CHAPTER 1

Introduction to Aerobiology

1. What is aerobiology

Aerobiology is a study of biological particles present in the air, both outdoors (extramural) and indoors (intramural). Many aspects of our lives are affected by biological particles that are carried in the air and are deposited from it. For example, many people have allergic reactions to inhaled biological particles and many human, animal and plant pathogens are transported by the air. Some organisms are adapted for wind transport whilst others become airborne incidentally, or only as debris. The main incentive for the development of aerobiology as a scientific discipline has been the desire to understand the dispersal of diseases of man, animals and plants in order to try and prevent them. Hence the dispersal of pollen and spores has been the main interest, while the ecology of the air itself has been of secondary importance.

Aerobiology requires an understanding not only of the biological particles being moved by the air but also of physics, as various physical processes explain the movement of air and particles suspended in it.

2. The Air Spora

The term the 'Air Spora' was first used in an article by P.H. Gregory published in *Nature* (Gregory, 1952).

> **The population of air-borne particles of plant or animal origin, which will here be called the air 'spora' (taking the Greek σπορά as a word of similar usage to 'flora' and 'fauna'), contains spores and pollens of various shapes ranging in size from 100 μ in diameter for some tree pollens down to 3-5 μ with some of the smallest fungus spores.**

In addition to pollen, plant and fungal spores, the air spora may also comprise protists (protozoa), bacteria, viruses and fragments of any biological origin.

3. What is in the air

The air that we breathe not only comprises the gases nitrogen, oxygen and carbon dioxide but also traces of other gases and particles of inorganic and biological material. When there are sufficient contaminants in the air it may be possible to see them with the naked eye in the form of dust, smoke or smog. Inorganic particles can include minute particles of rocks, products of combustion and dust from outer space. Particles of biological origin can include viruses, bacteria, actinomycetes, fragments of fungi and fungal spores, lichen fragments and their spores, protists (e.g. protozoa, algae and diatoms), spores of plants (e.g. mosses and ferns), pollen, plant fragments and small seeds, invertebrates (e.g. nematodes, mites, spiders and insects) and their fragments and faecal material, plus skin, hair, dried mucus and excrement from larger animals. These particles range in size from 1 to >200 μm. Even much larger animals such as frogs, fish and molluscs have been recorded to fall from the sky, presumably following unusual weather events such as tornadoes or waterspouts but these macroscopic organisms, plus flying insects, birds and bats, which can exert at least some control over their flight duration and trajectory, are not considered here in the context of aerobiology. Volatile chemicals in the air, while not living may originate from biological sources as metabolites in processes such as decomposition, fermentation or toxin production.

3.1. Outdoor air

A profile of the earth's atmosphere (Fig. 1.1) is shown on a logarithmic altitude scale to enable the various layers to be presented on one page, and to illustrate vividly that the properties of the atmosphere change most sharply near to the ground (Gregory, 1973). Barometric pressure, density of the air, and (as a rule) temperature, decrease with increasing height above the earth's surface. The three vertical panels in Fig. 1.1 show contrasting weather conditions: a still clear night, a cloudy day with increasing wind velocity, and a sunny day. The laminar boundary layer is a still microscopically thin layer of air at the surface of the earth and all objects protruding from it. Above this layer is the variable turbulent boundary layer (planetary boundary or mixing layer) through which most particle dispersion occurs, extending up to the stratosphere (an altitude of 10 km). In addition to turbulence or eddy currents, differential heating from the Earth's surface, particularly on sunny days, leads to pockets of outdoor air that are warmer than surrounding air, and which rise upwards as thermals.

The content of the outdoor air is dynamic, constantly changing with location, weather, season and time of day due to differing effects of these factors on the production, transport and deposition of the various components of the air spora (Mullins 2001).

3.2. Indoor air

Over recent years there has been much concern over the 'Indoor Air Quality' of buildings. Many of the indoor pollutants are of biological origin such as bacteria, fungal spo-

