CHAPTER 9

Environmental pollutants

Chapter outline

This chapter examines the various aspects of environmental pollution and explores some specific examples:

- Introduction
- Air pollution
- Particulates
- Acid rain
- Lead pollution
- Water pollution
- Arsenic
- Food chains
- Endocrine disruptors
- Mercury and methylmercury

Introduction

Pollution of our environment has become an increasing problem over the last century with the development of industry and agriculture and with the increase in population. That is not to say that pollution did not exist before the nineteenth century, indeed there was legislation enacted in Britain during the thirteenth century to control smoke from household fires in London. However, pollution on the current scale started during the **Industrial Revolution**. Nineteenth-century factories used coal for fuel and in certain processes, and consequently smoke was a major pollutant. Blast furnaces and chemical plants added other fumes and other types of noxious substance. As many industrial processes used water for power, as part of the process, or in some other way, factories were often sited near rivers and effluent was discharged into them. In this way both the atmosphere and rivers became polluted. More recently the land has also become polluted from agricultural use of fertilizers and pesticides, as well as from the dumping of toxic

wastes from factories and industrial processes. Consequently air, water and the earth have all suffered pollution and we may divide environmental pollution into these categories.

Despite the appalling working and living conditions which existed during the Industrial Revolution in parts of Britain during the nineteenth century and in heavily industrialized areas in other European countries and the USA, it was not until the twentieth century that a serious attempt was made to curb pollution. One event which precipitated this was the **'great smog' in London** in the winter of **1952**. A combination of weather conditions and smoke from domestic coal fires, factories and power stations resulted in a thick smog which contributed to the deaths of over *four thousand* people (Figure 9.1).

At around the same time the River Thames was found to be so highly polluted that fish, particularly salmon, could not live in the lower parts of the river. This was as a result of industrial processes and other processes dumping effluent into the river. The same was true in some other cities in the UK and in other industrial countries.

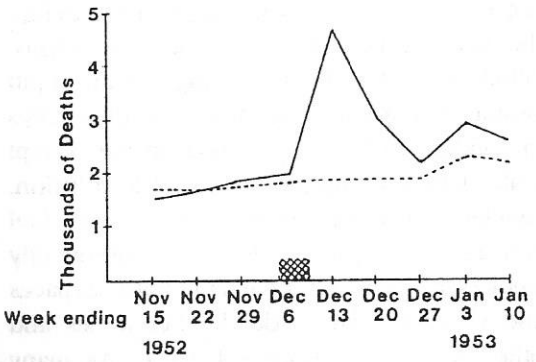

FIGURE 9.1 *Deaths associated with the London 'fog' of December 1952. The solid curve shows the number of weekly deaths in Greater London before and after the 'fog' whereas the dotted line shows the average number of deaths for the preceding 5 years. The hatched area shows the dates of the 'fog'.*
Data from Goldsmith, J. R. in Air Pollution, *Vol. 1. Chapter 10, pp. 335–386, Figure 1. Ed. A. C. Stern, NY: Academic Press, 1962.*

In Britain, as a result of the smog, the Clean Air Act was passed which led to a reduction in the production of smoke in cities. Other legislation concerned with pollution of rivers allowed the gradual clean-up of the Thames. Now smogs in London no longer occur and there are salmon swimming in the Thames. This has taken many years, however, and in other parts of Britain, as in some other countries, clean-up of the environment has not always been so successful. Air pollution from coal-burning power stations still occurs and it is now recognized that this pollution travels many hundreds of miles from countries such as Britain to Norway, Sweden and Germany, and from the USA to Canada. In these countries the air pollutants and acid rain (see page 125) cause damage to trees and other plant life and also to fish and other aquatic organisms. This illustrates that pollution is an *international* rather than a purely national problem.

Pollution of the environment is usually a continuous, deliberate process although industrial and other accidents may also contribute to environmental pollution in an acute rather than chronic manner. Let us consider some examples of environmental pollution.

Air pollution

The study of air pollution involves many disciplines ranging from chemistry, engineering, epidemiology, zoology, botany, ecology, toxicology and meteorology to economics and politics. It is not a new phenomenon although it has only relatively recently become of such importance.

The most visible form of air pollution is of course **smoke** but this contains many constituents depending on the source and is accompanied by various potentially **toxic gases**. The burning of the fossil fuels coal and oil as well as certain industrial processes give rise to the gases **sulphur dioxide**, **carbon dioxide**, **carbon monoxide** and **nitrogen oxides**, and perhaps **hydrogen sulphide**, **volatile hydrocarbons**, and **particulate matter** such as carbon and ash. In Britain these amount to millions of tonnes per year; sulphur dioxide from burning fuel amounts to at least 4 million tonnes discharged into the atmosphere every year. In the USA the five major pollutants which amount to 98 per cent of all the air pollution are carbon monoxide (52 per cent), sulphur oxides (18 per cent), hydrocarbons (12 per cent), particulates (10 per cent) and nitrogen oxides (6 per cent). These air pollutants arise from the combustion of fuels in **power stations** and domestically, from **car exhausts**, from **industrial processes**, and from **waste disposal**.

The composition and dispersion of air pollutants may also be influenced by climatic conditions and can lead to '**smog**'. Originally this term was coined to describe the combination of fog and smoke which hung over industrial cities under damp atmospheric conditions but it now also includes air pollution from car exhausts which has been modified by climatic conditions.

There are in fact two types of smog. **(1) Reducing smog** which has a high level of particulates and sulphur dioxide and comes from coal burning in particular. It results from a combination of incomplete combustion, fog and cool temperatures. **(2) Photochemical-oxidant smog**, for which Los Angeles is notorious, has a high concentration of ozone, nitrogen oxides and hydrocarbons. This is an oxidizing pollutant mixture arising particularly from the interaction of the constituents of car exhausts in bright sunlight. Meteorologic inversion, as occurs in the Los Angeles basin, not only promotes this interaction but also traps the pollutants near the ground. The constituents of air pollution may in turn be altered in the atmosphere. For example, hydrogen sulphide and nitrogen dioxide may be oxidized to sulphuric and nitric acids respectively.

Ozone arises from a cyclic reaction between nitrogen dioxide and oxygen, with ultraviolet light and hydrocarbons as necessary catalysts:

$$NO_2 \xrightarrow{uv} NO + O$$
$$O_2 + O \rightarrow O_3$$
$$O_3 + NO \rightarrow NO_2 + O_2$$

What are the effects of all these pollutants on the health of man and the animals and plants in the environment?

Some of the acute effects on human health are known from several episodes which have occurred within the last 50 years. The three major episodes which have led to increased human mortality and morbidity were in the **Meuse Valley** in Belgium (1930), in **Donora**, Pennsylvania (1948), and in **London** (1952). In each case the area was heavily polluted and the same meteorological conditions (inversion) prevailed which allowed a stagnant mass of polluted air to accumulate and the pollution level to rise.

Sixty-five people died in Belgium and twenty in Donora. *Four thousand* deaths in London were attributed to the smog (Figure 9.1). These deaths were mainly in elderly people who already had respiratory or cardiac disease. After the smog in Belgium it had been predicted that a similar occurrence in London would lead to 3200 extra deaths. In fact there were 4000. On the worst day of the smog, the daily average pollutant levels were: **sulphur dioxide** 1.34 ppm and **smoke** 4.5 mg m^{-3}. Another London smog in 1962 resulted in

400 extra deaths. It has been estimated that a sulphur dioxide level of 0.25 ppm and a smoke level of 0.75 mg m^{-3} will produce an increase in mortality over the normal rate. Epidemiological studies of human populations have shown a higher incidence of **pulmonary** and **cardiovascular disease** in association with smog. Air pollution is believed to be a factor in lung cancer, the incidence of which is higher in urban areas but there are many unknown and possibly confounding factors. Some correlation has also been detected between certain other diseases, such as heart disease, with pollution levels. Chronic air pollution certainly aggravates existing respiratory diseases including the common cold and may even be a contributory factor. Filtration of air gives relief to some susceptible individuals. One early study in Britain showed a striking correlation between levels of certain pollutants (the reducing type) and the level of discomfort of patients with chronic bronchitis. It was estimated that the levels of smoke and sulphur dioxide needed to be below 0.25 mg m^{-3} and 0.19 ppm respectively for there to be no response. Indeed, the mortality from chronic bronchitis is correlated with the amount of sulphur dioxide and dust levels.

