Resource Letter MP-2: Medical Physics

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This Resource Letter provides a guide to the literature on the uses of physics for the diagnosis and treatment of disease. It does not include molecular biophysics but does include biomedical engineering. © 2009 American Association of Physics Teachers.

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I. INTRODUCTION

Physicists sometimes use the terms medical physics and biological physics loosely and almost interchangeably. Within these fields, however, there is a distinction. In the United States the term medical physics has traditionally meant the physics used to diagnose and treat disease. We have diagnostic and therapeutic radiology, diagnostic and therapeutic nuclear medicine, ultrasound (mainly diagnostic but treatments are emerging), and magnetic resonance imaging. Recently the areas of interest to the medical physicist have expanded as still more diverse and sophisticated instruments such as lasers are used for diagnosis and treatment. The American Association of Physicists in Medicine is the professional organization affiliated with the American Institute of Physics to which most medical physicists in the United States belong.

Biological physics is the study of biological phenomena using physical techniques, encompassing studies as diverse as molecular and cellular structure and function, physiology, biomedical instrumentation, the medical physics areas described in the preceding paragraph, and mathematical biology. Sometimes the terms biological physics and biophysics are used interchangeably. However, in recent years the term biophysics has been used more narrowly to mean the study of molecular and cellular biology. Members of the Biophysical Society have interests primarily in biophysics, while members of the Division of Biological Physics in the American Physical Society are concerned primarily with biological physics.

This Resource Letter describes the use of physics to diagnose and treat disease in humans. This definition includes biomedical engineering as well as medical physics, but it ignores significant applications of physics in physiology and molecular and cellular biology.

In many cases a textbook is the most appropriate way to begin learning about a topic in medical physics. Where they are available, they open the list of references for each topic below. The journal articles cited here are representative examples rather than the state of the art or an exhaustive bibliography. One can explore further by reading the references in the articles cited, by scanning the journals listed here, or by using PubMed (www.pubmedcentral.nih.gov) to find other articles on the same subject. Another accessible source of information can be found at Scholarpedia (www.scholarpedia.org), which is similar to the better-known Wikipedia (www.wikipedia.org), except that each article is written by an expert and has a curator who must approve changes. Some Scholarpedia articles relevant to this letter are Bidomain Model, Cardiac Arrhythmias, Electroencephalogram, Functional Imaging, Functional Magnetic Resonance Imaging, Magnetic Resonance Imaging, Magnetoencephalogram, and Transcranial Magnetic Stimulation.

II. JOURNALS

A. Medical physics

British Journal of Radiology. The articles are primarily clinical. (IA)


IEEE Transactions on Medical Imaging. (IA)

IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control. Some of the articles are on medical ultrasonics. (IA)

International Journal of Radiation Biology. (IA)

Journal of Computer Assisted Tomography. This journal covers all CT modalities: Ultrasound, x-ray, SPECT, PET, and MRI. The articles are primarily clinical. (IA)
Journal of Magnetic Resonance Imaging. This journal has both instrumentation and clinical articles. (I,A)

Journal of Nuclear Medicine. (I,A)

Journal of Ultrasound in Medicine. The articles are primarily clinical. (I,A)

Magnetic Resonance in Medicine. (I,A)

Medical Physics. This is the journal of the American Association of Physicists in Medicine. Each issue contains original papers spanning all modalities of diagnostic imaging and radiation therapy physics, as well as a “point/counterpoint” article that debates an important current issue in medical physics. These articles provide an excellent way to become familiar with current issues. A compendium of articles (through February 2008 at the time of this writing) is available at www.aapm.org/pubs/books/PointCounterpointCompendium.pdf. (I,A)

Physics in Medicine and Biology. The Institute of Physics journal covering the application of physics to medicine, physiology, and biology. Its affiliated website (medicalphysicsweb.org) provides current news about medical physics. (I,A)

Radiation Research. Devoted to radiation biology. (A)

Radiographics. Contains peer-reviewed educational articles for radiologists, trainees, physicists, and other radiologic professionals. Topics include clinical and therapeutic radiology, physics, and informatics. (I,A)

