Chapter 1
Introduction

Any process in nature involves to a certain extent some type of energy transfer. From an engineering point of view, certain processes of energy transfer are undesired but still inevitable, as, for instance, energy dissipation in electromechanical systems; whereas other processes are desired and highly beneficial to the design objectives, the classical example from mechanical engineering being the addition of a vibration absorber to a machine for eliminating unwanted disturbances.

Targeted energy transfers (TETs), where energy of some form is directed from a source (donor) to a receiver (recipient) in a one-way irreversible fashion, govern a broad range of physical phenomena. One basic example of TET in nature, is resonance-driven solar energy harvesting governing photosynthesis (Jenkins et al., 2004), where energy from the Sun is captured by photobiological antenna chromophores and is then transferred to reaction centers through a series of interactions between chromophore units (van Amerongen et al., 2000; Renger et al., 2001). In addition, basic problems in biopolymers concern energy self-focusing, localization and transport (Kopidakis et al., 2001), with applications in photosynthesis (Hu et al., 1998) and bioenergetic processes (Julicher et al., 1997).

From the engineering point of view, the scaling down of engineering applications from macro- to micro- and nano-scales dictates an understanding of the mechanisms governing TET and energy exchanges between components possessing different characteristic lengths with dynamics governed by different time-scales. For example, as pointed out by Wang et al. (2007) in applications such as molecular electronic devices where the scales of the dynamics are at the level of individual molecules, classical concepts of heat transport do not apply, and heat is transported by energy transfer through discrete molecular vibration excitations. Hence, understanding and analyzing energy transfer mechanisms in molecular dynamics (such as, resonance energy transfer) is key in conceiving devices or studying processes for specific macromolecular applications, such as, for example, in the area of photophysics (Andrews, 2000; Jenkins and Andrews, 2002, 2003). Moreover, molecular dynamic simulations of energy transfers (for example, through solitonic waves) in mechanistic molecular or atomistic models have been used to study thermodynamic processes, such as, melting of polymer crystals and phase transitions in polymer-
clay nanocomposites (Ginzburg and Manevitch, 1991; Berlin et al., 1999; Ginzburg et al., 2001; Berlin et al., 2002; Gendelman et al., 2003). In Musumeci et al. (2003) issues related to nonlinear mechanisms for energy transfer and localization in biological macromolecules and related applications to biology are discussed. Moreover applications of nonlinear energy transfer in a broad area of applications ranging from cancer detection (Meessen, 2000; Vedruccio and Meessen, 2004) to wireless power transfer (Kurs et al., 2007) have been reported in the recent literature.

Therefore, it is not surprising that TET phenomena have received much attention in applications from diverse fields of applied mathematics, applied physics, and engineering. Representative examples are the works by Aubry and co-workers on passive targeted energy transfer (TET) between nonlinear oscillators and/or discrete breathers (Kopidakis et al., 2001; Aubry et al., 2001; Maniadis et al., 2004; Memboeuf and Aubry, 2005; Maniadis and Aubry, 2005), on breather-phonon resonances (Morgante et al., 2002), and on quantum TET between nonlinear oscillators (Maniadis et al., 2004). The dynamical mechanisms considered in these works were based on imposing conditions of nonlinear resonance between interacting dynamical systems in order to achieve TET from one to the other, and then “breaking” this condition at the end of the energy transfer to make it irreversible. A mechanism of TET along a line or surface by means of coherent traveling solitary waves is examined in Nistazakis et al. (2002); specifically, the transfer of a solitary wave to a targeted position was studied in the nonlinear Schrödinger (NLS) equation, the underlying nonlinear dynamical mechanism being resonance energy transfer from an ac drive to the solitary wave. Applications of energy localization and TET in diverse applications, such as, biological macromolecules – proteins and DNA, arrays of Josephson junctions in superconductivity applications, and molecular crystals are given in Dauxois et al. (2004), including analytical, computational and experimental results.

In other complex phenomena, such as turbulence and chaotic dynamics, multi-scale energy transfers between different spatial and temporal scales govern the dynamics. Perhaps the best known example is turbulence, where mechanical energy is supplied to a fluid system at relatively large length scales, peculiar spatiotemporal coherent structures are formed at intermediate scales, and dissipation of energy occurs at short scales (Bohr et al., 1998). Hence, energy transfer between these scales is what makes turbulence possible. Examples of works on multi-scale energy transfers in fluids are the works by Kim et al. (1996) and Tran (2004) who studied nonlinear energy transfers in fully developed turbulence, and by Brink et al. (2004) who studied nonlinear interactions and multi-scale energy transfers among inertial modes of a rotating fluid, modeling it as a network of coupled oscillators.

All nonlinear energy transfers involve to a certain extent some type of nonlinear resonance between a donor and a receptor. Resonance energy transfer has been identified as an important mechanism for energy and electronic transports in the area of photophysics of macromolecules (Jenkins and Andrews, 2002, 2003; Andrews and Bradshaw, 2004), and has been recognized as the principal mechanism for electronic energy transport in molecular chains following initial excitations (Daniels et al., 2003). Esser and Henning (1991) analyzed energy transfer and bi-