There is, however, less data on the effects of photochemical-oxidant pollution on human health. One study examined the performance of an athletic team in Los Angeles in the USA over several seasons and monitored photochemical-oxidant pollutant levels. There was a *striking correlation* between the level of oxidizing pollutants in the air and a decrease in performance, with effects demonstrated at a level as low as 0.1 ppm. The mean oxidant level in Los Angeles at this time exceeded 0.1 ppm and the maximum hourly level reached 0.6 ppm at certain times. Lung function as measured by **forced expiratory volume** is measurably reduced in people living in polluted areas but such data do not indicate which pollutant is responsible and other factors may be equally important.

Experimental exposure of animals or human volunteers to individual pollutants shows toxic effects on pulmonary airways such as constriction and, hence, increased resistance, but **synergistic** effects occur between pollutants when they are present in mixtures. For example, the reaction between sulphur dioxide, water and ozone to give sulphuric acid is facilitated by the presence of hydrocarbons and particulates. Sulphur dioxide is an irritant but its lethal concentration is far greater than the amount normally encountered in air pollution. **Levels of sulphur dioxide** greater than **0.05 ppm** have been reputed to cause an increased incidence of respiratory illness and chronic exposure to levels above 0.2 ppm increased mortality. Exposure to levels of 1–5 ppm gives rise to acute discomfort. Smoke has a synergistic effect on sulphur dioxide toxicity so that the *combination* has a *greater* effect than either individual constituent.

Nitrogen dioxide and **ozone** are *more toxic* than sulphur dioxide and are deep lung irritants. Nitrogen oxides arise from car exhaust and other sources and cause respiratory symptoms at concentrations of 5–10 ppm. The levels of nitrogen oxides in Los Angeles average 0.7 ppm. Ozone causes damage to sensitive plants and affects humans suffering from asthma at levels of 50 ppb, yet in July 1976 concentrations of 260 ppb of ozone were measured in Britain and these levels were maintained for a week. The permitted level of ozone in factories is 80 ppb.

Carbon monoxide is another constituent of pollution, especially that derived from car exhausts. Although the chronic toxic effects of carbon monoxide are uncertain, the acute effects are well known (see Chapter 11). Carbon monoxide is very toxic, binding *avidly* to **haemoglobin** in competition with oxygen so as to reduce the ability of the blood to

supply oxygen to the tissues. This will cause brain damage and death at high levels of blood saturation. It has been suggested that chronic exposure to carbon monoxide may cause heart damage resulting from tissue anoxia. Changes in blood pressure, pulse rate and cardiac output occur after 30 per cent saturation of blood with carbon monoxide, which is achieved at an ambient concentration of 75 ppm. The urban air concentration may be around 10–20 ppm resulting in about 4–8 per cent saturation. However, exposure levels as high as 100 ppm may be experienced in some circumstances such as by traffic policemen. These concentrations cause dizziness, headache and lassitude. Levels of 120 ppm for one hour or 30 ppm for eight hours are considered serious in the USA. Carbon monoxide is also present in **cigarette smoke** and heavy smoking may result in a level of more than 7 per cent carboxyhaemoglobin in the blood of the smoker. It is not clear whether exposure to carbon monoxide in the environment over the long term is a significant health hazard although it is believed to be an important factor in the cardiovascular effects of smoking. A positive correlation has been shown between carbon monoxide levels and myocardial infarction in Los Angeles but there were other confounding factors. Some individuals, however, such as those with anaemia who have low blood haemoglobin, are more sensitive to carbon monoxide than normal healthy people.

Pollution from power stations and especially car exhausts also contains **hydrocarbons** and these may be carcinogenic or have other toxic effects. The particulates present in smoke may become deposited in the lungs but this depends on the particle size as already described in Chapter 2. However, conclusive data on the effects of these pollutants on human health are not available. There are so many environmental factors which may adversely affect human health that attributing morbidity to a particular air pollutant is difficult.

Particulates

As well as airborne gases such as nitrogen oxides and substances such as lead, there are also particles present in the air we breathe. There is currently much concern about particular sized small particles, the so called **PM10**. These are particles which are less than 10 μm in diameter derived from cars and other vehicles. The particles vary in chemical composition but may simply be carbon emitted from car exhausts for example. There is increasing evidence that the levels of these in the air are connected to morbidity and mortality. The smallest of these particles can penetrate deep into the lungs and may therefore contribute to lung diseases. As well as a strong association between levels of particulates and deaths from respiratory diseases, there is also a correlation with hospital admissions and reports of symptoms of asthma (Bown, 1994).

Acid rain

In addition to having various effects on human health, pollutants may also be toxic to animals and plants in the environment and some of these effects can be demonstrated experimentally. One particular aspect of the environmental impact of pollutants currently of great concern is acid rain.

This term describes the **wet precipitation** of sulphuric and nitric acids and the **dry deposition** of sulphur dioxide, nitric acid and nitrogen oxides. It results from the burning of fossils fuels and certain industrial processes

which produce sulphur dioxide and nitrogen oxides:

$$H_2O + SO_2 \xrightarrow{O_2;\ uv} H_2SO_4$$
hydrocarbons

$$NO_2 + H_2O \xrightarrow{H_2O;\ uv} HNO_3$$
ozone

These acids may be present in clouds and be removed during rain formation. This is known as **washout**. Alternatively they may be removed from the atmosphere by the falling rain. This is known as **rain-out**.

The effects of acid rain have been particularly noticeable in Scandinavia, partly as a result of the type of soil there. Sweden for example received about 472 000 tonnes of sulphur dioxide in 1980 but only produced 240 000 tonnes, some of which would be deposited in other neighbouring countries, so Sweden suffered a net gain of 230 000 tonnes, despite having reduced its own production from 300 000 tonnes in 1978. Acid rain is clearly a world-wide problem whereby the pollution is transported from one country to the next. Britain exports much of its pollution to Scandinavia and continental Europe (Figure 9.2) something which the power generating companies are now beginning to accept. Increased acidity has now been recognized in Britain itself, in Scotland and Snowdonia for example. The effects of acid rain depend on the type of deposition, the soil type and other factors. The *buffering* capacity of the soil is particularly important, but the thin soils found in parts of Scandinavia have poor

