcome the limitations imposed by the low solubility of oxygen in water it has been necessary to develop special systems for acquiring and transporting O₂. Higher organisms such as

mammals use blood, an aqueous system, to transport and distribute essential nutrients and to expel waste products. The mammalian blood stream is therefore used to distribute O₂ to all cells in the body. Unfortunately the solubility of O₂ in water is very low and complex organisms can only gain access to the required amount of oxygen to support respiration by employing an oxygen carrier. Mammals employ the iron based protein haemoglobin (Hb) as an oxygen carrier; lower invertebrates make use of a different iron protein haemerythrin, while molluscs and arthropods rely on the copper based protein haemocyanin. Mammalian blood, can in fact, dissolve over 30 times as much O₂ as pure water as a result of the presence of haemoglobin.

Schematic representation of haemoglobin and haem group formula.



Oxygen has now become so important to human beings that asphyxiation will occur when the body is not able to access sufficient O_2 to support cellular respiration. This can occur whenever the level of oxygen in the air being breathed in is significantly depleted, and is always a cause for concern when people enter confined spaces. Moreover, in the presence of certain poisonous gases, known as chemical asphyxiants, asphyxiation can occur even when the inhaled atmosphere contains normal levels of oxygen. The sophistication of the chemistry displayed by haemoglobin is beyond the scope of this study; suffice it to say that it is ideally suited to pick up O_2 readily in the oxygen rich atmosphere of the lungs and to release it to the tissues where it is needed. The bonding of oxygen to the iron atoms in haemoglobin is of necessity quite weak, as the oxygen must be easily detached when needed. Threats can, therefore, be posed by other molecules that are able to bond more strongly. Fortunately the oxygen binding site in haemoglobin is generally well protected by the surrounding protein structure, however, chemical asphyxiants, such as hydrogen sulphide (H_2S), hydrogen cyanide (HCN) and CO, tend to be small molecules that can gain access, binding strongly to iron, thus inhibiting oxygen uptake and causing asphyxiation.

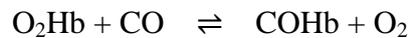


Schematic diagram to show how the protein protects the haem groups in haemoglobin

Harmful effects arising from exposure to chemicals can be classified as acute, when they occur almost immediately, or chronic, where they only develop over a period of time and tend to be associated with repeated exposures to very low levels. Most of the concern expressed about CO relates to the acute effects associated with high levels. Low levels of exposure can cause symptoms such as headache and breathlessness, which are associated with many other common complaints. Higher exposures can lead to unconsciousness and eventually death. However, where an individual suffers neither death, nor irreversible brain damage following exposure essentially complete recovery is normal. Any reduced oxygen carrying capacity of the blood is, however, likely to place increased stress on the heart, putting the health of individuals suffering from heart disease or angina at risk and even for the healthy possibly leading to coronary problems over time.

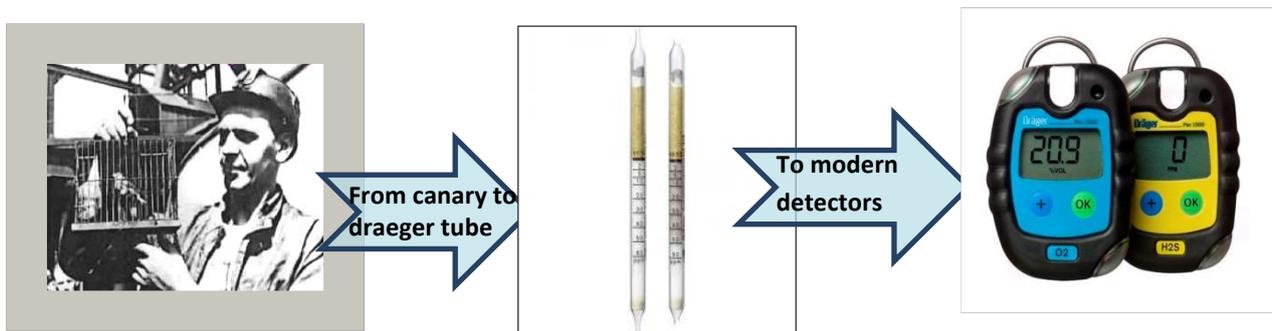
Although the acute toxicity associated with both HCN and H_2S is certainly higher than that of CO, it is the latter that poses the greatest threat to our health on account of its widespread occurrence and the difficulty of detection. Unlike hydrogen sulphide, for example, whose presence is readily perceived because of its intense and obnoxious smell, CO is a tasteless, colourless, odourless gas which is undetectable by our senses and victims are frequently unaware of its presence, even when they are being exposed to potentially fatal doses. As indicated above, the toxicity of CO arises from its ability to bind strongly to the iron atoms in haemoglobin and inhibit oxygen uptake. The binding of CO to haemoglobin is some 200

times stronger than that of O₂ which means that in an atmosphere containing normal levels of O₂, about 21% by volume, as little as 0.1% (1000 ppm) CO can rapidly reduce the amount of oxygen being carried by a factor of 2.