Radiology. The articles are primarily clinical. (I,A)

Ultrasonics. The articles are primarily about instrumentation and techniques. (I,A)

Ultrasonic in Medicine and Biology. The articles are primarily clinical. (I,A)

Ultrasonic Quarterly. The articles are primarily clinical. (I,A)

B. Biomedical engineering

Annals of Biomedical Engineering. This is the journal of the Biomedical Engineering Society. (I,A)

Annual Reviews of Biomedical Engineering. Volume 1 was published in 1999. For the topics in this Resource Letter, this journal replaces Annual Reviews of Biophysics and Biomedical Engineering, which in recent years has been devoted to molecular biophysics and which, after various name changes, is now called Annual Reviews of Biophysics. (I,A)

Critical Reviews in Biomedical Engineering. One of the CRC Critical Reviews. (I,A)

IEEE Engineering in Medicine and Biology Magazine. This magazine is analogous to Physics Today. It contains tutorial articles at the elementary to intermediate level. (E,I)

IEEE Transactions on Biomedical Engineering. (LA)

IEEE Transactions on Neural Systems and Rehabilitation Engineering. (LA)

IEEE Transactions on Information Technology in Biomedicine. (LA)

IEEE Reviews in Biomedical Engineering. The first volume appeared in 2008. (I)

Medical and Biological Engineering and Computing. The official journal of the International Federation of Medical and Biological Engineering. (I,A)

III. RELATED RESOURCE LETTERS

A number of Resource Letters are relevant to medical and biological physics. The first five are of historical interest. They show the state of the mathematical biology, biophysics, and biomedical engineering from the mid-1960s to the mid-1980s.


4. Resource Letter MP-1: Medical Physics, R. K. Hobbie, Am. J. Phys. 53(9), 822–829 (1985). This is the previous version of the present Resource Letter. Some of the references in it to pre-1985 literature are still very useful. (E,I,A)

5. Resource Letter PPPP-1: Physical Principles of Physiological Phenomena, B. Hoop, Am. J. Phys. 55(3), 204–210 (1987). Identifies physical principles that are important in classical physiology, such as the circulatory system, muscle contraction and energetics, action potentials, biomagnetism, mass transport, and ion channels. (E,I,A)

The next two Resource Letters are not about Medical Physics, but they show how physics applies to biology at the cellular level. See also Ref. 15.


The next three Resource Letters expand on material covered in this one.


IV. GENERAL TEXTS

This section lists textbooks and articles that cover several of the areas in this Resource Letter and that are suitable references for a physics teacher. Elementary physics texts containing just a few biological examples are not listed.


14. Introduction to Physics in Modern Medicine, 2nd ed., S. A. Kane (Taylor & Francis, New York, 2009). This elementary text discusses fiber optics, lasers, ultrasound, x rays, nuclear medicine, radiation therapy, and magnetic resonance imaging. (E)

15. Biological Physics, updated edition, P. Nelson (Freeman, New York, 2007). In general, we are not listing biological physics texts in this Resource Letter, but this one is so good that we provide it as an introduction to this field. (I)

Besides textbooks, several websites exist that teachers of medical physics may find useful, including the following:

(a) www.insidestory.iop.org (an Institute of Physics website with animations related to medical physics),
(b) www.teachingmedicalphysics.org.uk (an IOP website with teaching materials about medical physics for K-12 schools), and
(c) www.physicscentral.com/discover/biology-medicine.cfm (an American Physical Society website about applications of physics to medicine and biology).

Also of interest to those thinking about adding a medical physics class to the college curriculum is the following:


V. DIAGNOSTIC IMAGING

A. General

Diagnostic images are obtained using ultrasound, x rays, radioactive isotopes, and magnetic resonance imaging. There are two types of information a physicist may want about these modalities: First, the details of the physics behind the medical image and second, pictures of the equipment and typical diagnostic images. We give references for both. Examples are often best found in textbooks for radiologists or the allied health personnel (technologists) who actually perform the procedures.

The references in this subsection apply to all of these imaging modalities. Later subsections give references specific to each modality.