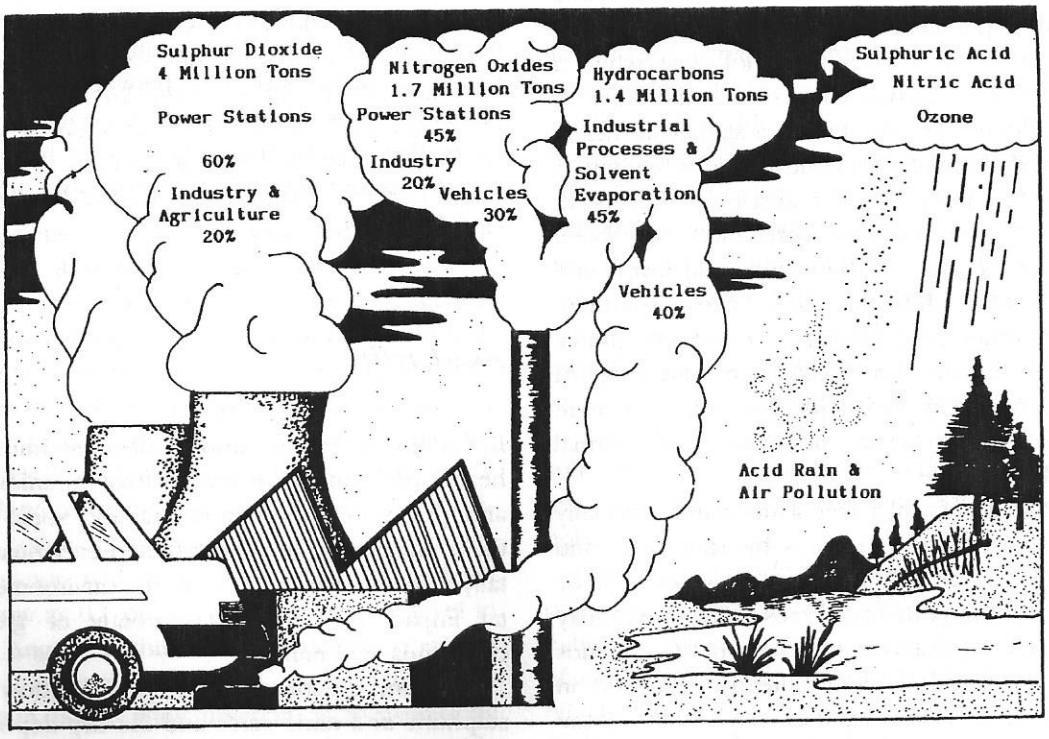

FIGURE 9.2 *A graphic illustration of the problems of air pollution and of acid rain which occur in industrialized countries. The figures give an indication of the situation in Great Britain at one time.*
Adapted from 'Why forests fear acid drops', The Sunday Times, *24 November 1985.*

buffering capacity and consequently the effects of the acidity are greater. The acidity in soil may also accumulate with time in some areas so that reducing the acid deposition will not have an immediate effect.

The sulphur and nitrogen oxides can cause rain, snow and mist to become acidic. Rain and snow mainly acidify the soil and ground water to a greater or lesser extent depending on the buffering capacity. The volume of rain or thaw water is also important for, if it is excessive, the water may overwhelm the natural buffers in the soil or saturate it. The water then runs straight into rivers and lakes with little contact with the bicarbonate and humus present in the soil which would buffer the acidity. Consequently, the rivers and lakes will become more acidic. Modern farming techniques, such as the use of **ammonium sulphate** fertilizers, may also exacerbate the increase in acidity. The actual acidity may cause certain organisms to die and will also upset the *balance* in the **ecosystem**. Water of *low* **pH** also *leaches* out metals such as **cadmium** and **lead** from the ground and causes **aluminium** salts to dissolve. These metals will damage plants if taken up by them and may also be toxic to animals. **Cadmium** is highly toxic to mammals, chronic exposure causing **kidney damage** and affecting bones in humans causing a **brittle bone syndrome**, which is known as **Itai-Itai** disease in Japan. **Aluminium** leached out of the soil and dissolved in acidic waters is believed to be one of the causes of the death of fish in Scandinavian lakes and rivers. One of the more vulnerable points is the reproductive cycle. How much damage wet deposition of acid causes to plants and especially trees is not yet clear. Dry deposition of sulphur dioxide, however, may damage leaves directly. There is serious damage to many types of **trees** in West Germany, and some estimate that 87 per cent of the firs are affected. This is now attributed to pollution. It may be due to a combination of factors and there is continuing discussion as to whether the major effect is acidification of the soil and release of toxic metals or direct damage to the leaves or needles. Clearly air pollution contains a number of different compounds, but it seems that **ozone** is the constituent which is more likely to be directly toxic to trees rather than sulphur dioxide. Acidic ground water will not only leach out toxic metals which will be taken up by the tree but it will also leach out essential nutrients and so the soil will become deficient in them.

Acid rain may directly damage leaves on contact and will damage roots following seepage into soil. It will also wash out or displace essential elements from soil thereby leading to a deficiency in these nutrients. For example, magnesium lost from soil due to acidification is believed to be an important factor in the **dieback** of trees that has occurred in Germany. Increased acidity may also increase the mobility of metals in soil resulting in migration to lower levels in the soil and so out of reach of roots. However, the effects of acidification will vary due to the different buffering capacities of the soil in different geographical regions.

The pH of lakes and rivers may be affected directly by acid rain and indirectly by changes in the microorganisms and plants. Many species are adversely affected by a low pH. For example, in a number of rivers in Nova Scotia the pH fell from 5.7 to 4.9 over the period 1954–73. During this period there has also been a fall in the number of Atlantic salmon. The balance between particular species of animal or plant will also alter as a result of acidification, some being lost and others thriving. Overall, however, there is a reduction in diversity.

Most scientists involved now agree that all of the constituents of pollution, from both power stations and cars, should be reduced as much as possible even though it is not yet clear which ones are the most important. However, some scientists and some Governments have argued that reducing sulphur dioxide, for example, may have little effect if the important determining factor is the level of ozone or hydrocarbons

which catalyze the conversion of sulphur dioxide and nitrogen oxides to sulphuric acid and nitric acid respectively. It is possible, however, to remove some of the sulphur dioxide from the smoke derived from fossil fuels before, during and after burning. Similarly, the output of carbon monoxide, nitrogen oxides and hydrocarbons from car exhausts can be reduced with **catalytic converters**. These are already in use in some countries and in the USA emissions of carbon monoxide and hydrocarbons from new cars have fallen by 90 per cent and nitrogen oxides by 75 per cent between 1970 and 1983. Two of these pollutants, nitrogen oxides and hydrocarbons, are involved in the production of ozone in the atmosphere and nitrogen oxides also contribute to acid rain as already described. In the view of British scientists at Harwell, *reducing* **hydrocarbons** in car exhausts is the best way to reduce atmospheric ozone. It should be noted, however, that some ozone in the atmosphere is necessary and that if the atmospheric level drops too low then more ultraviolet light reaches the surface of the earth, possibly leading to an increase in skin cancer. The **chlorofluorocarbons** used as aerosol propellants are believed to be one cause of a *reduction* in atmospheric ozone.

Perhaps when the real extent and economic consequences of the damage due to these pollutants such as to buildings and metal structures as well as to trees and humans become known, governments will enact legislation to cause a major reduction in output pollutants from all sources.

Lead pollution

Another major environmental pollutant is lead, known to be a poisonous compound for centuries. Its toxicity was certainly recognized by 300 BC as a case of **lead poisoning** was described by **Hippocrates** around that time. For centuries workers involved in lead mining and smelting have been occupationally exposed. Lead poisoning may even have contributed to the decline of the Roman Empire as high lead levels have been detected in Roman skeletons from that period. Lead pollution arises mainly from car exhausts but industrial processes, batteries, minerals and **lead arsenate** insecticide also contribute to lead in the environment. The use of cooking vessels with lead glaze or made of lead may have been another source in earlier times. Industrial poisoning became common in the Industrial Revolution, with a *thousand cases a year* in the UK alone at the end of the nineteenth century. However, a relatively recent study by the EEC in Glasgow showed that 10 per cent of babies had > 0.3 $\mu g\ ml^{-1}$ of lead in their blood indicating that there is still cause for concern. Lead is taken in from food, via the lungs and from water and although the amount found in food may be greater than that in air, the absorption is greater from the lungs than from the gut. Children are more susceptible than adults as they *absorb greater amounts* from the gastrointestinal tract.

It has been estimated that 98 per cent of the airborne lead in the UK is derived from leaded petrol and levels of lead in the air correlate with the amount of traffic. The lead in car exhausts is derived from **tetraethyl lead**, an anti-knock compound added to petrol which is converted to lead in the engine. Certain individuals, such as traffic policemen, may have higher blood lead levels than the average member of the urban population because they have greater exposure to car exhausts. **Cigarette smoke** is also a source of inhaled lead.

