# 17

# Introduction

Electromagnetic radiation is all around us and presumably present in the entire universe. From the experiments carried out with the electromagnetic fields that carry the radiation, it is concluded that such fields not only penetrate into all matter, but are also present in those regions of space where the amount of matter present is negligibly small. From the latter it is extrapolated that electromagnetic radiation is also present in regions of space where there is no matter at all (those regions are denoted as *vacuum regions*). This property distinguishes electromagnetic radiation from, for example, acoustic radiation; the latter is confined to matter, either in its fluid (i.e. gaseous or liquid) or its solid (or condensed) state. The property of omniperviousness makes electromagnetic fields ideally suited to carry out measurements in all subdomains of physics (and chemistry); in particular, most of the measurement standards in physics are nowadays defined through some property of electromagnetic radiation.

When following an electromagnetic wave on its course, we start with its *excitation* by an electromagnetic source (a transmitting antenna, a laser). Once it has been generated, the wave *propagates* along a certain, more or less confined, path (a "ray") from the source to the receiver. Depending on the properties of the medium through which the wave passes, this propagation can lead to continuous *refraction* by spatial and/or temporal changes in the medium (for example, atmospheric refraction), to *reflection* against and *transmission* across interfaces between different media, or to discontinuous *scattering* or *diffraction* by objects whose electromagnetic properties show a contrast with those of their surroundings. Finally, the wave motion is *received* by an electromagnetic receiving device (a receiving antenna, an optical detector). Figure 17.1 illustrates these different aspects.

Each of these aspects is the subject of extensive theoretical and experimental investigation. Usually, when the attention is focused on a particular detail, the remaining circumstances are chosen as simply as possible. For example, when one wants to investigate the directional characteristics of a transmitting antenna, the surrounding medium will be taken to be of the utmost simplicity as far as its electromagnetic properties are concerned, and of infinite extent. When studying refraction phenomena during the propagation of an electromagnetic wave, the source will be taken to be a simple one (mostly a point source, i.e. a source whose dimensions are negligibly small compared to the other characteristic dimensions of the configuration in which the propagation occurs), while the influence of the receiver will be neglected altogether (by taking it to be a point receiver). When studying the influence of a scattering configuration, both the surrounding medium and the kind of excitation will be taken to be very simple ones. All these simplifications are dictated by the impossibility of taking into account the influence of all parameters simultaneously, even with present-day, large-capacity, high-speed computers.

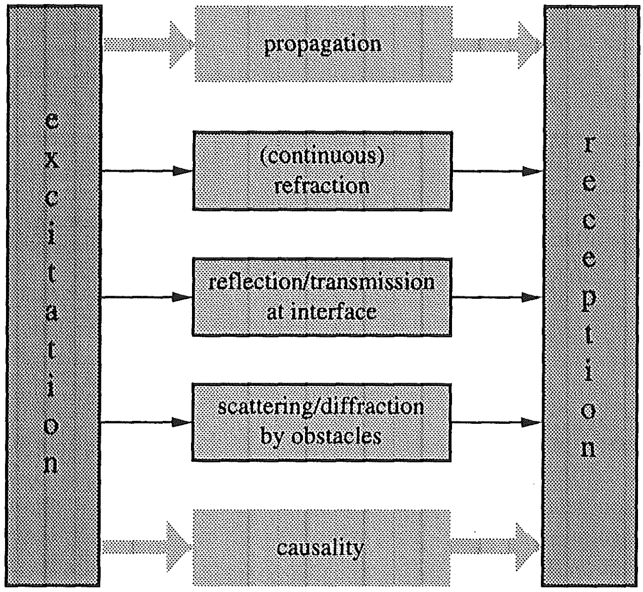


**Figure 17.1** Electromagnetic wave phenomena on their course from source to receiver.

It is the task of the electromagnetician to put the results of the partial model studies together in a judicious way in order to be able to judge the behaviour of electromagnetic fields and waves in the more complicated situations met in practice.

The practical applications of electromagnetic waves are widespread, and the number of fields in which they are used is ever increasing. In everyday life, electromagnetic waves are *carriers of energy* and *information*. In the field of medicine, they are used for *diagnostics* (for example, X-ray tomography, i.e. the imaging of an object (fetus, tumour) inside the body by means of electromagnetic radiation in the X-ray part of the spectrum) as well as for *therapy* (for example, in hyperthermic oncology). Another application is the use of electromagnetic fields in *exploration geophysics*, either in surface excitation and detection, or in borehole electromagnetics. Here, electromagnetic fields and waves are used to map the subsurface structure of the Earth in the search of fossil energy resources and minerals, as well as for environmental monitoring. Furthermore, the *non-destructive evaluation* of materials and of mechanical structures makes use of electromagnetic waves. The scattering of these waves by interior defects (inclusions, bubbles, cracks) makes the presence of these defects detectable at the surface of the structure, which is accessible for carrying out the necessary measurements. For location and navigation purposes *RADAR* (*RAdio Detection And Ranging*) systems are installed on almost any vessel or aircraft.