Tomography is derived from the Greek tomos, meaning slice. Tomography was originally a technique in which the film and x-ray tube were rotated about a point or line passing through an organ of interest, thereby blurring structures that are not close to the pivot. In computed tomography (CT), two-dimensional slices are reconstructed from a series of projections. CT is used in medical physics with x rays, radioactive isotopes, and magnetic resonance imaging. The reconstruction technique was developed simultaneously in radioastronomy, crystallography, radiology, and nuclear medicine. Two physicists shared the Nobel Prize in Physics or Medicine for this development. The next two references are their Nobel Lectures.


X-ray transmission tomography reconstructs in two dimensions the attenuation coefficient μ(x,y) from a series of projections of ∫μ(s)ds. In spiral or helical CT, the patient is moved through the continuously rotating x-ray apparatus along the z (long) axis, and linear interpolation is used to reconstruct the slices. It is now possible to produce three-dimensional reconstructions of organs, blood vessels, the inside of the colon, etc. and to examine them from any angle. It is estimated that in 2006 about 45 000 CT scanners were in use, most of which were whole-body spiral scanners (Ref. 53).

In emission tomography, a nuclear-medicine procedure, the concentration of a radioactive isotope C(x,y) is reconstructed from a series of projections ∫C(s)ds. In single-photon emission computed tomography (SPECT), a gamma-
emitting isotope is used. In positron emission tomography (PET), a positron emitter is used, and the two annihilation photons are detected in coincidence.

The following references discuss two or more imaging modalities:


22. *Farr’s Physics for Medical Imaging*, P. Allisy-Roberts and J. Williams (Saunders/Elsevier, Edinburgh, 2008). This brief book is intended for radiologists and covers all imaging modalities. (Nuclear medicine is called gamma imaging.) (E)


A number of very sophisticated image processing techniques are available to the radiologist. These include feature recognition, noise reduction, and compression techniques. Compression is important for the storage and transmission of diagnostic images. The image must be compressed in a manner that does not lose meaningful diagnostic information. The need to view, transmit, and store images from many vendors has led to the Picture Archiving and Communication System (PACS) and the standard for Digital Imaging and Communication in Medicine (DICOM). The ability to transmit and display diagnostic-quality images allows teleradiology: The radiologist can cover several clinics or hospitals from one location. All this is discussed in the next five references.


Computer-aided diagnosis or computer-aided detection (CAD) of diagnostic images is becoming increasingly prevalent. Notice the word “aided.” The radiologist still interprets the image but with the assistance of various computer-generated image enhancements or extracted data. The history and recent developments are described in Ref. 35.


B. Ultrasound

Ultrasound is widely used in medical diagnosis. Conventional ultrasound images show specular reflections from acoustic-impedance discontinuities between structures in the body. Doppler ultrasound detects moving structures, such as the beating fetal heart, or measures the velocity of red cells in flowing blood. The nonlinear response of tissue to high-intensity ultrasound leads to harmonic generation; these harmonics have recently been used for imaging. Ultrasound is also being used to measure the elastic properties of tissue (see, for example, Ref. 44). The use of ultrasound for therapy is described in Sec. VI.

There are several good general texts and articles. See also Refs. 13, 14, 19, 20, and 22.

36. *Diagnostic Ultrasound: Principles and Instruments*, F. W. Kremkau (Elsevier Saunders, St. Louis, 2006). This book is written for allied health personnel. The physics is elementary but complete. There are lots of
pictures of equipment and diagnostic images. (E)


38. **Basic Doppler Physics**, H. J. Smith and J. A. Zagzebski (Medical Physics, Madison, WI, 1991). This text for allied health personnel covers some very advanced topics at an elementary level. It assumes the reader understands B-mode ultrasound. (E)

The next two books are standard clinical texts with basic physics chapters at the beginning.