At the beginning of the twentieth century large-scale poisoning of children with lead became known, especially of those living in poor housing in slum areas of the USA. The source of this lead was mainly from paint con-

taining relatively large amounts of lead. The paint was taken in by children through contamination of food or fingers or perhaps by experimental tasting of flakes of paint. In children, the most serious effect of lead poisoning is **encephalopathy** with mental retardation, and seizures and cerebral palsy may be lifelong effects. The nervous system is a clear target for lead and is particularly susceptible in young children. A cause for concern is whether even a single episode of poisoning is sufficient to cause permanent damage in children.

After absorption, lead enters the blood where 97 per cent is taken up by the **red blood cell**. The half-life of lead in the red blood cell is 2–3 weeks. Some redistribution of the lead to liver and kidney occurs and then excretion into the **bile** or deposition in **bone** takes place. In bone the lead eventually becomes incorporated into the hydroxyapatite crystal. Due to this deposition in bone and teeth it is possible to estimate past exposure to lead by X-ray analysis. It is also possible to detect lead poisoning and exposure from urine and blood analysis as the amount in blood represents the current exposure.

The '**normal**' **blood levels** in the USA have been reported as between **0.15–0.7 μg ml^{-1}** with an average at 0.3 μg ml^{-1}. The threshold for **toxicity** is **0.8 μg ml^{-1}**, and encephalopathy occurs at 1–2 μg ml^{-1}. However, biochemical effects can be seen at lower levels: lead interferes with **haem** and **porphyrin synthesis** and its effects on the enzymes of this pathway can be demonstrated (Figure 9.3); myoglobin synthesis and cytochrome P450 may also be affected. The results of the effects on porphyrin synthesis are a reduction in haemoglobin level, the appearance of **coproporphyrin** and **aminolaevulinic acid** (ALA) in the urine. Free **erythrocyte protoporphyrin** is increased and **aminolaevulinic acid dehydrase** (ALAD) is inhibited. Inhibition of ALAD is the most sensitive measure of exposure and in human subjects there is a correlation between blood lead and the degree of inhibition of the enzyme. At blood levels of 0.4 μg ml^{-1} ALAD is inhibited to the extent of 50 per cent. At levels of 0.6–0.8 μg ml^{-1} there is a greater effect and mild symptoms; at levels of 0.8–1.0 μg ml^{-1} there are more definite clinical signs; at levels of 1–2 μg ml^{-1} encephalopathy occurs. The symptoms are non-specific **colic** and **abdominal pain**, **lassitude** and **constipation**. **Anaemia** occurs later and CNS effects occur after prolonged exposure. The blood lead level rises and ALAD falls within a few days of exposure. The ALA and coproporphyrin in urine increase after two weeks.

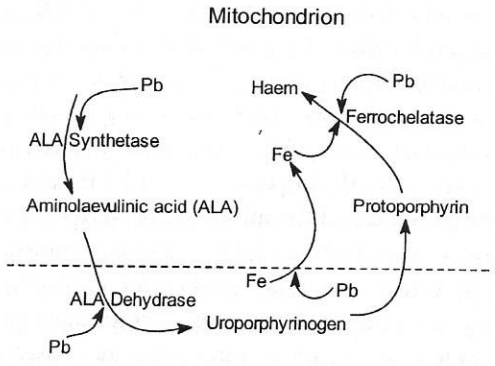

FIGURE 9.3 *The synthesis of haem in the mammalian erythrocyte. The points at which lead (Pb) interferes with this synthetic pathway are shown.*

Lead interferes at several steps in haem synthesis: with the enzymes **ferrochelatase**, **aminolaevulinate synthetase** (ALAS) and **aminolaevulinate dehydrase** (ALAD), and with the **uptake of iron** into the mitochondrion. Increased excretion of ALA in the urine is one marker for lead exposure. In 1970 10 per cent of all children in New York and Chicago had blood levels of 0.6 μg ml^{-1}. Many of these children lived in good housing. As with carbon monoxide exposure anaemic individuals who have a low haemoglobin level and reduced

red blood cell count may be more at risk as their lead carrying capacity is lower and the amount of haemoglobin is already low. Anaemia may result from lead exposure partly as a result of inhibition of haemoglobin synthesis and partly by causing the destruction of red blood cells.

Measurement of the inhibition of ALAD is too sensitive a measure of lead exposure, whereas the presence of haemoglobin and coproporphyrin in urine occurs after severe damage. The detection of ALA in urine is the most useful method for determination of lead poisoning.

As well as affecting the CNS and haem synthesis, in children lead also causes **skeletal changes** following chronic exposure. Bands at the growing ends of long bones can be detected and bone shape may also be affected. Chronic exposure may also be detected by a lead line on the gums. Acute exposure to lead may also cause **kidney damage**, while chronic exposure may lead to interstitial **nephritis**. This may be the cause of the nephritis associated with drinking moonshine whisky as the stills used sometimes contained lead piping or lead solder.

Whether lead in the atmosphere in cities poses a real threat to the mental health of children is currently disputed. Barltrop does not believe that the data shows there is a clear relationship between the body lead burden and IQ decreases in children but it may be difficult to prove such a relationship. In the UK there have been three reports on this: by the DHSS, by a Royal Commission and by the Medical Research Council; all have concluded that many of the studies on this aspect of lead poisoning were inadequate. Studies are under way to look at blood lead levels of 0.4–0.8 $\mu g\ ml^{-1}$ in relation to the function of the central and peripheral nervous system. It has been suggested that subclinical disease of the central and peripheral nervous system and kidney may follow long-term exposure at levels to which the general population are exposed in the urban environment. This is very difficult, however, if not impossible to prove in the human population.

So far we have been considering inorganic lead, yet **organic lead** is probably *more toxic* as it is lipid-soluble and therefore well absorbed. For example, triethyl lead, which results from combustion of petrol containing tetraethyl lead, is readily taken up through skin and into the brain and will cause **encephalopathy**. This has been the cause of toxic effects in workers exposed in industry where the tetraethyl lead is manufactured. The effects occur rapidly and the symptoms are **delusions**, **hallucinations** and **ataxia**.

How much of a hazard the levels of lead in our air, food and water pose to the health of children and adults is currently unclear. However, it is probable that we could remove much of that pollution and the hazard by removing lead from petrol without any major effect on petrol prices or car performance. Lead is known from both animal and human studies to be highly toxic and the levels to which many of us are exposed can be shown to have effects on biochemical pathways. It is surely only prudent to reduce the exposure to this toxic metal as much as possible by reducing its use and release into the environment.

Water pollution

Water in rivers, lakes and the sea may be polluted directly by the discharge of effluent from factories and industrial processes, and of domestic waste. Water may become polluted also by substances on the land such as pesticides and fertilizers applied to crops and washed by rain into rivers and lakes and eventually into the sea. The rain can also directly accumulate substances from the atmosphere. Industrial companies may dump toxic waste

into underground storage tanks and leakage of these has been known to lead to contamination of the water table. The domestic water supply in such areas then becomes contaminated.

Some water pollutants, such as **fertilizers** from agricultural run-off, **sewage** and **organic waste products** from the food industry lead to overgrowth of **algae** and other aquatic plants which eventually choke the local environment and use up the available **nutrients**. The algae then die, and decay with the help of **aerobic bacteria** which use up the oxygen in the water. This is followed by the appearance of **anaerobic bacteria** which continue to feed from the decaying plant matter at the bottom of the lake or river. These bacteria produce toxic compounds which, along with the lack of oxygen, cause the water to become stagnant and so other aquatic organisms such as fish die. This process is known as **eutrophication**.

Humans, other animals and plants may become exposed to toxic pollutants in water either by drinking that water, living in it or eating other organisms which have become contaminated by it. Although in Western nations drinking water is normally highly purified, this may not be the case in less developed countries. However some toxic substances, such as heavy metals, are not necessarily removed by the normal water-treatment procedures.

