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Ball and Moore's
Essential Physics for Radiographers

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Fourth Edition
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Preface

The decade leading up to the publication of the third edition of *Essential Physics for Radiographers* in 1997 saw a revolution in the education and training of radiographers in the UK. By contrast, the 10 years which have elapsed since then have been a period of consolidation. Although in most ‘schools of radiography’ traditional physics and equipment are no longer taught as separate subjects, we have remained faithful to our original concept of focusing on the physical principles underpinning radiography and have resisted the temptation to write an integrated physics and equipment book. Our aim remains to ensure the ‘essential physics’ on which the integrated approach is based is made clear and readily understandable to students. Consequently, some sections remain largely unchanged except for the updating of references to the applications of physical principles.

However, the introduction of new radiation safety legislation in the past decade demanded that we employ a more drastic approach to the revision of the chapter on radiation safety. With this in mind, and with an eye on the future of ‘Ball and Moore’, we took the opportunity to invite long-time friend and colleague Steve Turner onto our writing team. Steve has brought a fresh mind and valuable expertise to the project. He has contributed the whole of Chapter 21 as well as influencing the revision of other chapters.

We have retained the extremely successful and popular innovations introduced in the last edition: the *Maths Help File*, decimal numbering of paragraphs and sections, and reference citations, updated to include Internet sources. The physical principles of magnetic resonance imaging form the basis of a new chapter, Chapter 23.

We are happy to acknowledge the help we have received from many sources during the 2-year revision period. As always, we have been sustained in our efforts by the support and encouragement offered by our professional colleagues and by our friends and families. We also thank the editorial staff of Blackwell Publishing for their continuing commitment to our work.

*John Ball*

*Adrian D. Moore*

*Steve Turner*

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How to use the Maths Help File

A note to the reader

It has been our experience as teachers that students of radiological physics are frequently confused by some of its mathematical aspects. Often, the student may merely need to be reminded of the mathematical procedures involved. In other cases, the student may be totally unfamiliar with a particular procedure or concept and will benefit from a fuller explanation.

To overcome these difficulties, we have provided an appendix called the Maths Help File, following Chapter 23, which offers extra help on some of the mathematical methods and concepts found in the main text.

As you work through the book, you will encounter the Maths Help File icon in the left-hand margin, particularly alongside many of the mathematical worked examples, e.g.

The icon indicates that extra help is available, if you require it, in the Maths Help File. The number on the calculator (e.g. 12) tells you in which section of the Maths Help File you will find guidance and explanation relevant to the specific mathematical problem involved.

We hope that you will find the Maths Help File both easy to use and a valuable resource.
Chapter 1
General Physics

1.1 Energy and matter

Physics is concerned with the study of two concepts: energy and matter, and the relationships between them.

1.1.1 Energy

Energy is described as the ability to do work. Consider what would happen if there were no energy available. Without energy nothing would happen, nothing would ever change and nothing would ever get done. Energy is needed to make things happen. It exists in many forms and can be converted from one form to another, e.g.

- The human body converts chemical energy (obtained from the food we eat and the oxygen we breathe) into energy of movement (kinetic energy) when we walk or run.
- Light energy is converted into electrical energy in a solar-powered electronic calculator.

1.1.1.1 Conservation of energy

As well as being converted from one form to another, energy can also be stored, but it is not possible to create or destroy energy. In other words, in a self-contained or closed system (i.e. one with no ‘leaks’) the total amount of energy does not change. This concept is embodied in the law of conservation of energy, which
Chapter 1

states that the total energy in the universe is constant. This concept is fundamental to our understanding of physics.

1.1.2 Matter

Matter is the name given to the material of which all things, including us, are made. It normally exists in one or more of the three main physical states of matter solid, liquid and gas, but it may also exist in liquid crystal and plasma states.

Matter can be converted from one form to another by physical or chemical means, e.g.

- Ice can be melted and turned from a solid into a liquid. This is a physical change because both the solid and the liquid are made of the same substance (water). The process is reversible: liquid water can be frozen back into ice.
- Wood can be burned and changed into ash. This is a chemical change because wood and ash are fundamentally different materials. Although it is not possible to reverse this process by converting ash back into wood, some chemical changes are reversible: e.g. the chemical combination of oxygen with the haemoglobin of red blood cells, which takes place in the lungs, is reversed when oxygen is released from haemoglobin in the tissues.

1.1.2.1 Is matter conserved?

In most everyday situations, when a physical or chemical change occurs matter is neither created nor destroyed: the total amount of matter involved remains constant. For example, when melted, a 1-kilogram block of ice forms 1 kilogram of liquid water: there is no net gain or loss of matter. In the case of the burning of wood, however, matter does not at first sight appear to have been conserved: 1 kilogram of wood produces less than 1 kilogram of ash. Nevertheless, if all the matter involved in the process is taken into account (i.e. the oxygen gas consumed and the smoke particles, gases and water vapours produced during combustion), a balance can be demonstrated and it is found that matter has been conserved.

For many years, the conservation of matter was believed to be as fundamental a concept as the conservation of energy. All the experiments and observations seemed to confirm that matter was indeed conserved. Since the beginning of the twentieth century, however, it has been known that there are processes in which matter is not conserved; e.g. the nuclear fusion process which generates the energy output of the sun involves a net loss of matter and a net gain of energy. Consequently, although the conservation of matter remains a useful concept, it no longer warrants the status of a physical law because it is not universally true.

1.1.3 The relationship between energy and matter

Albert Einstein showed that energy and matter are not two entirely different concepts and that it is possible to convert one into the other. It seems that matter is a special form of stored energy and, in certain circumstances, its energy can be released and used.