Chapter 1

INTRODUCTION

1.1 Introduction

Narrowly defined, 'Physics of the Environment' simply refers to the body of physical laws governing the environment within which we live. In its wider usage, the term is understood to encompass a more active human involvement, including on the one hand the observation and study of the environment and on the other the employment of physical laws and technologies for (in principle) the betterment of all. This text attempts to include both aspects. No claim is made that the content is in any sense comprehensive, but the material has been chosen to reflect the main issues of the moment, current technologies and some of the options for the future.

People in agricultural communities in both developed and developing countries alike live lives that are closely tied to the environment. Work is dictated by the seasons and success or disaster by the vicissitudes of the weather — too much rain at the wrong time can spell disaster. In developed countries, infrastructure exists (e.g. insurance, government compensation schemes, etc.) to mitigate the effects, but nevertheless the connection is close and tangible.

In urban communities, whether it is a large metropolis in an industrialised country or an often equally large shanty town from a poor country, life seems much more detached from the natural environment. Livelihoods have to be earned using different specialised skills, often based in the crowded workplaces of the factory or the office. The concentration of resources in towns allows for the development of centralised facilities, hospitals, schools, markets, and government offices. Expensive to maintain and operate, such services can only be sustained if the catchment area is sufficiently populated, which is clearly not the case in rural districts. Of course, urban workers are no more immune to the vagaries of life than their counterparts in the village. Governments change and companies go bankrupt or get taken over, and employees are made redundant as a result.

The lives of city dwellers in both the first and third world countries, are also intimately dependent on the environment, even if it is not immediately apparent. The food has to be grown somewhere, waste has to be removed and safely disposed of, and electricity generated from fuel extracted in various ways from the environment. All societies, whatever their level of development, are ultimately and *absolutely* dependent on the environment for the provision of their needs, be it for food, energy or waste disposal.

A proper understanding of our dependence on the natural world allows us to use the available resources in sustainable ways. This is not merely a question of self-denial, but of the intelligent deployment of technology based on correct science for the greatest benefit of humankind.

1.2 Scientific Method

There are in essence three premises on which the scientific method is based. Firstly, we assume that observations made through our senses (and by extension scientific instrumentation) are an objective representation of reality. Secondly, we assume that the world may be described by a set of self-consistent rules that are constant in time and space. Thirdly, we assume that the observed phenomena have discernable causes, i.e. causality.

Measurement lies at the heart of observation. Quantification of the observable allows comparison and verification with observations made elsewhere and at other times. The human senses vary considerably from individual to individual, and even for the same individual may change over time and in response to circumstances. Visual observation, for example, depends strongly on the ambient light level as the iris adjusts the eye's aperture to suit light conditions. Evidently, there is a need for sophisticated instrumentation with a performance that is known and which can be calibrated against internationally agreed standards. In tandem with this, there must be agreed scales of units that have universally accepted definition. Only then, when measurements are repeated by others or with more precise instrumentation, can errors and uncertainties be corrected and resolved.

It is not possible to prove that the laws of nature are, as we perceive them on Earth, constant and apply throughout the universe. Nonetheless, it does seem to be the case. Frequently, our understanding of physical laws has to be refined as the 'frontiers' of knowledge and experience are increased. For instance, Newton's laws of motion should now be viewed as a low velocity limit, since at sufficiently high speed the relationships between time and space have to be described in relativistic terms. Similarly, when the dimensions of a system are very small, it must be described in quantum mechanical terms. Neither implies any conflict with 'normal' classical mechanics, only that there are dimensional regimes when one particular set of laws provides an adequate description. (In the latter case, classical mechanics may be thought of as the large scale approximation of quantum mechanics.)

In many situations, the principle of cause and effect may be demonstrated by laboratory experiments. A deliberate test can be set up to examine whether, if under a given stimulus, the system under study responds in the expected manner. This implies the existence of some idea or 'model' of the system's behaviour. In other words, having carried out a variety of quantified measurements, and having thought carefully about the process, some hypothesis has been developed to describe the observed behaviour. The hypothesis should have predictive power, i.e. if the system is excited in this way, then according to the hypothesis it ought to respond in that way. If it does not, then having ensured that there was no trivial mistake or error, the hypothesis has to be refined or discarded as necessary. Eventually, this process will reveal a working thesis that would appear to explain the results.

In the physical sciences, such models are generally expressed in mathematical terms that allow precise calculation and manipulation of observed values with a degree of rigour not always available in other branches of science. The expression of accepted models in mathematical form allows the extrapolation to situations beyond the laboratory into un-testable regimes. When harnessed to the processing power of modern computers, it becomes feasible to simulate, for example, the effects of different levels of atmospheric carbon dioxide on the rate of global warming and to determine concentrations that should not be exceeded.

1.3 Contents

This book is intended for use mainly by students of physics in their second or subsequent year of undergraduate study. It presumes a basic familiarity with the classical laws of Newtonian physics, an understanding of SI units and a corresponding level of mathematical competence. The text aims to show that the application of the laws of physics at a relatively elementary level can provide a sound description of the environment within which we live.