39. **Diagnostic Ultrasound**, 3rd ed., C. M. Rumack, S. R. Wilson, and J. W. Charboneau (Elsevier/Mosby, St. Louis, 2005). This clinical text begins with 34 pages on physics, 20 pages on biologic effects and safety, and 20 pages on microbubble contrast agents. (E)

40. **Diagnostic Ultrasound**, J. P. McGahan and B. B. Goldberg (Informa Healthcare, New York, 2008). This is a clinical text with a short section on basic physics. (E)

The following three texts are written for graduate students in medical physics or engineering:


In addition to the specular reflection from organ boundaries, there is diffuse scattering from microstructures in the organ tissue. This signal is 40–50 dB less than the specular reflection, but it can be used to characterize the tissue.


Microbubbles are used as contrast media. This is described in Refs. 39 and 41 as well as in


C. X-ray images

Everyone is familiar with the x-ray image or radiograph made on film. A beam of x rays from a point source passes through the body and exposes a photographic plate. Structures that attenuate the x rays more appear lighter on the developed film. The x-ray dose to the patient should be the lowest that provides a satisfactory signal-to-noise ratio. To reduce the dose the film is made more sensitive to x rays by sandwiching it between fluorescent screens in a cassette. See Refs. 13, 14, 19, 20, and 21. In mammography the characteristics of the x-ray beam are optimized for soft-tissue imaging. The radiology texts listed earlier describe the apparatus in detail and have many examples of diagnostic radiographs.

Dental x-rays have their own considerations for beam energy and film properties. Many texts for the dentist and the technician are available. See, for example,


In recent years solid-state detector systems have replaced the film-screen combination. In computed radiography (CR) a storage phosphor replaces the film in the cassette. After exposure the storage phosphor is read out and digitized by scanning it with a laser and recording the light produced. Direct radiography (DR) comes in two forms. In direct conversion the x rays interact with a photoconductor that is in contact with a thin-film transistor array. In indirect conversion, the x rays strike a scintillator, and the resulting light is detected by a charge-coupled detector (CCD) array.


Once one has digital images, all sorts of manipulations can be done. For image manipulation, see Refs. 8, 13, 14, 19, 20, 21, 31, 34, and 35.

Most of the references in the general section above describe x-ray computed tomography. The history of x-ray CT is found in


54. “AAPM/RSNA Physics tutorial for residents: Physics of cardiac imaging with multiple-row detector CT,” M. Maresh and D. D. Cody, Radiographics 27(5), 1495–1509 (2007). This tutorial description for residents is quite accessible to physicists. (I)


Digital techniques are now being used in mammography. See


D. Nuclear medicine

Diagnostic nuclear-medicine techniques involve measuring the distribution of a radioactive substance in various organs, often as a function of time. The spatial resolution is not as good as in radiology, but one obtains information about function—the uptake and disappearance of the isotope from an organ. The gamma camera or scintillation camera produces images similar to those in conventional radiography. It produces a two-dimensional picture showing “hot spots” or “cold spots,” with no information about the depth of the source in the body. Computed tomography with radioactive isotopes includes SPECT and PET.

Most single-photon imaging is done with the isotope 99mTc, which has a half life of 6 h. It is produced as the decay product of 99Mo. The latter’s 67 h half life means it can be produced at a national facility and shipped to hospitals. The positron emitters used in PET have much shorter half lives. The one that is used almost universally is 18F, with a half life of 110 min. It is made into 18F deoxyglucose (18FDG). Glucose is C6H12O6. In the compound two-deoxyglucose (DG, C6H12O5), an OH group in the glucose molecule is replaced by a hydrogen atom. Deoxyglucose enters the cell and starts down the metabolic pathway but gets trapped because the OH group is missing. Thus DG accumulates in cells with high metabolic activity. Another H can be replaced by 18F to make 18FDG, C6H11FO5, which gets trapped at the same metabolic stage. Thus 18FDG concentrates in regions of high metabolic activity, such as tumors. It was originally thought that each hospital would need its own cyclotron to produce the isotope, but it has proven feasible to have regional distribution centers that produce 18F in a cyclotron by a (p,n) reaction on 18O and then make up the 18FDG.


