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Radiation and Detectors

Introduction to the Physics of Radiation and Detection Devices

Springer

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To Fabiola, for her support and encouragement, and to Mattia and Luca, who arrived around the time of this project

Preface

This textbook is based on my lectures for the undergraduate course of radiation detectors, in the School of Physics and Astronomy at Queen Mary University of London, given in the years 2012 and 2013.

The book provides an introduction to the field of radiation, to the mechanisms of interaction between radiation and matter, and to the exploitation of those mechanisms for the purpose of designing radiation detectors. Significant attention is paid to all of those aspects in equal measure, defining and explaining the language and the first principles with little assumption. The mathematical formalism is kept to a minimum, but simple derivations are presented in order to guide the reasoning and understanding of the physics principles. Detectors are introduced by both their general working design and by modern examples of devices currently operating around the world. There are over 140 original experimental figures, detector schematics, and photographs in this book, which help relate the material to the broader research context and can be used to find out more through the selected referenced documents.

Since interaction processes become more or less relevant depending on the energy, on the materials and the detection objectives, in this book the interaction mechanisms and the detectors are presented interleaved, and the description of a technology always follows the particular interaction mechanism which it exploits. For example, in describing the interaction of photons, the photoelectric effect is introduced first in Chap. 9 by only the details needed in the context of photomultipliers, then expanded in Chap. 10 together with Compton scattering and pair production which anticipate the discussion of electromagnetic showers and the technology of calorimeters. In other words, in organising the material in this book only the physics principles most relevant are presented first, clearly and extensively, just before describing a class of detectors.

The first five chapters are dedicated to *radiation*, as we understand it today based on subatomic physics, including the language in use, its metrics, and the most common natural and man-made forms of radiation. Realistic worked examples of the various types of radiation and its energy accompany the presentation. Dosimetry (Chap. 3) is presented from a modern, user-led point of view, and

relativistic kinematics (Chap. 4) is introduced to give the basic knowledge needed to handle the more formal aspects of radiation dynamics and interaction. Part II is dedicated to the *interaction* between radiation and matter, and to *detectors*. The energy loss by ionisation (Chap. 6) is described in some detail, anticipating the principles of ionisation detectors (Chap. 7), semiconductor detectors (Chap. 8), and scintillation detectors (Chap. 9). The topics in Chap. 10 span several interaction mechanisms that underpin the phenomenology of showers and the design of calorimeters. Chapter 11 covers a number of additional phenomena including Cherenkov and transition radiation and the detection of neutrinos. Finally, a summary of statistics and probability distributions is presented in the Appendix.

Through this book, the reader is expected to acquire an awareness of how radiation and its exploitation are rapidly expanding to many diverse contexts in the modern world, including in medical physics. The reader will also acquire the preliminary broad knowledge needed if wishing to undertake advanced studies in one of the areas presented. The introductory level of the material makes the book of particular interest to undergraduate students, graduate students (for an introduction to radiation detectors or selected aspects of it), and lecturers as support for a one-semester undergraduate course on radiation detectors.

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Rome, Italy Lucio Cerrito

Contents

Acronyms

AC	Alternating Current
ACE	Advanced Composition Explorer
ADC	Analog-to-Digital Converter
ALICE	A Large Ion Collider Experiment
AMANDA	Antarctic Muon and Neutrino Detector Array
ANTARES	Astronomy with a Neutrino Telescope and Abyss Environmental Research
APEX	Atacama Pathfinder Experiment
ATLAS	A Toroidal LHC Apparatus
CDF	Collider Detector at Fermilab
CERN	European Organisation for Nuclear Research
CMB	Cosmic Microwave Background
CMS	Compact Muon Solenoid
CNAO	Italian National Centre of Oncological Hadron-therapy
COBE	Cosmic Background Explorer
CT	Computed Tomography
DC	Direct Current
DESY	Deutsches Elektronen-Synchrotron
D0	D0 Experiment
EM	Electromagnetic (Calorimeter)
ESA	European Space Agency
FIRAS	Far Infrared Absolute Spectrophotometer
FNAL	Fermi National Accelerator Laboratory
GEM	Gas Electron Multiplier
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
LABOCA	Large APEX Bolometer Camera
LAr	ATLAS Liquid Argon Calorimeter
LHC	Large Hadron Collider

LHCb	Large Hadron Collider beauty
LINAC	Linear Accelerator
LNT	Linear-non-Threshold
LO	Leading Order
LOFT	Large Observatory for X-ray Timing
MICROMEGAS	Micromesh Gaseous Structure
MSGC	Multistrip Gas Chamber
MWPC	Multiwire Proportional Chamber
NASA	National and Aeronautics Space Administration
NLO	Next-to-Leading Order
PDF	Probability Distribution Function
PID	Particle Identification
PMT	Photomultiplier
PVT	Polyvinyl Toluene
QCD	Quantum Chromodynamics
RHIC	Relativistic Heavy Ion Collider
RICH	Ring Imaging Cherenkov
RF	Radio Frequency
RMS	Root Mean Square
RPC	Resistive Plate Chamber
SI	International System of Units
SM	Standard Model
SNO	Sudbury Neutrino Observatory
SNU	Solar Neutrino Unit
SWOOPS	Solar Wind Observations Over the Poles of the Sun
SWICS	Solar Wind Ion Composition Spectrometer
TPC	Time Projection Chamber
TRD	Transition Radiation Detector (ALICE)
TRT	Transition Radiation Tracker (ATLAS)
UV	Ultraviolet
WMAP	Wilkinson Microwave Anisotropy Probe