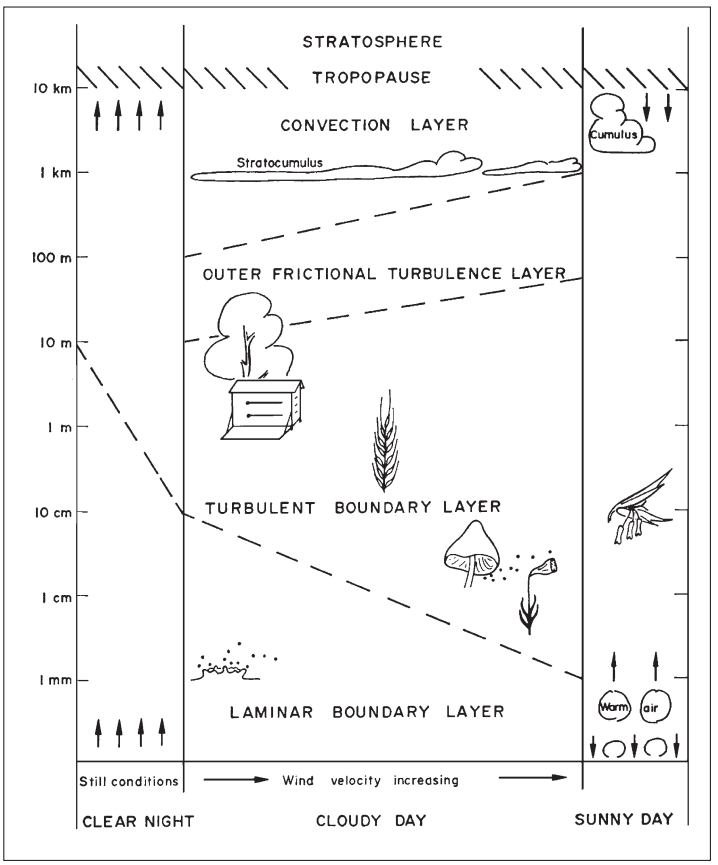


Figure 1.1
Diagrammatic representation of layers of the atmosphere (Gregory 1973).

res (Flannigan, 2001) and also skin, mucus, saliva, nematode eggs and invertebrate faeces. The environmental conditions or microclimate inside buildings is different and less variable than outdoors, leading to an air spora that is relatively homogeneous with time or season, compared to outdoors, but is still very heterogeneous according to the type of building and its use. Clearly, outdoor air is often vented into buildings but the concentration of particular particles will differ indoors compared to in the turbulent outdoor planetary boundary layer, due to local deposition or production of particles indoors.

3.3. Biological particles

The majority of pollen in the air comes from the inconspicuous flowers of anemophilous plants (mainly gymnosperms, grasses, and some angiosperm trees), which release clouds of pollen to be blown in the wind. Plants pollinated by insects (or occasionally other organisms such as hummingbirds) have larger, coloured flowers often with nectar to attract the pollinators and the pollen is generally larger, heavier and often sticky.

Viruses, such as the virus causing foot and mouth disease of cattle and sheep, as well as bacteria, algae and protists may become airborne in aerosols produced by splashes of water, urine, wave action or in human or animal breath.

Fungi, actinomycetes, lichens and non-spermatophyte terrestrial plants such as

mosses and ferns, reproduce by airborne spores in at least one stage of their life-cycles. Many of these spores are produced and adapted for wind dispersal. A range of mechanisms exist in order for these spores to escape the laminar boundary layer of still air in order for airborne dispersal to be effective (Fig. 2.1).

3.4. Inorganic particles

Fine sand or dust has been reported to blow from the Sahara desert in Africa to southern Europe, often reaching as far north as the Alps or southern England before being deposited (usually by rain) (Simons, 1996). This material and also dry clay or other rock dust may become airborne due to eddy currents, whirlwinds or tornados. Additionally, inorganic particles (here not used in the strict Chemistry sense, but meaning particles of non-biological origin) may enter the atmosphere as smoke particles (rather than gasses) from vehicles and fires, and dusts from industrial and other activities of man or from volcanoes. These inorganic particles are concentrated primarily in the layers of the atmosphere closest to the earth's surface, mainly the planetary boundary layer, although smoke from large forest fires can reach several km in altitude and dusts from volcanic eruptions may go higher still, causing light scattering phenomena such as blue moons or halos around the sun (Simons, 1996). Inorganic particles can also enter the earth's atmosphere from space. On average an annual mass of 40,000 tonnes of extraterrestrial dust enters the Earth's atmosphere from space due to the earth's gravity (pers. comm. Matthew Genge, Imperial College, London). These particles reach high temperatures, often melting or partially melting, because although small particles have a relatively slow fall-speed, they are unable to loose heat, produced by air friction, quickly enough.

4. Early History of Aerobiology

In his book *The Microbiology of the Atmosphere*, Philip Gregory (1973) gave a very good historical introduction to the early development of the study of aerobiology, salient sections are quoted in full.