60. Diagnostic Nuclear Medicine, edited by M. P. Sandler, R. E. Coleman, J. A. Patton, F. J. Th. Wackers, and A. Gottschalk (Lippincott/Williams and Wilkins, Philadelphia, 2003). A book designed for residents containing a short description of scintillation cameras, SPECT and PET, with a great deal of material on imaging different organ systems. (E,I)


See also Refs. 8, 13, 14, 20, 21, and 29.

Since the images obtained with nuclear medicine do not have the spatial resolution of x-ray images but provide information about function, one can obtain additional information by superimposing a PET image on a CT image. This is described in some of the nuclear-medicine texts and also in

E. Magnetic resonance imaging

Magnetic resonance imaging (MRI) has become one of the most versatile imaging methods in the clinician’s arsenal. Nuclear magnetic resonance (NMR) depends on the precession of nuclear spins (often $^1$H) about a strong static magnetic field. After a radio-frequency magnetic field excites the spins, they relax to their equilibrium position. The precession frequency and relaxation time constant depend sensitively on the spin’s environment, which allows researchers to extract much information from NMR experiments. The addition of gradient magnetic fields allows imaging, where the spatial information is encoded in the frequency or phase of the spin precession. MRI provides high-resolution images without ionizing radiation.

In 2003, Paul C. Lauterbur and Peter Mansfield received the Nobel Prize in Physiology or Medicine for their discoveries concerning magnetic resonance imaging. The first two references are their Nobel Lectures.


70. MRI: From Picture to Proton, 2nd ed., D. W. McRobbie, E. A. Moore, M. J. Graves, and M. R. Prince (Cambridge U. P., Cambridge, 2007). An introduction to MRI presented backward to the traditional order: Starting with clinical considerations and then working back to basic physics principles. (E, I)


75. Principles of Magnetic Resonance Imaging: A Signal Processing Perspective, Z.-P. Liang and P. C. Lauterbur (IEEE, New York, 2000). This text emphasizes signal processing more than physics, but it does analyze MRI from the point of view of its inventor, Paul Lauterbur. (A)


Functional MRI (fMRI) has become a very important technique in magnetic resonance imaging. It detects changes in blood oxygenation to provide information on brain function as well as anatomy.


Diffusion tensor imaging is another recent imaging method based on MRI. In anisotropic tissue, such as muscle or white matter in the brain, the technique uses magnetic-field gradients applied in different directions to determine the diffusion tensor. From this tensor one can obtain its trace, which supplies an orientation-independent measure of diffusion that is useful when imaging stroke. Alternatively, one can determine the principle axes of the tensor, which indicates the fiber direction and could be used to map fiber tracks in the brain.


Large magnetic-field gradients are allowing magnetic resonance images with higher spatial resolution, creating the new field of MRI microscopy.


Many other interesting applications of MRI have been developed.

84. “Magic angle effect in MRI of articular cartilage: A review,” Y. Xia, Invest. Radiol. 35, 602–621 (2000). Anisotropy of biological tissues can be measured using the magic-angle effect in MRI. When the line between two nuclei makes an angle of 55° to the main magnetic field, the interaction of the two dipoles is zero, reducing their tendency to dephase and thereby lengthening the T2 time constant. (I)

86. “Magnetic resonance imaging for ischemic heart disease,” H. Sakuma, J. Magn. Reson Imaging 26, 3–13 (2007). An overview of MRI applied to the heart, including the use of contrast agents such as gadolinium. (I)


88. “Direct detection of neuronal activity with MRI: Fantasy, possibility, or reality?” P. A. Bandettini, N. Petridou, and J. Bodurka, Appl. Magn. Reson. 29, 65–88 (2005). The question posed in the title of this paper has not been answered yet, but if biomagnetic fields could be used as the contrast agent in MRI, it would provide a whole new type of functional imaging. (I)

89. Ultra High Field Magnetic Resonance Imaging, P.-M. Robitaille and L. J. Berliner (Springer, New York, 2006). Many researchers are pushing for higher and higher magnetic-field strengths (e.g., 7 T) for use in MRI. (I,A)


VI. THERAPY

Radiation therapy is the greatest area of employment of medical physicists. The most common treatment beams are high energy photons; electrons or protons are also used at some centers. Brachytherapy uses radioactive sources that are implanted in tissue or placed in a body cavity to deliver ionizing radiation to the tumor. External beam therapy and brachytherapy are well covered in Resource Letter MPRT-1, Medical Physics in Radiation Therapy, Ref. 10, and in a classic text.


