Preface

Rogue and dispersive shock waves are phenomena that occur in nonlinear dispersive media. They have been studied in different fields of physics, including ocean waves, nonlinear optics, Bose-Einstein condensates, plasma physics, etc. They are apparently very different phenomena; however, they are both characterised by the development of extremes: while the amplitude of a rogue wave reaches large values, shock waves develop extreme gradients. The presence of rogue and shock waves in an incoherent wave system drastically influences its statistical properties.

During the last 15 years, the field of “rogue waves” has experienced a very quick development. The original motivation of the research was related mostly to the occasional measurement of extreme waves on the surface of the ocean and to the occurrence of various accidents caused by the impact of large amplitude waves on ships. Only more recently, it has been shown that extreme light fluctuations could be observed in an optical fibre; the research activity has now broadened up to the creation of a new field in its own.

A rogue wave is the manifestation of a process of focussing of energy. One of the most accredited explanations of the formation of rogue waves (at least in an idealised case) is the modulational instability process by which a small perturbation of a plane wave can grow exponentially fast in time. This mechanism has been known from the late sixties, but only at the beginning of the new century, it has been associated to rogue waves. The nonlinear stages of the modulational instability are described by exact solutions of the nonlinear Schrödinger equation. Those solutions, named breathers, have been considered as the prototypes of rogue waves in the ocean.

The development of an infinite gradient in finite time (gradient catastrophe) with consequent wave-breaking is probably a less baleful phenomenon, nonetheless of extreme nature. Mathematically, a classical shock wave is a discontinuous (weak) solution describing propagation beyond a breaking point where an infinite derivative develops. Starting from the last century, in several branches of physics, it has been recognised that the dissipation plays an important role in regularising the jump leading to physical shock waves characterised by strong but finite gradients. A completely different non-trivial dynamics may result when dispersion dominates.

In the latter case, after wave-breaking, the infinite gradient is regularised by the spontaneous onset of fast non-stationary oscillations that progressively fill an extended region. The effect of dispersion on the regularisation of shock waves is very intriguing, leading to a complex strongly non-stationary dynamics. Optics has provided only recently the opportunity to observe these dynamics that appear to be similar to those produced in hydrodynamics under specific conditions involving, for examples, strong tidal bores propagating upstream in river estuaries. Shock waves have impact on many practical situations ranging from photonics to hydraulic dam-breaking to traffic or gas dynamics problems, for which the dispersive effects, which are normally neglected, may determine a qualitative change of the system behaviour.

In the summer of 2015, we have organised a school on rogue and dispersive shock waves in the beautiful village of Cargese, Corsica (France). The idea was to bring together top-level theoretical physicists, mathematicians and experimentalists working mainly in ocean waves and nonlinear optics with the aim of presenting to students and young researchers a unifying concept of rogue and dispersive shock waves. The school lasted for 2 weeks: the first one was characterised by a set of 3-h lectures whose goal was to introduce the students to the deterministic and statistical approach to the subject in the various fields. During the second week, shorter talks, in the workshop format, were given in which more advanced topics were discussed. It turned out that the event was very successful with about 70 (including students and lecturers) participants and many useful discussions. The present book can be considered as a collection of notes from some of the 3-h lectures. It includes a first chapter "Hydrodynamic and Optical Waves: A Common Approach for Unidimensional Propagation" in which a close analogy between optics and hydrodynamic waves is made. The chapter introduces the reader to the nonlinear Schrödinger (NLS) equation which has played a major role in the understanding of rogue waves. A second chapter "Integrability in Action: Solitons, Instability and RogueWaves" is devoted to the role played by integrable equations in the development of the field; the chapter explains how to construct solutions that describe coherent structures such as solitons and rogue waves or how to investigate patterns as those caused by shock waves or instabilities. The third chapter "Hydrodynamic Envelope Solitons and Breathers" and fourth chapter "Experiments on Breathers in Nonlinear Fibre Optics" describe experiments in hydrodynamics and nonlinear optics where exact breather solutions of the NLS equation have been reproduced experimentally. The following three chapters are devoted to a statistical description of rogue waves in water waves: in chapter "Hamiltonian Description of Ocean Waves and Freak Waves" a theory for estimating the kurtosis and the skewness of the surface elevation from wave spectra is explained. The theory has a major relevance in the forecasting of rogue waves in operational systems. Its validation with field measurements is also reported. In chapter "Modelling Transient Sea States with the Generalised Kinetic Equation" an extension of the theory presented in chapter "Hamiltonian Description of Ocean Waves and Freak Waves" is discussed: in particular, the role of sharp changes of wind in the generation of rogue waves is highlighted. Chapter "Rogue Waves in Random Sea States: An Experimental Perspective" describes the results from a number of experiments performed in wave tanks with the aim of establishing the probability of formation of rogue waves in different sea states; experiments including currents under the waves are also described. In chapters “Introduction to Wave Turbulence Formalisms for Incoherent Optical Waves” and “Integrable Turbulence with Nonlinear Random Optical Waves” the attention is turned to the description of incoherent optical waves. The reader is brought to the construction of statistical tools for describing a system of a large number of interacting optical waves; issues related to condensation, thermalisation, incoherent modulational instability and wave turbulence are discussed. Chapter “Integrable Turbulence with Nonlinear Random Optical Waves” is related to the emerging field of integrable turbulence, i.e. the nonlinear state generated by a large number of incoherent waves described by integrable equations. Experiments in optical fibres ruled by NLS equation and numerical simulations revealing the formation of heavy tails in the probability density function of the wave amplitude are described. The last two chapters deal with dispersive shock waves: the first of the two includes a pedagogical introduction to the Whitham modulation equation that plays a major role in the understanding of dispersive shock waves. The last chapter includes experimental results in optics and hydrodynamics displaying dispersive shock waves.

Our idea was to create a book accessible to graduate students and researchers working in various fields of physics and applied mathematics. Moreover, we hope that this work might be useful to students by bringing to their attention problems of fundamental nature that are often neglected in graduate courses. The book cannot be considered as exhaustive; the reason is that the field on rogue and dispersive shock waves is rapidly evolving, and every month, new interesting ideas appear in the literature. We have made a selection of the topics, giving priorities to what we believe are the results described by a common and interdisciplinary language. Each chapter is self-consistent and it does not require the reading of the previous one.

We would like to thank all the authors of the chapters of the book and, more generally, all the speakers of the school in Cargese with whom we have exchanged many fruitful and interesting discussions on rogue and dispersive shock waves. Finally, we would also like to acknowledge the CNRS, the Università di Torino, the Università di Brescia and the European Geophysical Union for their financial support to the school.

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