A patient suffering from CO poisoning is therefore likely to be treated with oxygen to try to move equilibrium towards the left.

CO is currently produced by a wide range of both natural and anthropogenic processes. It arises mainly from the incomplete oxidation or combustion of carbonaceous materials. Efficient combustion of such materials produces mainly carbon dioxide (CO₂) which is generally considered to be harmless at low concentrations. Inefficient combustion, however, can produce carbon monoxide which can be fatal, following prolonged exposure to even low levels. In the past CO was considered primarily an occupational hazard with most cases of poisoning arising from the exposure of coal miners in underground caverns. The difficulty of detecting dangerous levels of CO led to miners taking a canary down the mine with them. Canaries are even more sensitive to CO levels than humans, so if the canary fell off its perch the miners knew it was time to evacuate. The development of stain tube detectors, by the German company Draeger (draeger tubes), early in the last century, represented a major step forward. In use a predetermined volume of air is drawn through a calibrated tube containing an adsorbed chemical that reacts with a particular gas to produce a colour change, thus



enabling atmospheric levels to be determined. There are currently some 300 draeger tubes but the first was developed to detect CO.

Combustion of any fossil fuel or other carbonaceous material will produce both CO₂ and CO, with levels of CO tending to be low under ambient O₂ concentrations but rising sharply as oxygen concentrations decrease. Oxygen is, of course, consumed in the combustion process but providing a fire is well ventilated atmospheric levels are likely to be maintained. However, where ventilation is poor, as for example in a house or workplace where the windows and doors are closed, oxygen levels are likely to fall and CO levels to rise rapidly as combustion progresses. Carbon monoxide represents a major hazard in house fires, where individuals might readily be overcome by the developing levels. In fact the majority of fatalities in house fires would appear to result from CO poisoning. Sleeping individuals are

particularly at risk as they can be poisoned without even waking up. It is now considered prudent to have smoke alarms fitted in houses to wake sleepers and warn them of a potentially dangerous situation.

The risk of exposure to CO has been further increased by the widespread use of efficient boilers as a source of domestic heating. Unlike open fires where the secondary supply of air is not controlled and in general the fire is well ventilated, such boilers control the supply of air to provide the correct amount for efficient combustion of the fuel. If such boilers are not well maintained air levels may start to vary, possibly producing dangerous conditions, where heightened levels of CO are emitted. Exit gases from the boilers are usually exhausted to the outside of buildings, but if the exhaust becomes blocked dangerous levels can be emitted directly inside the building. Deaths from CO poisoning, due to poorly maintained boilers, are currently an all too regular occurrence. Even open coal or wood fires are not without their risks. Where such fires are allowed to extinguish themselves there is often a prolonged period of inefficient combustion producing significant levels of CO. This may give rise to risks to occupants particularly in small poorly ventilated rooms. Smoke detectors will provide no direct warning of heightened CO levels and dedicated CO detectors are recommended where boilers are present in homes.



CO detectors, to warn of elevated levels indoors, can employ a range of different chemical principles but tend to be more complex, more expensive and less efficient than smoke detectors. The first marketed CO sensor was based on a metal oxide semiconductor. Unfortunately this technology is not ideal for domestic appliances as the sensors have high power requirements and must be mains-powered, placing limitations on where they can be sited.

Also, as the response of the sensor is not specific to CO, false alarms tend to occur with many other substances such as air fresheners, paint fumes and hair sprays. Subsequent detectors have been developed based on biomimetic sensors using optical detection and electrochemical technology where the generated current can be directly related to the level of CO in the atmosphere. Such electrochemical sensors are able to differentiate between the high levels of CO likely to cause acute poisoning and lower, but still potentially harmful concentrations. Palladium chemistry provides the basis for a convenient method of detecting CO leaks. Small self-adhesive badges containing a circular spot of palladium(II) chloride dehydrate and copper(II) chloride can be affixed to the wall near a potential source of CO. The orange palladium chloride is turned black by reduction of Pd(II) to the metal by CO.



The process is reversible with copper chloride catalysing regeneration when the badge is exposed to air free from CO.