Water pollutants may affect organisms within the environment in different ways. High concentrations of a toxic compound may kill most or all of the organisms within a particular area where the concentration is sufficiently high. However, this area may become repopulated in time from another area. A more insidious pollutant may damage the reproductive cycle of certain organisms in some way. Fish eggs are very susceptible to toxic compounds at low levels for example and this may lead to a decline in the fish population.

Another way in which a pollutant can interact with the environment is by entering **food chains** (see below), without causing damage to the lower organisms in the chain, but possibly killing the predators at the top of the chain or interfering with their reproductive cycle. Persistent compounds such as **methyl mercury** and **DDT** enter food chains and act in this way.

The pollutant may not however remain the same once it is in the environment as it may be altered by chemical or biochemical processes. Consequently, two important aspects of environmental pollution are the involvement of food chains and the alteration of the compound by the environment itself.

Arsenic

This element is widely distributed in the Earth's crust and is associated with ores used for zinc, copper, gold and lead extraction. The mining of these ores is therefore an important source of exposure. Arsenic is also used in pesticides. Although seafood may be contaminated with arsenic this may be in the organic form which is less toxic than the inorganic form. Also water from ground water wells and hot springs may be naturally contaminated with arsenic.

Ground water is a significant source of arsenic poisoning and in some parts of the world levels may be especially high. For example in Taiwan levels as high as 1.8 mg^{-1} have been recorded. Significant contamination of water also occurs in Bangladesh and Argentina. In Bangladesh there has been a particular problem of wells contaminated with arsenic from ground water being used to replace wells contaminated with bacteria and this arsenic contamination has led to wide-scale disease. In this and other countries with high levels of contamination, chronic exposure to arsenic causes hyperpigmentation of the skin, keratosis and cancer. It may also cause a

peripheral vascular disorder known as **black-foot disease** which has been reported in Taiwan. In both Taiwan and Argentina, **skin cancer** has been associated with exposure to high levels.

Food chains

For a terrestrial animal the most likely route of exposure to a toxic compound such as a pollutant is via its **food**. The food chain is one method by which animals and man become exposed to persistent pollutants. Substances may however be persistent in one environment or species but not in another, depending on the particular characteristics of the system. The food chain can involve water-borne pollutants and also soil and airborne pollutants. There are two main types of food chain; **grazing** and **detritivore**. A grazing food chain is a sequence in which one organism, such as a plant, is eaten by another such as a herbivore which is in turn eaten by a carnivore and so on (Table 8.3). A detritivore food chain involves the decay of organisms after death. The organisms involved tend to be small and there is no increase in size between the lower and higher trophic levels. Both types of food chain can be involved in environmental toxicology as can other types of feeding relationships. The overall system may be termed a food web.

The amounts of a pollutant in species at each trophic level (Table 8.3) may be measured and compared to give a concentration factor. However, these must be interpreted with caution. For example, the mode of **sampling** a population may have inherent **bias**. Ideally sampling should be random, but it may not always be so. If animal carcasses are sampled the levels of a particular pollutant may vary widely depending on the cause of death. Indeed the concentration of pollutant in live animals may be at least as important as the concentration in those dying of unknown cause. This is because the pollutant may have subtle population effects, such as on breeding behaviour or the production of eggs, which will affect the whole population. Another important point is that the mere presence of a chemical in the environment does not necessarily mean there has been significant pollution and similarly the presence of a chemical in an organism does not necessarily mean that it is causing toxic effects. Our *ability* to measure toxic compounds at minute levels should not blind us to the necessity for a reasonable assessment and *interpretation* of those data. Unlike controlled laboratory experiments, environmental exposure may often be intermittent and pollutants do not always reach a steady state but can fluctuate wildly. As already mentioned, persistence of a chemical can vary between species or ecosystems. For example, it has been reported that small mammals may have a low level of organochlorine insecticides whilst birds feeding on them may have very high and possibly lethal levels. This may be due to differences in the metabolism of the pollutant by the two species.

Thus, the mammal might eliminate the substance relatively rapidly whereas the bird may not and so it will *accumulate*. Again sampling can be an important factor in studying this problem as predators may take prey from a wide area in which there are great variations in exposure. It is clear that environmental toxicology deals with complex systems in which prediction is sometimes very difficult.

Although the effects of pollutants on individual human beings may be perceived by man as the most important, ecologically and biologically an effect on the population may be more important. Consequently, a pollutant which reduces or stops reproduction of the species at some stage is more important than a pollutant which is more acutely toxic but only causes the

death of the older, more susceptible members of that species. The latter would be more obviously distressing but would have *less effect* on the population if the victims were past significant reproductive capacity. The toxic compound would be just one more cause of death. Indeed not all individuals in a population reproduce and so there may be less effect than might be expected for a toxic pollutant which leads to the death of only some members of that population.

An example which illustrates this effect on the reproductive cycle and the problems of persistent pesticides in food chains is the effect of **organochlorine** insecticides on **eggshells** in predatory birds, as mentioned in Chapter 8. The predatory bird is at the top of a food chain and hence may have the highest concentration of pollutant. The **peregrine falcon** population in Britain declined precipitately between 1955 and 1962. At the same time the frequency of egg breakage increased because of a decrease in eggshell thickness. There is a linear relationship between eggshell strength and the thickness index. Peregrine falcon eggs studied during the period 1970–1974 had a lower thickness index and strength than those studied between 1850 and 1942. **DDE**, a metabolite of DDT is believed to be one cause of this decreased thickness. Direct toxicity of **dieldrin** to falcons has been suggested as another cause of the decline in population. Areas such as the north of Scotland had a higher eggshell thickness index and lower levels of DDE than eggs from more southern areas of the UK. Similarly data from the USA for kestrels showed a correlation between eggshell thickness and DDE concentration (Figure 8.2).

Pollutants which contaminate water may either dissolve in it if they are ionized/water-soluble substances or are miscible. Alternatively if they are hydrophobic they may form a suspension or aggregate and remain undispersed in the same manner as the familiar oil slick. Although water-soluble substances may reach a sufficient concentration to be toxic to aquatic organisms and to man, unless they are in an enclosed system they will tend to disperse eventually. Such compounds are not likely to accumulate in organisms. Hydrophobic substances however behave differently. Substances which are not polar and are soluble in lipid rather than water are well absorbed by living organisms especially by aquatic organisms which pass water over gills to extract oxygen and to filter water in search of food. Consequently, small organisms such as ***Daphnia*** and **zooplankton** become contaminated with lipophilic pollutants such as DDT. These small organisms are then eaten by other, larger organisms such as small fish and the contaminant enters the fatty tissue of this larger organism. However, if the small organisms are ingested in large numbers and the compound is not readily excreted, the concentration of the substance in the larger organism increases. This process is repeated with ever larger and larger organisms until the ultimate predator, at the top of the food chain may accumulate sufficient of the substance to suffer toxic effects (Table 8.3; Figure 9.4). Food chains may occur in aquatic environments with water pollutants, or in terrestrial organisms with airborne, soil, water or food borne pollutants, or a combination of these. The important aspect of any food chain, therefore, is the scope for **biomagnification** of the substance as it moves up through the chain. Furthermore the compound may be non-toxic at the low levels encountered by the organisms at the bottom of the chain which therefore survive and contaminate the predators further up the chain.

The most important characteristics of a substance which enters a food chain are its **lipid solubility** and its **metabolic stability** in biological systems. These determine the

extent to which the compound is taken up by the organism and its ability to localize in fat tissue and remain there until the organism is ingested by a predator. Hydrophilic compounds, which are polar and ionized, may be taken up by organisms but will tend to be readily excreted. Lipophilic pollutants which are absorbed and then *rapidly metabolized* to *polar metabolites* similarly tend to be *readily excreted* and hence will not persist in the organism or be transferred to the predator.

