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The physics of solar flares

THE PHYSICS OF SOLAR FLARES

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Units, constants, and symbols

Because of its overwhelming use in the solar physics community, we have, a little reluctantly, decided to use cgs units throughout this book. In addition, we yield to another common practice among solar physicists and discuss the wavelength of radiation in terms of angstroms. The reader will therefore, for example, encounter magnetic fields measured in Gauss ($1\,G = 10^{-4}$ tesla), pressure in dyne cm^{-2}, currents in statamps, and wavelengths of spectral lines referred to in angstroms (1 angstrom $= 10^{-8}$ cm). The different symbols used will be defined in the text, since the same symbol (letter) may be used to denote different parameters or constants. However, when no definition is given, the following letters will always refer to the following physical constants or parameters:

Boltzmann's constant	$k = 1.38 \times 10^{-16}$ erg K^{-1}
Planck's constant	$h = 6.626 \times 10^{-27}$ erg s
Gravitational constant	$G = 6.67 \times 10^{-8}$ dyne $cm^2\,g^{-2}$
Velocity of light	$c = 2.998 \times 10^{10}$ cm s^{-1}
Electron rest mass	$m_e = 9.1 \times 10^{-28}$ g
Proton rest mass	$m_p = 1.67 \times 10^{-24}$ g
Elementary charge	$e = 4.80 \times 10^{-10}$ esu
Thermal conductivity coefficient	$K = 1.0 \times 10^{-6}$ erg $cm^{-1}\,s^{-1}\,K^{-7/2}$
Temperature	T (K)
Electron number density	n_e (cm^{-3})
Frequency	$\omega = 2\pi\nu$ (s^{-1})
Magnetic field	B (G)
Coulomb logarithm	$\ln \Lambda$ [equation (4.64)]
Collisional stopping parameter	$C = 2\pi e^4 \ln \Lambda$ [equation (4.69)]
Bremsstrahlung cross-section coefficient	$\kappa_{BH} = \frac{8\alpha}{3} r_0{}^2 m_e c^2$ [equation (5.23)]
Electron plasma frequency	$\omega_{pe} = (4\pi n e^2/m_e)^{1/2}$ [equation (3.75)]

Preface

Few phenomena have stirred the interest of solar scientists more than the explosive manifestation of energy release we call solar flares. A rich literature exists describing this many-faceted phenomenon, and hypotheses and theories abound trying to explain the different stages observed during a flare. In 1976 Švestka's excellent book *Solar Flares* appeared, and in the late 1970s the Skylab data on flares were studied and a workshop on Solar Flares was conducted by NASA, leading to a comprehensive monograph edited by Sturrock (1980). Another workshop on flares was conducted by NASA in 1983–84, focusing on the excellent results from the Solar Maximum Mission, and the workshop proceedings, edited by Kundu and Woodgate (1986), have recently appeared.

With this background we hesitated at first, when approached by Cambridge University Press, to agree to writing another book on solar flares. However, we also realized that the nature of workshop proceedings generally dictates a very different approach than does the philosophy behind the presentation in a text such as the present volume. We will draw heavily on results from the SMM, but other sources, both from space-borne and ground-based instrumentation, will play crucial roles. In addition, we will incorporate the findings of many new theoretical investigations, always trying to put them in the logical physical context. Consequently, we venture to present *The Physics of Solar Flares* in the hope that its main emphasis – on understanding the physical processes – will make our effort worthwhile.

Solar activity manifests itself in many ways and, while the minor manifestations, for example facular and plage brightening, do not require large amounts of energy, the cataclysmic flare phenomenon severely taxes most available energy sources. Ultimately, one is left with only two: the energy stored in nonpotential magnetic fields and the energy available in the vast photospheric and subphotospheric mass–motion fields. Controversy exists as to how one uses these energy sources to explain solar flares. We can consider solar activity as manifestations of the interaction of magnetic fields with the solar plasma in motion, and this book tries to apply this formula to the flare phenomenon.

The book therefore differs from its predecessors in the sense that it is aimed primarily at beginning graduate (or advanced undergraduate) students who are assumed to be acquainted with the basic knowledge of physics required to understand what we have learned about flares but who need an introduction to the context in which this knowledge is to be applied. The book starts from basic physical principles, such as Maxwell's equations and the equations of fluid mechanics, and develops these into the 'language' of solar flare physicists. Readers who have grasped the content of this book should feel qualified to contribute to current research in solar flare physics and to read published papers in the field critically.

We have divided the book in two main parts. After an overview of the observational aspects of flares, the next four chapters present the tools we deem necessary to attack the physics associated with the flare, and then the following four chapters treat the different phases of the flare or, stated differently, the different manifestations of the flare phenomenon.

The mathematical and physical background that provides the tools for a proper and indepth study of flares consists of Spectroscopy (Chapter 2), Magnetohydrodynamics and Plasma Physics (Chapters 3 and 4), and Radiation Processes (Chapter 5). Thus equipped, we then follow the evolution of the flare process from Pre-flare Conditions (Chapter 6) through the Impulsive Phase (Chapter 7) to the Gradual Phase (Chapter 8). The interaction of flares with prominences and the corona is treated in Chapter 9 in the context of mass ejections. In the Epilogue we offer a brief prognosis for solar flare research in the near future.

Huntsville, June 1987

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A. G. Emslie

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To Erna and Buffie