Ultrasound is also used for therapy. At low intensities it is used for diathermy: Tissue heating by a few degrees to promote blood flow and healing. High-intensity focused ultrasound (HIFU) was first used in the 1950s to destroy deep-seated lesions by creating high temperatures at the focal region, but it did not catch on. Though there are still drawbacks, there has recently been a revival of interest that is described in Ref. 44 and the following articles. Ultrasound is also used for lithotripsy, the pulverization of kidney stones.

92. “High Intensity Focused Ultrasound: Past, present and future,” G. ter Haar and C. Coussios, Int. J. Hyperthermia 23(2), 85–87 (2007). This short review article provides a nice introduction to HIFU. It is the lead article for the March 2007 issue of Int. J. Hyperthermia, which is entirely devoted to HIFU. (E)

93. “A resurgence of therapeutic ultrasound—A 21st century phenomenon,” G. ter Haar, Ultrasoundics 48(4), 233 (2008). This is the preface to an entire issue devoted to therapeutic ultrasound. (E)


VII. EFFECTS OF IONIZING RADIATION

Detailed information on the interaction of photons and charged particles is very important for designing x-ray and nuclear-medicine equipment and for understanding the dose to the patient. Cross sections, attenuation coefficients, and absorption coefficients for photons are available on the Web, as are stopping powers and ranges for electrons, positrons, and protons.


The quantities used to describe the energy deposited in tissue or a detector are the energy transferred, the energy imparted, and the absorbed dose. The absorbed dose is measured in gray (Gy) or J kg⁻¹. The equivalent dose to a target organ multiplies the dose by a dimensionless weighting factor that takes into account the relative biological effectiveness of the radiation on that organ. For photons and electrons, the weighting factor is one. The effective dose takes into account the amount of radiation received by all organs. Both the equivalent and effective doses are measured in sievert (Sv). The details are described in Refs. 13 and 20, as well as in


99. Photon Interactions: A Simulation Study with MacDose, R. K. Hobbie (University of Minnesota Media Resources, Minneapolis, 1991) is a 26 min QUICKTIME movie that uses simulations to demonstrate photon interactions in water. It introduces the concepts of energy transferred and energy imparted and shows the importance of multiply-scattered photons. This movie is in the public domain and is available at www.tc.umn.edu/
Both the immediate effects such as skin reddening (erythema) and long-term effects (such as cancer) depend on the dose. This is discussed in Refs. 9, 10, 13, 14, 20, and 59, as well as in


A great deal has been done over the years to reduce the dose from conventional x-ray procedures.


The dose in classic x-ray procedures ranges from <0.1 to 40 mSv for non-CT exams and 1–15 mSv for a CT exam (Ref. 108). The average U.S. background radiation from naturally occurring sources is about 3 mSv. Doses for cancer therapy are typically 20–80 Sv to the tumor.

Population doses have increased significantly with the increase in the number of CT procedures. These increases in exposure are documented in


105. “Computed Tomography—An increasing source of radiation exposure,” D. J. Brenner and E. J. Hall, New Engl. J. Med. 357(22), 2277–2284 (2007). The authors argue that about 62 × 10^5 CT scans were done in the United States in 2007, a 20-fold increase since 1980, and that one-third of these were not necessary. Doses are 15–20 mGy per scan in adults and are two to five times larger in children. They estimate that up to 2% of all cancers in the United States might be due to radiation from CT studies. (I)

106. “The AAPM Statement on Radiation Dose from Computed Tomography, in Response to the Brenner and Hall NEJM Article Published Nov. 29, 2007,” on the web at (www.aapm.org/publicgeneral/CTScans.asp). The AAPM agrees that unnecessary CT scans should not be done, but AAPM is concerned that people may decline scans that are warranted. (E)

The Alliance for Radiation Safety in Pediatric Imaging recently initiated the “image gently” campaign to reduce radiation exposure to children (see (www.imagegently.org)).