This is another example of the importance of **physico-chemical characteristics** in toxicology.

Although some environmental pollutants are not lipophilic initially they may be *metabolized* by micro-organisms, plants or higher animals to lipophilic metabolites which are more persistent. DDT is an example of this; its metabolite DDE is more lipophilic and much more persistent (Figure 8.1 and Table 8.2). Another is inorganic mercury (see page 138).

Endocrine disruptors

'Endocrine disruptors are exogenous substances which cause adverse health effects in an intact organism or its progeny subsequent to changes in endocrine function'.

Over recent years a number of coincident observations have led scientists to the conclusion that chemical substances in the environment may be interfering with the endocrine systems of humans and various animals. These so-called endocrine disruptors may be responsible for a range of dysfunctions in the reproductive systems of humans and a variety of animals in the wild. The wildlife effects are well documented and some can be reproduced experimentally. The human effects are more difficult to definitively associate with environmental chemicals and some effects are controversial.

However, there is considerable interest in the area which is potentially of great importance.

It is widely accepted that chemicals that are capable of causing endocrine disruption have been released into the environment. These chemicals may act as **oestrogen mimics**, as **anti-oestrogens** or as **anti-androgens**. The end result is a change in the hormone balance which may result in a variety of physiological and pathological effects. The debate, however, is whether the concentrations of these chemicals is sufficient to cause all of the effects undoubtedly observed in animals and the effects suspected as being related in humans.

There is a variety of chemicals believed to be responsible, most of which are man-made but some natural chemicals from plants or fungi are included as well. The chemicals include **organochlorine insecticides** (e.g. DDT) and industrial chemicals such as **polychlorinated biphenyls** (PCB's) and **alkylphenols** and drugs such as used in the **contraceptive pill** and **diethylstilboestrol** and synthetic oestrogens which are excreted into the urine and hence appear in rivers via sewage. Natural products include the fungal product **zearalenone** and the plant product **genistein**. Some of the chemicals are lipophilic and persistent, undergoing bioaccumulation and biomagnification in the environment.

WILDLIFE EFFECTS

The evidence for, and examples of, endocrine disruption in wildlife comes from many parts of the world over a number of years and in a variety of animal species ranging from molluscs to alligators. One of the first observations was of

changes in fish in rivers in the UK and in the USA. It was noticed that some fish (roach and rainbow trout in the UK and winter flounder in the USA) in rivers polluted with sewage outfall or industrial effluent were showing **hermaphroditism**. The incidence of intersex was as much as 100% of the fish in the river Aire in the UK. Male fish were also found to be producing vitellogenin, a protein which female fish produce in response to oestrogen. This response could be reproduced experimentally when fish were exposed to sewage. **Vitellogenin** is therefore a biomarker of response for the effect of certain chemical substances on fish.

Some of the specific substances that cause male fish to produce vitellogenin, such as the alkylphenols, **octylphenol** and **nonylphenol**, have now been identified. These compounds also decrease testicular growth in fish and bind to the oestrogen receptor. However, although nonylphenol is potent, it is still very much less potent than natural oestrogen. However, it has also been shown that the synthetic oestrogen, **ethynyloestradiol**, will, at concentrations found in the effluent from sewage treatment works, cause male fish to produce vitellogenin and will retard testes growth.

Plant steroids have also been suspected of causing masculinization in female fish. Such compounds are found in the effluent from paper mills.

A well described and studied effect of an environmental pollutant on the reproductive system of aquatic organisms is the effect of tributyl tin on molluscs. **Tributyl tin oxide (TBTO)** is used as a biocide in wood preservatives and in paints used for the undersides of small boats to stop fouling by algae and barnacles. The tributyl tin concentration in crowded harbours and marinas may be sufficient to cause effects on molluscs such as the **dog whelk**. Molluscs appear to be especially sensitive to the effects of tributyl tin and concentrations of less than 1 ng per litre will produce adverse effects. The results of the exposure are imposex, in which females become masculinized with the growth of a penis. This effect has been observed in many parts of the world with a large number of different species of marine snails and also have been reproduced in the laboratory.

The mechanism may involve inhibition of **aromatase**, an enzyme involved in the metabolism of sex hormones. Tributyl tin also has other toxic effects in mammals causing damage to the thymus. This leads to depletion of lymphocytes and so adversely affects the immune system. However, this occurs at concentrations several orders of magnitude higher than those which cause imposex in molluscs.

However, the most celebrated example of endocrine disruption is that caused by organochlorine compounds in alligators in Florida. It was reported that the population of alligators in **Lake Apopka** in Northern Florida was declining. This seemed to be due to poor reproductive success. The male animals had small phalli, poorly organized testes and low testosterone levels. In contrast the females had high oestrogen levels but abnormal ovarian morphology. The mechanism was suggested as being due to an effect of the pollutants on the metabolism of steroid sex hormones. There was clearly a high level of pollution by organochlorine compounds such as the DDT breakdown product DDE. This compound has been shown experimentally to have reproductive and hormonal effects in alligators.

HUMAN EFFECTS

There are a number of effects on the human reproductive system that have been observed and documented. Although some are contentious, some are clearly established.

There has been an undeniable increase in **testicular cancer** and **breast cancer** over the period since 1945 particularly in certain countries. It is also suggested by some, but not all data, that **sperm counts** and **sperm quality** in men has declined over the same period. This seems particularly apparent in some Scandinavian countries but is not supported by data from some other countries. There may also be an increase in other disorders of the male reproductive system such as **cryptorchidism** and **hypospadia**.

In contrast to the effects observed and reproduced in animals, the effects on human reproductive function and the organs involved, while documented, have not been clearly associated with exposure to particular chemicals. The notable exception to this is diethylstilboestrol which was used therapeutically in the 1950s to prevent miscarriages in women until its use was stopped in the early 1970s. This synthetic oestrogen was found to cause problems in the reproductive systems of the male and female offspring of women who had received the drug. These findings lend credence to the hypothesis that oestrogenic compounds could be responsible for some at least of the observed effects. This substance has also been administered to animals in which similar effects have been recorded.

In a significant proportion of girls born to mothers who had been prescribed diethylstilboestrol there was dysfunction of the reproductive organs, disruption of the menstrual cycle and abnormal pregnancies. In a small number, adenocarcinoma of the vagina developed when the girls reached puberty. Male offspring showed increased incidence of cryptorchidism and microphallus. There was some evidence of decreased sperm count and motility. These effects and also testicular cancer have been reproduced in experimental animals. As diethylstilboestrol does not bind to sex hormone binding globulin it is able to enter cells freely and therefore has a greater effect than an equivalent blood concentration of endogenous oestrogens.

Diethylstilboestrol was also used as a growth promoter in cattle and so humans may also have been exposed to residues in meat. Human exposure to the synthetic oestrogens used in the contraceptive pill may occur via the drinking water. Ethynyloestradiol has been detected in drinking water in the UK but the data have been questioned. Metabolites of such compounds as well as natural oestrogens will be excreted into urine and thence may find their way into drinking water or contaminate crops, via the sewage system. This could be more of a problem in times of drought when concentrations may be higher.