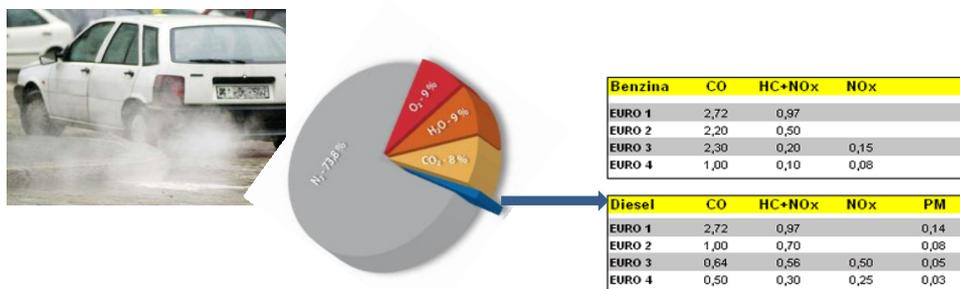
Regardless of the detector chosen its placement is crucial for efficient detection. Carbon monoxide is slightly lighter than air and is often, in fact, released in a stream of warm rising

air. Detectors are, therefore, ideally located affixed to the ceiling and should certainly be positioned at least 2 metres above floor level. Care must also be taken to protect the detector from damage arising from external agencies. Detectors must not be placed too near to a fireplace or flame-producing appliance and should be kept well away from pets and children. Ideally a carbon monoxide detector should be located on each floor of a building but if only one detector is being used in a house it should certainly be sited in the proximity of the sleeping area with an alarm loud enough to wake sleepers in an emergency.

Alarms need to be arranged to go off before inhabitants are likely to experience any harmful or debilitating exposures. It is, therefore, important that individuals do not ignore the alarm but evacuate themselves and other occupants of a building quickly on hearing it. Once in the fresh air it is important to ascertain if anyone is suffering any of the symptoms of carbon monoxide poisoning and seek appropriate medical help where necessary.

The widespread, and ever increasing, use of cars for transportation, following the development of the internal combustion engine, now represents the major source of environmental CO. While open fires and domestic boilers both seek to combust carbonaceous material in the presence of sufficient O₂ to ensure efficient combustion, which will produce little CO, the situation is very different in the case of the internal combustion engine. Traditionally, internal combustion engines have not been designed primarily for efficient energy use but to maximise power. This is achieved, in so called 'lean-burn' engines, by restricting the secondary air supply so that there is an excess of the fuel, e.g. petrol. This inevitably leads to inefficient combustion and produces elevated levels of CO which are expelled through the exhaust into the surrounding atmosphere. Modern cars use computerised control of air intake and catalytic convertors in the exhaust to help control emissions. Nevertheless, whenever a car engine is left idling in a confined space, such as a closed garage, levels can build up quickly, possibly overcoming and poisoning any occupants. Problems may even arise outdoors, if the density of traffic becomes sufficiently high, and hazardous concentrations frequently arise in large cities at times of high traffic density, such as rush hours.

Chemical composition of exhaust gases for gasoline and diesel engines



Concern has been expressed that traffic police working in inner city areas may be placing their long-term health at risk due to regular exposures to elevated CO levels. Once emitted, CO is relatively stable with a residence time in the atmosphere of about four months.

Cigarette smoking, besides resulting in exposure to many toxic by-products, also produces CO and elevated levels of COHb are found in the blood of smokers. Concern that the

diminished oxygenation of blood might harm a developing foetus has led to expectant mothers being advised not to smoke during pregnancy. Smokers are often unaware of their level of exposure to carbon monoxide or even to the extent that they inhale cigarette smoke. Here the measurement of carbon monoxide concentrations in exhaled breath can be useful. The amount of CO in expiratory breath can be directly related to the amount of CO bound to haemoglobin in the blood and is dependent on the extent to which an individual smokes and whether they inhale or not. Such measurements have an important role to play in informing and counselling smokers regarding the risks to which they are exposing their health and the need to moderate or stop their smoking. CO exposure also differs with the tobacco product used. For example the average amount of CO produced when 1 gram of cigar tobacco is burned lies between 39 and 65 mg of CO while for cigarette tobacco this value falls to around 19mg of CO per gram of tobacco. This difference arises because cigarette paper is porous so the tobacco will tend to burn more efficiently than in a more tightly wrapped cigar. It should be noted that while it is the toxicity of CO which is rightly seen as the major concern, the gas is also extremely flammable and mixtures of air containing between 12% and 74% CO are explosive. The literature contains numerous reports of explosions and accompanying fatalities and property destruction, resulting from leaks of town gas supplies containing CO.

Finally, despite our preoccupation with the harmful effects associated with carbon monoxide, we must acknowledge that a number of useful applications have been found for this gas. For example, some meat products are packaged in an atmosphere enriched in CO, rather than normal air, to inhibit spoilage. However, carbon monoxide will bind to myoglobin in the meat to give a pleasant pink colour associated with fresh meat. Although no health hazards are directly associated with this process, concerns about consumer safety have been expressed. People tend to buy meat according to how it looks. While normal meat tends to darken in colour as it spends time on the shelf, meat that has been packaged in an atmosphere enriched in carbon monoxide will continue to look pink and fresh past the point at which it should no longer be sold. There are of course other indicators of a lack of freshness, such as a slimy appearance or bulging packaging due to gases released through bacterial action, but one can be easily misled by appearances.