Classical writers believed that the wind sometimes brought sickness to man, animals and crops. Hippocrates… held that men were attacked by epidemic fevers when they inhaled air infected with 'such pollutions as are hostile to the human race'.[1]

Lucretius in about 55 B.C.… observed the scintillation of motes on a sunbeam in a darkened room and concluded that their movement must result from bombardment by innumerable, invisible, moving atoms in the air. This brilliant intuition enabled him to account for many interesting phenomena, including the origin of pestilences.[1]

Following Lucretius, it took over 1500 years before scientists began to realise the diversity of living particles present in air. The belief in 'spontaneous generation' of organisms causing decay and disease was held by many people and persisted for a couple of centu-

ries. Micheli (1679-1737) was a botanist in Florence who, by putting spores of moulds on slices of fruit, showed that they were 'seeds' of the moulds. As some control slices became contaminated he concluded that spores of moulds were distributed through the air (Buller, 1915). In his letters to the Royal Society in 1680 Anton van Leeuwenhoek reported that he was able to see minute organisms with his handmade lenses, he later came to suppose that 'animalcules could be carried over by the wind, along with the bits of dust floating in the air' (Dobell, 1932).

J.G. Koelrueter, in 1766, was perhaps the first to recognize the importance of wind pollination for some plants and of insect pollination for others. C.P. Sprengel in 1793 developed these views and concluded that flowers lacking a corolla are usually pollinated in a mechanical fashion by wind. Such flowers have to produce large quantities of light and easily-transported pollen, much of which misses its target or is washed out of the air by rain. T.A. Knight in 1799 reported that wind could transport pollen to great distances.[1]

By the beginning of the nineteenth century, therefore, it was recognised that pollen of many, but by no means all, species of flowering plants, and the microscopic spores of ferns, mosses, and fungi – as well as protista [protozoa] – were commonly liberated into the air and transported by the wind. The potential sources of the air spora had been discovered and identified in the main before the year 1800, but their role remained obscure.[1]

Ehrenberg accumulated evidence that small microscopic particles might be carried great distances by wind in a viable state. Ehrenberg found sixty-seven kinds of organisms in dust (Fig. 1.2) collected by Charles Darwin (near the Cape Verde Islands in 1833 during his voyage on the Beagle. Darwin had found the atmosphere hazy with dust from Africa and realised at once the importance of Ehrenberg's findings to the geographical distribution of organisms (Darwin, 1846). There are many diatoms in the illustration indicating proximity to water.

Louis Pasteur (1822-95) worked for many years on the cause of putrefaction. He sterilised flasks containing nutrient medium and exposed them to air in different situations, disproving the idea of spontaneous generation and showing that infection was caused by germs (Pasteur, 1861). He also developed a gun-cotton filter to extract suspended dust from the air for microscopic examination.

Pasteur had demonstrated visually the existence of an air spora, he had pointed out that it should be measured while in suspension and not after deposition on surfaces, and he made the first rough visual measurement of its concentration in the atmosphere of the city of Paris: a few metres above the ground in the Rue d'Ulm, after a succession of fine days in summer, several thousands of microorganisms were carried in suspension per cubic metre of air. He then abandoned the method – remarking, however, that it could doubtless be improved and used more extensively to study the effects of seasons and localities, and especially during outbreaks of infectious diseases.[1]