The issue is not yet decided. AAPM is also concerned about some of the assumptions made in Ref. 105, such as applying data from a single radiation dose to a population that has multiple lower doses. However, some of the higher CT doses are now larger than the lowest doses encountered in the atomic-bomb survivor studies.

Considering the following model will help the reader understand the issue. The probability \( p \) of acquiring a radiation-induced cancer is assumed to be proportional to the effective dose \( H: p = \alpha H \), where \( \alpha \) is determined from higher effective doses, often in studies of the atomic-bomb survivors. This is called the linear-no-threshold (LNT) model. Since \( p \) is usually small, the number of radiation-induced cancers in a population can be predicted using the binomial distribution.

The mean number of cases \( m \) in a population \( N \) is \( m = \alpha NH \). The product \( NH \) is widely used in radiation protection and is called the collective dose, expressed in person-Sv. The following example, simplified from p. 15 in Ref. 104, helps put this in perspective. Among 100 people, half men and half women, about 42 will be diagnosed with cancer during their lifetime, in the absence of any excess radiation. If they had all received a whole-body dose of 100 mSv (100 mGy of x rays or electrons), there could be one additional cancer in the group.

Even if the LNT model is correct, mitigation efforts are sometimes misdirected. For example, there has been concern about lung cancer from radon in houses. The following study considered the lung cancer risk from radon in Quebec. In a population of 60,000, a total of 109 lung cancer deaths is predicted. Mitigation to the recommended level of <200 Bq m\(^{-3}\) would reduce this number from 109 to 105. The same number of lives would be saved by reducing smoking by 0.04%!


A detailed reference on the effects of ionizing radiation at low doses can be found in “Resource Letter EIRLD-1: Effects of ionizing radiation at low doses” (Ref. 9).

Helical CT and multislice systems have more complicated geometries that make it necessary to define new dose parameters.

108. “The measurement, reporting, and management of radiation dose in CT,” Report of AAPM Task Group 23 of the Diagnostic Imaging Council CT Committee, American Association of Physicists in Medicine, College Park, MD, 2007. This report describes in detail the multidetector CT geometries of the major manufacturers and the additional parameters required to assess dose. (I)

The discipline of health physics is concerned with the health effects of radiation and other physical stimuli (such as lasers, ultrasound, and nonionizing electromagnetic fields), as well as ways to protect the public and workers in these
fields. Many of the books listed above discuss radiation protection, but texts such as these provide more details.


110. An Introduction to Radiation Protection in Medicine, J. V. Trapp and T. Kron (Taylor & Francis, New York, 2008). (E,I)

VIII. OTHER MEDICAL PHYSICS AND BIOMEDICAL ENGINEERING AREAS

In the past 20 years, biomedical engineering has blossomed into a unique discipline with its own textbooks, academic departments, and even its own institute (the National Institute of Biomedical Imaging and Bioengineering) in the National Institutes of Health. The field is broad, and in this Resource Letter we focus on a few topics that highlight the application of physics to medicine.

111. Introduction to Biomedical Engineering. 2nd ed., J. Enderle, S. Blanchard, and J. D. Bronzino (Elsevier, Burlington, MA, 2005). One of the standard textbooks in biomedical engineering. (I)

112. Medical Physics and Biomedical Engineering, B. H. Brown, R. H. Smallwood, D. C. Barber, P. V. Lawford, and D. R. Hose (Institute of Physics, Bristol, Philadelphia, 1999). (I)


A. Electrical signals from the body

Bioelectricity is a large and growing field. Several good textbooks are the following:


One important application of bioelectricity is electroencephalography (EEG), which measures the electric field of the brain.


Often clinically useful information can be gained by measuring the electrical conductivity of tissue.