Although DDT has been implicated as a possible xenoestrogen, it does not interact significantly with the oestrogen receptor and nor does its persistent metabolite p,p′-DDE. However, **p,p′-DDE** *does* interact with the **androgen receptor** and therefore could conceivably be an anti-androgen and this may warrant further study. Studies have measured DDE in breast adipose tissue in an attempt to correlate the levels with the incidence of breast cancer but the results have been equivocal. It has been suggested that there may be a slight association with only the hormone responsive type of breast cancer. However, it should be noted that the current exposure of the human population to DDT is relatively low and continually decreasing. Furthermore, studies of humans exposed to very much higher levels of DDT when it was first introduced, especially in those manufacturing and using the compound have revealed little toxicity. The organochlorine compound **chlordecone**, however, has been shown to have oestrogen-like activity in humans. Male workers exposed to high levels during its manufacture were found to have changes in the reproductive system including abnormal sperm with decreased motility and low sperm counts. Although some **polychlori-**

nated biphenyls (PCBs) possess weak oestrogenic activity, others are anti-oestrogenic. Similarly, **dioxin (TCDD)** shows significant anti-oestrogenic activity. In both cases the activity seems to be correlated with the binding to the **Ah receptor**. Dioxin has a number of effects on the male and female reproductive systems of mammals, for example having adverse effects on spermatogenesis, sexual behaviour and reproductive capability. Effects on the reproductive system have been shown at doses as low as 0.001 μg/kgbw/day in rats and monkeys. After one human exposure situation, **Seveso** in Italy in 1976, studies in fact revealed a *decreased* incidence of breast cancer.

Alkylphenols, such as octylphenol, do show oestrogenic activity which appears to be mediated via the oestrogen receptor. However, the activity is three orders of magnitude less than oestradiol and the likelihood of effects on humans is probably low.

Finally, it should be noted that there are many naturally occurring oestrogens which, although many times less potent than oestradiol, may have far greater potency than some of the man-made chemicals often mentioned. Thus, the plant products **isoflavone**, **coumestans** and **lignane** and the fungal product **zealarone**, all bind to the oestrogen receptor. Other plant-derived products such as **indole-3-carbinol** found in vegetables, have anti-oestrogenic activity.

It is clear that there is human exposure to a wide variety of compounds in the environment which have some oestrogenic activity (xenoestrogens) and some anti-oestrogenic activity. Whether many of these individually at the likely exposure concentrations pose a threat to human reproductive health is still unclear. However, our environment contains many such compounds and so combinations of weakly oestrogenic compounds may show synergy so that significant oestrogenic activity results. This is an area currently receiving considerable attention.

Xenoestrogens may act through other pathways than via the oestrogen receptor. For example, they can interact with other receptors such as the Ah receptor or the growth factor receptor. Indeed, there seems to be an association between binding to the Ah receptor and anti-oestrogenic activity. Alternatively, some xenoestrogens may act by altering oestrogen metabolism. For example, 17β-oestradiol is metabolized to both 2-hydroxyoestrone and 16α-hydroxyoestrone. 2-Hydroxyoestrone has low activity and low genotoxicity whereas **16α-hydroxyoestrone** is **genotoxic** and is a **potent oestrogen**. In breast cancer patients it has been found that levels of 16α-hydroxyoestrone are higher than in control patients and that the ratio of 16α-hydroxy to 2-hydroxy oestrone is associated with breast cancer. Some polycyclic aromatic hydrocarbons for instance inhibit the formation of 2-hydroxyoestrone and so divert the metabolism of oestradiol towards the more potent 16α-hydroxyoestrone.

Another, alternative mechanism for affecting the reproductive system, is if a chemical possesses anti-androgenic activity.

Mercury and methylmercury

Mercury is 'the hottest, the coldest, a true healer, a wicked murderer, a precious medicine, and a deadly poison, a friend that can flatter and lie.' (Woodall, J. (1639) *The Surgeon' Mate or Military & Domestic Surgery.* London, p. 256, quoted from *Casarett and Doull's Toxicology.)*

Like lead, mercury is a highly toxic metal the toxic properties of which have been known about for centuries. The phrase 'Mad as a

Hatter' has its origins in the effects on exposed workers of the mercury salts used to cure felt for hats. Mercury and its salts have been used in many ways for centuries. In the Middle Ages it was used to treat syphilis.

Mercury exists in three chemical forms: elemental, inorganic and organic. All three forms are toxic in different ways. **Elemental mercury (Hg^0)**, often used in scientific instruments, is absorbed as the vapour and is highly toxic. Mercury readily vaporizes even at room temperature and exposure to it can lead to damage to the **central nervous system**. **Inorganic mercury** (Hg^+ and Hg^{2+}), in mercury salts, is not readily absorbed but when it does gain access to the body, it causes mainly **kidney damage**. **Organic mercury** compounds ($R\text{-}Hg^+$) are readily absorbed by living organisms and, therefore, are more hazardous than inorganic mercury. As with elemental mercury, the target is the **brain** and **nervous system**.

The different forms of mercury may act by basically similar mechanisms of action involving the reaction of the metal or its ions with **sulphydryl groups**. These sulphydryl groups may be part of a protein, such as an enzyme, and hence mercury is a potent inhibitor of enzymes in which the SH group is important. The differences in the toxicity of the three forms of mercury are due to differences in distribution. Elemental mercury is readily taken up from the lungs and is oxidized in red blood cells to Hg^{2+}. Hg^0 is also readily taken up into the brain and the foetus and is also metabolized to Hg^{2+} in these tissues. The mercury is then trapped in these sites by virtue of being ionized. Consequently elemental mercury causes mainly neurological damage. Inorganic mercury cannot cross the blood-brain barrier, but reaches the kidney and it is this organ particularly that is damaged. Organic mercury is sufficiently lipid-soluble to distribute to the central nervous system where it also is oxidized to Hg^{2+}, and causes mainly neurological damage. So, although all three forms of mercury are probably toxic as a result of binding to sulphydryl groups in proteins, the *differences in distribution* lead to differences in the type of toxicity. This is another illustration of the importance of distribution in the toxicity of foreign compounds.

Exposure to mercury used to be mainly an occupational hazard rather than an environmental one, but more recently mercury has also become an environmental pollutant. This has occurred through the use of **organomercury fungicides** and through the industrial use of mercury in the manufacture of plastics, paper and batteries with the resultant discharge of the contaminated effluents into lakes and rivers. High levels have been detected, as in water near a battery plant in Michigan, where levels of 1000 ppm were found when the permissible level was 5 ppb. Mercury has also been detected in air, presumably arising from industrial processes.

Dumping of the inorganic form of the metal used to be tolerated because it was thought that this form was relatively innocuous and easily dispersed.

The use of mercury-containing fungicides has led to water contamination via run-off from fields. Other sources of environmental mercury are wood pulp plants and chloroalkali plants. These and possibly other sources were presumably responsible for the contamination of freshwater fish by high levels of mercury detected by Swedish scientists. As with other lipid-soluble substances in the environment, bioconcentration in the food chain also occurs.

Mercury dumping is now controlled and organomercury fungicides are being phased out.

A tragic and now infamous event, which occurred in Japan in the 1950s, highlighted the dangers of inorganic mercury as a water pollutant. In 1956 a new factory on the shores of **Minamata Bay** in Japan began producing vinyl chloride and acetaldehyde. Mercuric chloride was used as a catalyst, and after use was discharged into the bay with the rest of the effluent

from the factory. Within a year a new illness had appeared among the local fishermen and their families which became known as **Minamata Disease**. Their pet cats also suffered similar symptoms. It was eventually recognized that the disease was due to contaminated seafood and mercury was suspected in 1959. **Methylmercury** was detected in seafood in 1960 and in sediments derived from the factory in 1961. The methylmercury was being taken up by the seafood which was eaten by the local population. A food chain was involved with the organic mercury being concentrated by the aquatic organisms because, unlike inorganic mercury it is lipid-soluble. It became apparent that the inorganic mercury that discharged into rivers, lakes or the sea was not inert but could be *biomethylated* to methylmercury by micro-organisms (Figure 9.4). This occurred especially under *anaerobic* conditions, such as in the effluent sludge which collected at the bottom of Minamata Bay. This highlighted the fact that inorganic mercury dumped into rivers and lakes is by no means innocuous and is not necessarily dispersed.