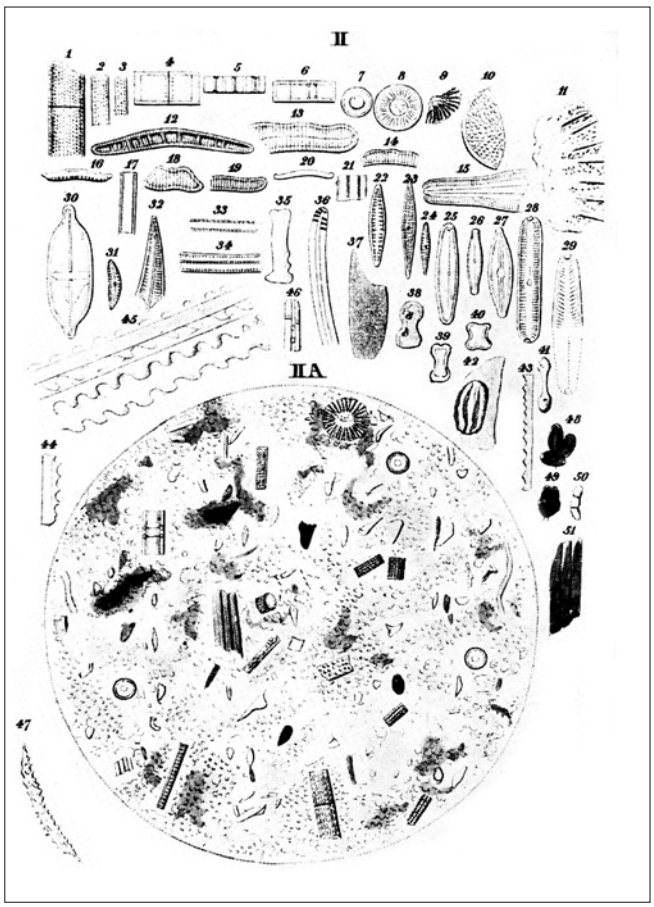


Figure 1.2
Ehrenberg's illustration of dust collected by Charles Darwin on the Beagle near the Cape Verde Islands, January 1833 (Gregory, 1973).

During the last half of the 19th century bacteriological work in laboratories and clinics identified the causes of disease in man (see Bulloch, 1938); e.g. Robert Koch identified the cause of anthrax, tuberculosis and cholera between 1876 and 1883. His statement of Koch's postulates has given a method of confirming that a disease is caused by a particular organism. The suspect is isolated, inoculated into a healthy specimen of the plant or animal, and if the disease develops and can then be re-isolated, it is proved to be the cause of the disease (Holliday, 1992).

Other workers investigated outdoor air to see if the microbes present were connected to disease. Maddox (1870) invented the 'aeroconiscope' and Cunningham (1873) developed this to use in two gaols in Calcutta where cholera and fevers were rife. His aeroconiscope (Fig. 1.3) consisted of a conical funnel with the mouth directed into the wind by a vane and ending in a nozzle behind which dust from the air was impacted on a sticky microscope cover glass. He sampled for 24-hour periods but no correlation was found between his catch and the diseases. His catches were mainly of fungal spores and pollen (Fig. 1.4).

The Observatoire Montsouris, situated south of Paris, was set up in 1871 to make records needed for meteorology and agriculture. The dust in the air was also studied. P. Miquel was the first to make a long-term survey of the microbial content of the atmos-

Figure 1.3
Cunningham's aeroconiscope. A = side view of apparatus (partly in section); B = face of sticky surface behind apex of cone (on larger scale) (Gregory, 1973).

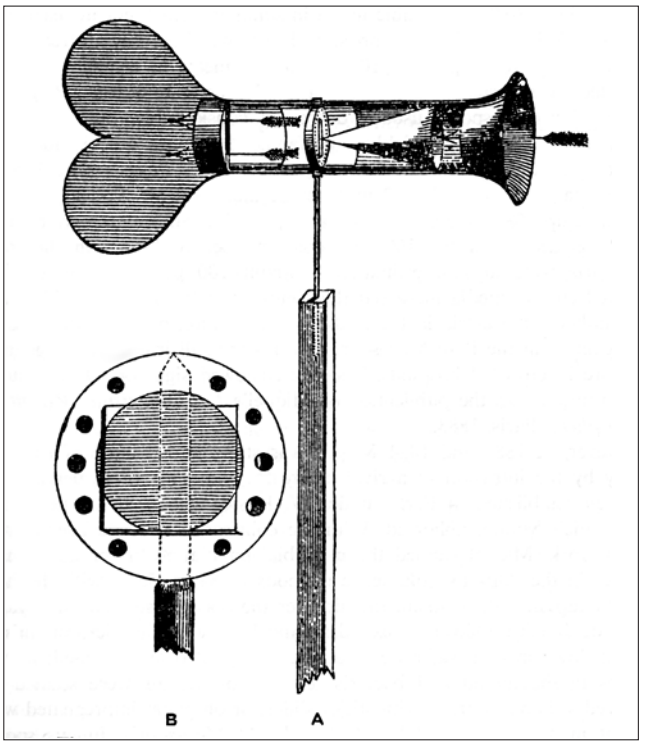
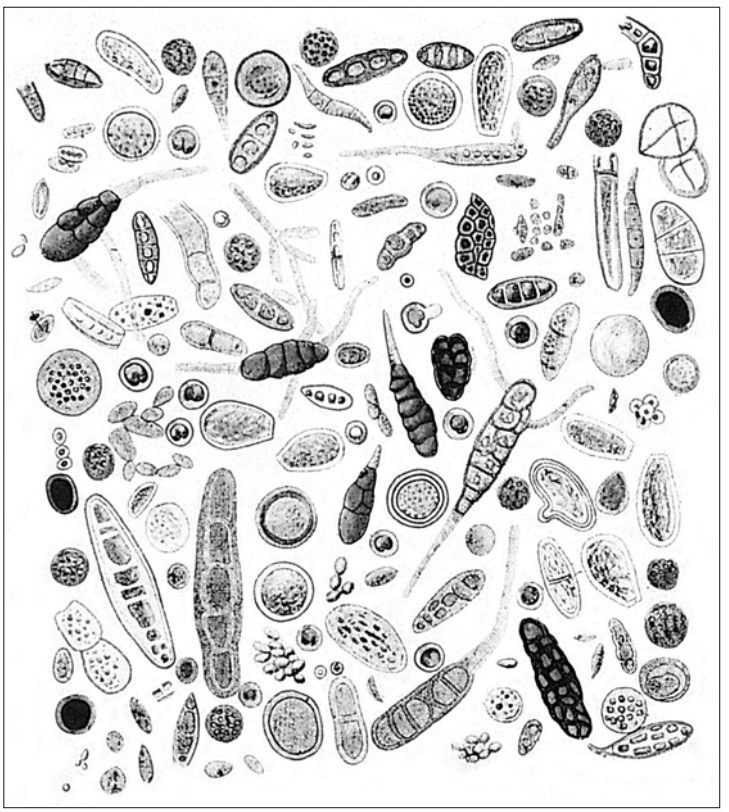