Another subject of major importance is the *ElectroMagnetic Compatibility* (*EMC*) of electric and (micro)electronic devices and systems, in which respect the theory of electromagnetic interference and shielding plays a vital role. With the ever-increasing use of electromagnetic waves for signal transmission in telecommunication and information systems, the crowding in the available frequency bands becomes extreme. Through electromagnetic radiation, each part of a circuit can, in principle, interfere with the performance of another part of the same circuit, or with another circuit, in an unwanted and often intolerable manner. Judicious design and/or

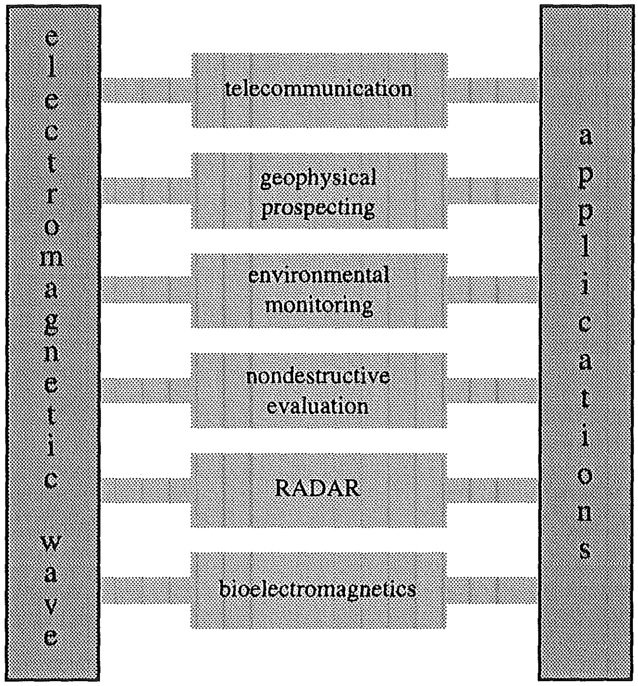


**Figure 17.2** Applications of electromagnetic waves.

effective shielding measures are the only answers to this difficulty. In Figure 17.2 the different applications are listed.

We shall develop the theory of electromagnetic radiation on a *macroscopic scale*. This implies that in all interactions between electromagnetic radiation and matter a large number of elementary building blocks of matter is involved and that the exchange of energy takes place through large numbers of energy quanta. Occasionally, we shall use microscopic considerations to elucidate the physical concept behind the macroscopic phenomena. The basic laws of macroscopic electromagnetic theory were formulated by James Clerk Maxwell and can be found in his famous book (Maxwell, 1873). For a survey of the history of the subject the reader is referred to Whittaker (1953). From the theory it follows that there exist electromagnetic waves that travel with a finite wave speed which *in vacuo* seems to be a universal constant, independent of the state of motion in which the observer carries out his or her experiments. (The latter is not the case for waves in matter, and, hence, also not for acoustic waves, for example.) Since through a wave motion with a constant wave speed the changes in position in space and the changes in time are interrelated in a rigid manner, electromagnetic waves in vacuum can serve as a means to interconnect the space–time observations for two observers in relative motion. This concept has led Einstein to the development of the theory of relativity (see Einstein 1956, Moeller 1972, Van Bladel 1984). Classical treatises on the subject are the ones by Jeans (1925, 1946), Stratton (1941), Jones (1964) and Van Bladel (1964). Advanced topics are covered by Felsen and Marcuvitz (1973).

As in any kind of wave motion, the physical quantities that describe the electromagnetic wave motion depend on position and on time. Their time dependence in the domain where the source is acting is impressed by the excitation mechanism of the source. The subsequent dependence on position and time elsewhere is governed by propagation and scattering laws that follow from the pertaining fundamental field equations and the principle of causality.

## Exercises

### *Exercise 1-1*

Make a list of the names and the SI-units (written in full with the corresponding) symbols of the electromagnetic field and wave quantities occurring in the chapters of Part 3. (*Hint:* Consult the General Introduction for the pertaining international standardisation.)

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