120. Electrical Impedance Tomography: Methods, History and Applications, edited by D. S. Holder (IOP, Bristol, 2005). Overview of a growing field including recent developments such as magnetic resonance electrical impedance tomography (a combination of electrical impedance tomography and measurement of currents using MRI) and magnetic-induction tomography (a technique to image conductivity by inducing eddy currents and measuring the magnetic field they produce). (A)


B. Magnetic signals from the body

SQUID magnetometers can detect the magnetic fields arising from the body.

122. Biomagnetism: Interdisciplinary Research and Exploration, The Proceedings of the 16th International Conference on Biomagnetism, edited by R. Kakigi, K. Yokosawa, and S. Kuriki (Hokkaido, Sapporo, Japan, 2008). This biennial conference is the primary meeting in the field of biomagnetism. The proceedings of earlier conferences are also useful. (A)


Electromagnetic induction can be used to excite neurons in the brain, a method called transcranial magnetic stimulation.


C. Pacemakers and defibrillators

The cardiac pacemaker/defibrillator is one of the triumphs of biomedical engineering.

graphy and no knowledge of cardiac pacing whatsoever.” (E)


129. Machines in our Hearts: The Cardiac Pacemaker, the Implantable Defibrillator, and American Health Care. K. Jeffrey (Johns Hopkins U. P., Baltimore, 2001). Provides an excellent introduction to the history and development of this important industry. (I)

A discussion of the electrical properties of cardiac tissue, including the formation of “spiral waves” and other arrhythmias, can be found in


131. The Geometry of Biological Time. 2nd ed., A. T. Winfree (Springer, New York, 2001). The late Art Winfree wrote this classic. The second edition has an expanded section on the electrical behavior of the heart from the perspective of a mathematical biologist. (A)

132. Cardiac Bioelectric Therapy: Mechanisms and Practical Implications, edited by I. R. Efimov, M. W. Kroll, and P. J. Tchou (Springer, Boston, 2009). This collection contains chapters by most of the leaders in the field from an experimental and theoretical rather than clinical point of view. (A)

133. “Introduction: Mapping and control of complex cardiac arrhythmias,” D. J. Christini and L. Glass, Chaos 12, 732–739 (2002). Introduces a Focus Issue of the journal Chaos dedicated to cardiac electrophysiology, which includes papers by many of the leading researchers in this field. (A)


D. Other effects of electric and magnetic fields


Radiofrequency ablation is particularly important in treating some heart disorders.


There is much debate, at least in the popular press, about possible health risks of low-frequency (nonionizing) electromagnetic fields produced by power lines and cell phones.


E. Prostheses and other medical devices

A wide variety of prosthetic devices is available, including artificial organs.


F. Lasers and optics

Lasers have introduced many medical applications of light, from infrared to the visible spectrum to ultraviolet.


A fascinating and fast-growing new technique to image biological tissue is optical coherence tomography (OCT). It uses reflections like ultrasound but detects the reflected rays using interferometry.

153. **Optical Coherence Tomography**, M. E. Brezinski (Elsevier, Amsterdam, 2006). Overview of the physics of OCT and applications to cardiovascular medicine, musculoskeletal disease, and oncology. (I)


With infrared light, scattering dominates over absorption. In this case, light diffuses through the tissue. Optical imaging in turbid media is difficult but not impossible.


One impetus for medical applications of light has been the development of new light sources, such as free-electron lasers and synchrotrons. In both cases, the light frequency is tunable over a wide range.


Finally, photodynamic therapy uses light-activated drugs to treat diseases.


G. **Elemental analysis and mass spectrometry**

Sometimes, important medical information can be obtained if you can learn what molecules or elements are present. Mass spectrometry is used in medicine to identify molecules, although the method is destructive. X-ray fluorescence allows elemental identification with high spatial resolution, often taking advantage of synchrotron x-ray sources.


162. **Breath Analysis for Clinical Diagnosis and Therapeutic Monitoring**, edited by A. Amann and D. Smith (World Scientific, Hackensack, NJ, 2005). Identification of molecules in a patient’s breath, using a variety of methods, can be surprisingly important for the diagnosis of some diseases. (I)

H. **Miscellaneous**

Finally, there is much abuse of physics that goes under the name of “alternative medicine.” For a skeptical point of view by a physicist, see the following:


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