Figure 1.4
Spores collected in a Calcutta gaol, 1872 (Cunningham, 1873).



phere by volumetric methods. He used a water operated pump to produce a suction of 20 litres of air per hour through an orifice to impinge on a glycerine-coated glass slide. His estimates of mould spores outdoors in the Parc Montsouris averaged about 30,000 per m^3 in summer, occasionally up to 200,000 in rainy weather. Numbers of airborne bacteria were high in the centre of Paris compared to the park, but higher still in dwellings and particularly in the crowded hospitals (Miquel, 1883). As it became clear that many epidemic diseases were caused by bacteria, work at the laboratory concentrated on the bacterial analysis of drinking water.

In Germany, Hesse made an apparatus consisting of a narrow horizontal tube containing a layer of Koch's nutrient gelatine. Air was aspirated slowly through the tube allowing microorganisms in the air to settle and grow on the medium.

Hesse found that moulds penetrated much further into the tube than did the bacteria, and he made the important deduction that mould germs as found in the atmosphere are on average lighter than the bacterial germs. This led him to conclude that, whereas fungal spores were usually present in air as single particles, the aerial bacteria mostly occur in the air as large aggregates or attached to relatively large carrier particles of dust, soil or debris (Hesse, 1884; 1888). He also observed that most colonies consisted of single species – bacteria usually in small colonies of pure culture and fungi as isolated spores – and deduced that the airborne germs are not in the form of aggregates of different species.[1]

In London, P.F. Frankland (1886, 1887) used Hesse's method to study the air on the roof of Imperial College, London and inside crowded or empty buildings. He also used horizontal dishes with Koch's nutrient medium. He noticed that the number of colonies was greater when the mouth of the tube faced the wind rather than in other directions.

Frankland seems to have been the first person to realize that aerodynamic effects are of major importance in techniques for trapping the air spora.[1]

Although hay fever had been attributed to inhalation of pollen it was not until Blackley (1873) did inhalation experiments on himself that this was proved to be correct. Inhaled fungal spores were also recognised as allergens by Cadham (1924) and Feinberg (1935). Stepanov (1935) was one of the first to try to understand the processes of dispersal of spores.

By the early years of this [the 20th] century it became possible to assess the value of the ancient belief that the wind brings disease. Many diseases of crops, but very few diseases of man, have proved to be caused by minute particles carried on the wind. The particles are not some sort of invisible atoms as Lucretius thought; indeed, among the motes in the sunbeam, he may himself have been watching some of the baleful fungal spores and pollens which cause crop diseases and respiratory allergy.[1]

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1 From Gregory, 1973.

5. Aerobiology as a discipline

In the 1930s the American F.C. Meier first used the word **Aerobiology** to describe a research project on microbial life in the upper air. Unfortunately he was killed in an air accident over the Pacific Ocean in 1938 when only preliminary abstracts of his work had been published (Haskell and Barss, 1939). The new discipline was eventually launched by a symposium on extramural and intramural aerobiology published by the American Association for the Advancement of Science (Moulton, 1942).