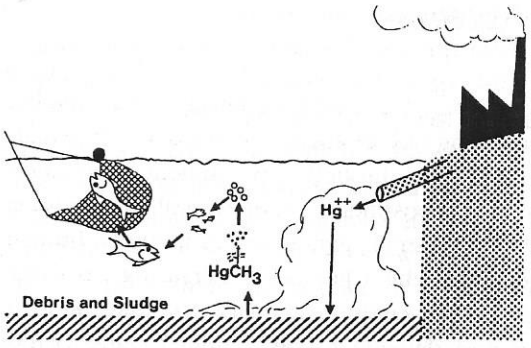

FIGURE 9.4 *The way in which inorganic mercury in effluent was taken up into the food chain and led to the poisoning of several hundred local inhabitants in Minamata Bay in Japan. The inorganic mercury was methylated by micro-organisms in the anaerobic sludge lying at the bottom of the bay and so became more soluble in fatty tissue and was easily taken up into living organisms.*

The contamination at Minamata led to 700 cases of poisoning and over 70 deaths. Diversion of effluent by the factory eliminated the disease. Mass poisonings have also occurred in various parts of the world as a result of the use of organomercury compounds as fungicides to treat seed grain. The treated grain should not be used as food but if it is used to feed livestock, the meat becomes contaminated. One such large-scale poisoning incident occurred in Iraq in 1971–1972 when alkylmercury fungicides were used to treat cereal grain. This involved 6000 people and resulted in 500 deaths.

In another incident in 1969, a New Mexico family fed treated grain to pigs, and then ate the pigs. Three of the ten children exposed experienced behavioural abnormalities and other neurological disorders. A child exposed *in utero* was born with brain damage and the urinary level of mercury was found to be *15 times* that of the mother.

The symptoms of methylmercury poisoning reflect the entry of the compound into the central nervous system, beginning with memory loss, paresthesias, ataxia, narrowing of the visual field, and progressing to loss of muscle co-ordination and emotional instability and eventually **cerebral palsy**. The latter was the most distressing effect seen at Minamata. Children and new born infants seemed to be most severely affected and those exposed *in utero* were born with severe cerebral palsy even when the mothers were symptom-free, a classic characteristic of a **teratogen**. Methylmercury is able to cross the placenta and may consequently *concentrate* in the fat tissue and brain of the embryo and foetus. In addition, foetal red blood cells concentrate methylmercury 30 per cent more than the adult red blood cells. The damage caused by methylmercury is permanent.

The methylmercury that enters the brain is demethylated and the inorganic mercury

released can then bind to the **sulphydryl groups** of enzymes and inactivate them. Methylmercury has a *long half-life* in the body, approximately 70 days. It is localized particularly in the liver and brain, with 10–20 per cent of the body burden of mercury in the brain. It is possible to calculate from this and the known toxic concentration that the **allowable daily intake** with a safety factor of 10 would be 0.1 mg day^{-1} This would correspond to eating 200 g of fish with a mercury level of 0.5 ppm, but fish in Lake Michigan and in the sea off the coast of Sweden have been found to contain as much as *ten times* more mercury than this in some cases.

Like humans, birds and other animals may ingest mercury. For example, studies of the Crested Grebe show that tissue mercury levels have been steadily increasing since about 1870 (Figure 9.5).

Substances, such as pesticides and other chemicals, which may contaminate the environment have to be tested for toxicity in a variety of species including fish, *Daphnia*, honey bees and earthworms. Also, **ecotoxicity testing** requires determination of the **biochemical and chemical oxygen demand**, abbreviated BOD and COD respectively. The **BOD** indicates the ability of micro-organisms to metabolize an organic substance. The **COD** is the amount of oxygen required to oxidize the substance chemically. The ratio of the COD and BOD is an indication of the *biodegradability* of the substance. There are a number of other tests which will give an indication of the persistence of the compound in the environment such as determination of abiotic degradation. Details of these can be found in the documents issued by such governmental organizations as the Environmental Protection Agency (EPA) in the USA and the Health and Safety Executive (HSE) in Britain.

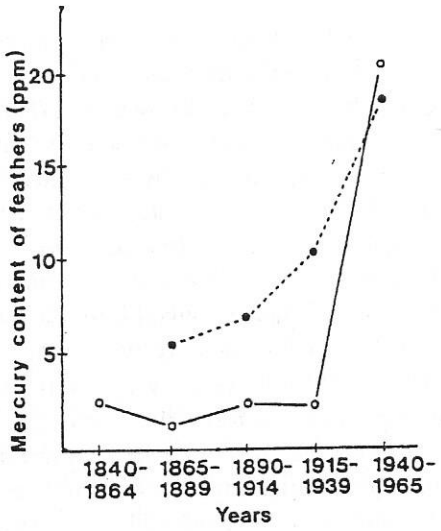

FIGURE 9.5 *The increase in mercury levels detected in two species of birds, Crested Grebe (●) and Goshawk (○), over a 100-year period. The mercury content was determined in feathers from museum specimens of Swedish birds. Data from Wallace* et al. *(1971) Mercury in the Environment: The Human Element, ORNL-NSF Environmental Program, Oak Ridge National Laboratory, Figure 4.*

Summary and learning objectives

Exposure (via skin contact, oral intake, breathing) of biological systems to chemicals may occur through environmental pollution of the atmosphere, water or soil. This results from industrial, agricultural and other human activities which has been increasing since the nineteenth century. Human morbidity, mortality and damage to other animals and plants in the environment may result. The ***atmosphere*** may be polluted by gases such as sulphur and nitrogen oxides and ozone, carbon monoxide, hydrocarbons and ***particulates*** contributing to smog (reducing and

photochemical). Some of these pollutants contribute to ***acid rain*** and die back of trees. The acidification of lakes and rivers damages aquatic organisms such as salmon and the acid rain damages leaves and leaches essential minerals from the soil. Heavy metals such as ***lead*** from car exhausts and industrial activity may pollute air, soil and water. Lead causes damage to kidneys, red cells, bones and the nervous system. ***Water*** may be polluted with industrial, domestic or agricultural waste which can lead to overgrowth of algae and then *eutrophication* or direct toxic effects. Ground water in some countries may be polluted with ***arsenic*** leading to cancer and skin diseases. A variety of pollutants (e.g. alkylphenols, DDT, PCBs) and fungal products are known to be ***endocrine disruptors*** which can cause dysfunction of the reproductive system in animals (e.g. alligators, dog whelks, fish) as a result of oestrogenic, anti-oestrogenic or anti-androgenic activity. Humans may be affected (e.g. low sperm counts) but the link is not proven.

Environmental pollutants, particularly if lipophilic (e.g. DDT, dieldrin), may accumulate in organisms and those animals at the top of the ***food chain*** (e.g. predators) may be exposed to much higher concentrations than exist in the environment (bioaccumulation). ***Mercury***, an important pollutant, exists in three forms (organic, elemental or inorganic), all toxic. It contaminated factory effluent which was allowed to pollute the waters of a bay in Japan (Minamata), bioaccumulated in fish and caused death and disease (e.g. birth defects) in many people exposed. Pollutant chemicals now require testing for their potential impact on the environment (BOD, COD) and organisms in it (e.g. *Daphnia*, earthworms).

Questions

Q1. Indicate which of the following is true: Lead:

a is toxic because it inhibits mitochondrial respiration
b is present in cigarette smoke
c damages red blood cells
d is not toxic to the nervous system
e can be absorbed through the lungs.

Q2. Which of the following statements is not true?

a metallic mercury is non-toxic
b organic mercury is toxic to the kidney
c inorganic mercury is toxic to the brain
d inorganic mercury binds to SH groups
e methylmercury has a half-life of 70 days.

Q3. Indicate which of the following statements is true:

a the great smog in London was in 1852
b photochemical smog contains only nitrogen oxides
c ozone is a non-toxic gas that promotes good health
d PM10 means a concentration of oxidants of 10 $\mu g\,m^{-3}$
e acid rain is formed from chlorinated hydrocarbons interacting with the ozone layer
f reducing smog has a high level of sulphur dioxide and particulates.