Often confused with climate, the daily weather is the result of vertical and horizontal movement of air. Broadly speaking, the former governs rain and precipitation, and the latter winds. Atmospheric motion takes place on the global scale, where interaction with the rotation of the Earth and the oceans give, for example, the Trade Winds, and dictates local averages of temperature and rainfall. The time scales are short in relation to those associated with changes of climate, although trends in the weather may well be a direct consequence. The dynamic behaviour of the atmosphere constitutes the subject matter of Chapter 2.

Global warming, the seemingly remorseless increase in the mean temperature of the planet, is probably the topic of greatest concern at the present time. The basic physical processes underpinning global warming, radiative forcing, feedback effects, greenhouse gases etc., form the content of the Chapter 3. The main culprit is generally accepted to be the emission of carbon dioxide from power stations and transport. A short account is included of the abortive attempts to restrict these emissions under the Framework Convention on Climate Control — firstly, the voluntary Rio de Janeiro proposals and the subsequent more binding (but equally unsuccessful) Kyoto Protocol.

Despite current concerns over climate change, fears about ozone depletion predate those of global warming and led to the adoption by virtually the entire world of the first, and to date the only successful international agreement on environmental controls: the Montreal Protocol. The role of ozone in screening out harmful ultraviolet radiation and the mechanisms behind its depletion are discussed in Chapter 4.

The basic mechanisms of heat transfer are reviewed in Chapter 5, which lays the foundations for subsequent chapters on power generation and transport.

The generation of electrical power from the combustion of fossil fuels is discussed at some length in Chapter 6. Embedded within this chapter is a review of the basic principles of thermodynamics that govern and limit thermal efficiency. The technologies for coal and gas fired generation and their relative merits are then described, including new techniques for the sequestration of CO_2 that could prove important in managing greenhouse gas emissions.

There are, of course, alternative sources of carbon-free power generation, namely nuclear and the renewable sources. The physics of nuclear power, discussed in detail in Chapter 7, is frequently ignored or glossed over in environmental textbooks, partly because the dynamics of neutrons within a reactor core and the problems of sustaining a chain reaction are challenging and complex. There is also probably a widespread assumption that the technology will always be too dangerous to be adopted (especially post-Chernobyl) except in a few countries, such as France, Japan and South Korea, which have elected to 'go nuclear' for reasons of national interests.

Renewable sources, which is really a collective term for a disparate group of technologies including wind, solar, biomass, hydroelectric and geothermal, pose particular problems of their own. The basic physics and technology of these energy sources are discussed in Chapter 8, together with some comments on the problems of their utilisation. With the exception of geothermal sources, renewables are 'land hungry' and variable (especially wind). Additionally, the power generated at a single site is low compared with a conventional power station making integration into grid-based networks difficult.

Chapter 9 is devoted to issues of transportation. One of the great freedoms of modern times has been the freedom to travel and it is one that has, in the industrialised countries at least, come to be taken for granted. The invention of the internal combustion engine coupled with the discovery of extensive reserves of cheap oil duly led to the widespread ownership and use of private cars. Unfortunately, they are a major source of CO_2 emission and despite significant advances in engine design and the use of catalytic converters, they will continue to be so as long as they burn hydrocarbon fuels. Potentially hydrogen may be used as a clean fuel for cars, either as a direct replacement for hydrocarbon fuels in adapted internal combustion engines, or in fuel cell-electric motor combinations. The technological challenges inherent in the 'hydrogen economy' (as it has come to be called) are demanding. Hydrogen is a gas at ordinary temperatures and pressures, making on-board storage in vehicles difficult. None of the currently available solutions have so far emerged as superior to its competitors. In addition, although it is one of the most abundant elements on Earth, hydrogen only exists in compound form (e.g. in water) and not as the free element required for its use as a fuel. It is a *secondary* source that still has to be produced from some other *primary* energy source.

All waste emissions, whether gaseous or liquid, must ultimately be accommodated within the environment. Harmful products have to be dispersed and diluted to safe levels — in the case of liquid effluents usually into rivers or the sea; in the case of smoke and gases, into the atmosphere. The mechanisms of dispersal, principally diffusion and advection, are discussed in Chapter 10. As a rule, individual systems are much too complex to be described by analytical solutions and invariably have to be modelled on a case-by-case basis. Nevertheless, they are physical processes governed by common general principles and the purpose here is to provide some intuitive appreciation of the underlying physics.

Groundwater flow, or the motion of water *within* the ground, is of considerable significance for human public health. Much of the water used for human consumption is derived from what amounts to vast natural underground reservoirs, known as aquifers. They are replenished by the same diffusion mechanisms that govern the dispersal of waste products into the environment, underlining the universality of these processes.

The final chapter considers some of the current ethical issues. It does not focus on the 'hard science' *per se* but on less tangible questions relating to the stewardship of the environment. The energy deficit that is currently on the minds of western governments, and which is engendering a renewed interest in nuclear power, is reviewed. How should planning authorities estimate risk and harmful issues and balance these against their potential benefits? How their does a democratic government reconcile legitimate competing and conflicting interests? A related topic is the consumption of finite material resources, arguably of greater significance in the long run than climate change. Ultimately, such questions often reduce to a matter of individual lifestyle choices and corporate decisions; in short, how we choose to steward the environment.