Scientists at Rothamsted Research have made a major contribution to aerobiology over the past 60 years primarily by studying the epidemiology of plant diseases (Hirst, 1994). Philip Gregory has been called the father of modern aerobiology and it was his inspiration that initiated work on air sampling resolving many basic principles (Hirst, 1990, 1992; Lacey *et al.*, 1997). The different stages of the aerobiology pathway, (Fig.1.6. and Chapter 2) have been studied as ways of understanding, forecasting, controlling and preventing the spread of plant diseases. His interest in medical mycology started when he went to Winnipeg, Canada to work on human pathogenic fungi under the guidance of the mycologist, A.H.R. Buller. Because of the great economic depression he had to return to England in 1934 and was able to return to work on the diseases of narcissi at Seale Hayne College in Devon. With food shortages at the start of the Second World War he went to work on virus diseases of potatoes at Rothamsted Research Station.

5.1 Gregory's basic principals of aerobiology

Gregory observed infection gradients while working on insect-vectored virus diseases of potatoes (Gregory and Read, 1949). His interests turned to fungal spores and he read widely on the subject, even learning Russian to translate a 1935 paper by Stepanov. This lead to Gregory's paper on 'The dispersion of airborne spores' (Gregory, 1945), which demonstrated a clear understanding of the physical factors controlling the dispersal of both single and clumps of spores (and pollen). He developed and tested his theories, comparing them with others such as Stepanov (1935) and the meteorologists, Schmidt (1925) and Sutton (1932). He discussed the terminal velocity of spores, eddy diffusion, dispersion from both point and line sources, transport by wind and deposition. He observed that gradients of airborne plant infections originating from a point source were closely predicted by his theory but those known, or suspected of being splash dispersed, were not.

Some of Gregory's early experiments used *Lycopodium* spores, liberated after working hours into the natural draught along the corridor of the Plant Pathology (North) building at Rothamsted, and trapped on sticky slides and cylinders, in Petri dishes and, as a volumetric standard, a cascade impactor (Hirst, 1990, 1992). The results showed that many careful experiments were needed to explain how particle size, wind speed, turbulence and the dimensions and configuration of the trap surfaces affected deposition (see Chapter 2). These physical properties were studied, using a purpose-built small wind

tunnel, which had a 30 cm (1 ft) cross section (Fig. 2.7) and enabled wind speeds to be varied from 0 to 10 m s^{-1} (Gregory, 1951; Gregory and Stedman, 1953). The work was continued by O.J. Stedman, J.M. Hirst and F. Last (Gregory moved to Imperial College as Professor of Botany in 1954), establishing the standard measurement of air spora as the number of spores m^{-3} air.

5.2 The Hirst spore trap

Jim Hirst (Bainbridge and Brent, 1999) worked at Rothamsted, initially on potato blight, and realised that a reliable suction trap was needed to sample the air for plant pathogen spores rather than rely on the available traps (sticky cylinders). The cascade impactor (May, 1945 and Fig. 3.2) was used as the standard in calibrating other traps but the surfaces onto which particles were deposited became overloaded very quickly. Hirst resolved to use just one orifice (the 2nd; 2 mm wide), but moved a sticky slide past this using a mechanical clock (Hirst, 1952). The resulting deposit was more countable and the time of deposition could be calculated enabling diurnal periodicity or association with meteorological events to be established (traps are normally changed at 9.00 a.m. to coincide with weather records). The suction speed was set at 10 l min to give isokinetic efficiency at mean outdoor wind speeds, a wind vane enabled the orifice to point into the wind.

The Hirst spore trap (Fig. 1.5) revealed a wide diversity of air spora, mainly comprising pollen grains and spores of *Cladosporium, Alternaria*, smuts and rusts in dry wea-

Figure 1.5
A Hirst 24-hour volumetric spore trap (Lacey, J., 1996, with permission from *Mycological Research*).

ther, while at night and after rain there were many hyaline spores including ascospores and basidiospores (Hirst, 1953). Initially (summer 1952), many spores trapped were not identified and could only be placed in 'broad-form' groups e.g. 'dark basidiospore' (Gregory and Hirst, 1957). Other early studies of the total air spora using the Hirst trap were at an estuary (Gregory and Sreeramulu, 1958), at two contrasting rural sites (Lacey, M., 1962) and a two-year study over a paddy field in India (Sreeramulu and Ramalingham, 1966).

5.2.1 Early applications of the Hirst trap

Gregory was an asthma sufferer, who had worked in medical mycology, and thought that the occurrence of basidiospores in the air might be related to symptoms of some sufferers. Counts were made of hyaline, yellow and dark basidiospores during the months of August and September of 1951 with the suggestion that the spores could be allergenic (Gregory and Hirst, 1952). Two buildings containing fructifying dry rot fungus, (then named *Merulius lacrymans*, now *Serpula lacrymans*, Pl. 9.29), were also sampled (Gregory *et al.*, 1953). Thus the Hirst spore trap became an established air sampling technique for health (both indoor and outdoor) and plant pathological studies.

5.2.2 Manufacturing the Hirst spore trap

The great potential of the Hirst trap soon became widely appreciated, particularly among the medical profession. In 1953 Casella Ltd commercially manufactured the Hirst trap and it was operated at St Mary's Hospital, Paddington (Hamilton, 1959) and Cardiff (Hyde, 1959; Hyde and Adams, 1960). The design was improved and in 1966 Burkard Manufacturing Co. Ltd started to produce the seven-day recording volumetric spore trap. A battery powered pump and a 24-hour single slide holder were further developements. These traps, and the Lanzoni VPPS Hirst-type trap are now used in many countries for monitoring the air for airborne biological particles including plant pathogens, and allergens, and provide samples for the pollen counts given with the weather forecasts (see Chapter 4 for details of operating the Burkard trap).

5.3 Rotating or whirling arm traps

The development of a trap based on impaction of particles on sticky arms rotating through the air, powered by a simple electric motor, was another important advancement (Perkins, 1957). Due to its relatively low cost and compact size, numerous rotating arm (or rotorod) traps can be used collectively, improving the quality of information gained in studies on the distribution of airborne particles at different heights, directions and distances around a source (see Chapter 3). For example, rotating arm traps were used to assess pollen dispersal around a non-GM maize crop in France to assess risk of GM pollen dispersal (Jarosz *et al.*, 2003).

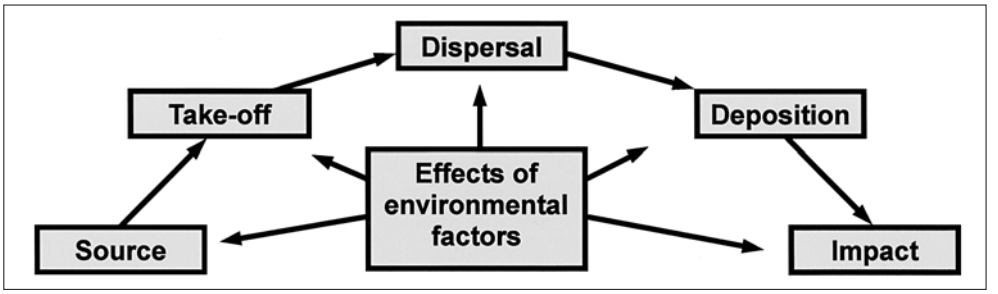

Figure 1.6
The aerobiology pathway (Lacey, J., 1996, with permission from *Mycological Research*).

5.4 Recent developments

Americans Edmonds and Benninghoff (1973) first published the concept of the **Aerobiology Pathway** (Fig. 1.6) as a simple method of explaining the different stages of the transport of organisms through the air. This concept was established and expounded by Edmonds (1979) and Cox (1987). The processes include the production and release of the biological particle, its dispersal through the air, its deposition and impact (effect) on the substrate on which it lands. Much of the early work was done outdoors, but with current emphasis on health and safety, much research is now focussed on indoor environments (Flannigan *et al.*, 2001).

Furthermore, recent developments have tended to reduce emphasis on visual identification of airborne particles in favour of more automated methods of detection and quantification. These techniques will be discussed here only briefly. Initial trapping of airborne particles often uses well-established principles but identification methods have diversified considerably. The integration of air-sampling methods with molecular and immunological diagnostic techniques for example can avoid the tedious nature of particle identification and even quantification (Williams *et al.*, 2001; Calderon *et al.*, 2002; Fraanije et al., 2005). In particular, molecular techniques, DNA or RNA probe technology and polymerase chain reaction (PCR), can be applied to air samples and may answer many previously unanswered or unasked questions such as proof of individual clones of plant pathogens being dispersed large distances to infect crops in different countries or even different continents (Hovmøller *et al.*, 2002; Brown and Hovmøller, 2002). The technique developed by Calderon *et al.* (2002), detected spores collected on the surface of waxed tape (from Burkard or rotating arm samplers) by probing for specific target DNA. Williams *et al.* (2001) described a technique that uses microscopic glass beads (Ballotini beads), in a shaker to disrupt spores (of *Penicillium roqueforti*), collected directly in Eppendorf tubes using a miniature cyclone sampler, and followed by detection using PCR. Air sampling coupled with molecular techniques has also proven to be a very convenient way of assessing the genetic diversity of a population of the target spore-producing organism in a particular region, this has also been helped by the development of the miniature cyclone sampler. However, molecular techniques are not always necessary in diversity studies; Limpert *et al.* (1999) used a jet spore sampler mounted on a car, which was driven across Europe to sample the diversity of barley powdery

mildew virulence. Spores were deposited into Petri dishes containing detached barley leaf sections, with virulence of spores from the resulting colonies tested on a differential set of cultivars.

The use of immunological techniques in aerobiology also has been facilitated particularly through development of the miniature cyclone sampler (Emberlin and Baboonian, 1995), a rotating arm sampler modified for collecting spores in wells of rows of a microtitre plate (Schmechel *et al.*, 1996), and a microtiter immunospore trapping device (MTIST) (Kennedy *et al.*, 2000). The latter technique uses a suction system to trap air particulates by impaction directly in microtiter wells, enabling detection and quantification of target particulates by enzyme-linked immunosorbent assay (ELISA).

Another (automated) development identifies target particles e.g. spores of a particular fungus using flow cytometry [of impinged samples] (possibly enhanced with selective staining and use of image analysis and neural network systems) (Day *et al.*, 2002; Morris *et al.* 1992). Flow cytometry allows spores and other particles (which would need to be trapped from the air and incorporated into liquid) to be analysed optically. For each particle, several parameters are analysed (e.g. light scatter, autofluorescence, particle width) to allow discrimination.

Improvements in modern computing power allowed the development of laser induced fluorescence spectroscopy, which can be used to detect bioaerosols. The apparatus of Cheng *et al.* (1999) found four bacteria tested to have similar fluorescence spectra, while Eversole *et al.* (2001) developed a prototype single particle fluorescence analyser, which could detect concentrations of bioaerosols as low as a few (1-5) particles per litre.

The Biotrace Biological Detection System (BBDS) and the Biotrace Intelligent Cyclone Air Sampler (ICAS) (Biotrace International plc.) use wet cyclones to trap airborne particles into liquid, which is then processed in a continuous flow luminometer to give near real-time detection of microbial contamination by ATP bioluminescence.

Filters can be used to detect toxins present in the air or airborne particles such as fungal spores following deposition e.g. onto porous polycarbonate or cellulose filters, followed by appropriate extraction and purification techniques for toxins (GC-MS, HPLC, TLC etc) or followed by diagnosis/culturing of plant or fungal spores or bacteria (Skaug *et al.*, 2001; Agranovski *et al.* 2002).

6. Aerobiology in action

6.1 British Aerobiology Federation

The British Aerobiology Federation was formed in 1990 to bring together people interested in aerobiology in the UK and to promote work and research in the subject area. BAF holds regular scientific meetings and workshops.

6.2 The National Pollen and Aerobiology Research Unit

The National Pollen and Aerobiology Research Unit conducts research on aerobiology

and in particular the abundance and dispersal of pollen. The work covers many aspects including distribution patterns in allergenic pollen, pollen monitoring,
fever and asthma, testing filters, forensics and the dispersal of pollen from GM crops. The UK pollen monitoring network has 33 sites, monitoring seasonal changes and the geographic distribution of pollen. Thirteen of these sites monitor the major allergenic pollen (grass and tree pollen), while others monitor grass pollen during the peak season (early summer) only.

6.3 Midlands Asthma and Allergy Research Association

The Midlands Asthma and Allergy Research Association (MAARA) is a charity which conducts and funds research into asthma and other allergies. MAARA has carried out aerobiological research since the charity was founded in 1968 and has the longest pollen and fungal spore dataset in the UK and one of the longest in the world.

6.4 International Association for Aerobiology

The International Association for Aerobiology (IAA) was founded at a meeting at the 1st International Congress of Ecology at The Hague on October 11th 1974. The IAA organises the Quadrennial Congress (International Congress on Aerobiology - ICA) which includes plenary sessions, symposia, scientific meetings, meetings of sections, commissions, committees, working groups and exhibitions on all aspects of aerobiology.