RADIOGRAPHY *in the* DIGITAL AGE

FOURTH EDITION

PHYSICS

EXPOSURE

RADIATION BIOLOGY

Quinn B. Carroll, M.Ed., R.T.

RADIOGRAPHY IN THE DIGITAL AGE

FOURTH EDITION

RADIOGRAPHY IN THE DIGITAL AGE

Physics—Exposure—Radiation Biology

By

Quinn B. Carroll, M.Ed., R.T.

CHARLES C THOMAS • PUBLISHER, LTD.
Springfield • Illinois • U.S.A.

Published and Distributed Throughout the World by

CHARLES C THOMAS • PUBLISHER, LTD.
2600 South First Street
Springfield, Illinois 62704

ISBN 978-0-398-09408-9 (Hard)
ISBN 978-0-398-09409-6 (Ebook)

First Edition, 2011
Second Edition, 2014
Third Edition, 2018
Fourth Edition, 2023

Library of Congress Catalog Numbers: 2023007112 (print)
2023007113 (ebook)

With THOMAS BOOKS careful attention is given to all details of manufacturing and design. It is the Publisher's desire to present books that are satisfactory as to their physical qualities and artistic possibilities and appropriate for their particular use. THOMAS BOOKS will be true to those laws of quality that assure a good name and good will.

Printed in the United States of America
CM-S-2

Library of Congress Cataloging-in-Publication Data

Names: Carroll, Quinn B., author.
Title: Radiography in the digital age : physics, exposure, radiation biology / by Quinn B Carroll.
Description: Fourth edition. | Springfield, Illinois : Charles C Thomas, Publisher, Ltd., 2023. | Includes index.
Identifiers: LCCN 2023007112 (print) | LCCN 2023007113 (ebook) | ISBN 9780398094089 (hardback) | ISBN 9780398094096 (ebook)
Subjects: MESH: Radiography | Physics | Radiology--methods | Radiographic Image Enhancement | Technology, Radiologic | Radiobiology
Classification: LCC RC78.7.D53 (print) | LCC RC78.7.D53 (ebook) | NLM WN 200 | DDC 616.07/572--dc23/eng/20230518
LC record available at https://lccn.loc.gov/2023007112
LC ebook record available at https://lccn.loc.gov/2023007113

REVIEWERS

Consulting Physicist

Charles E. Willis, PhD, DABR, FAAPM, FACR

University of Texas MD Anderson Cancer Center

Philip Heintz, PhD, DABR

University of New Mexico Health Sciences Center

Daniel J. Sandoval, PhD, DABR

University of New Mexico Health Sciences Center

Meg Rollins Petty, MSRS, RT(R)(N)

Radiography Program Director
Southwestern Community College
Sylva, North Carolina

Shane Mountain, AS, RT(R)

Adjunct Faculty
NHTI Concord's Community College
Concord, New Hampshire

Kelli Haynes, RT (R), FASRT, FAERS

Department Head, School of Allied Health
Northwestern State University
Natchitoches, Louisiana

Ajesh Singh Dip, BSc (Med Imaging)

Lecturer, School of Clinical Science
Queensland University of Technology
Brisbane, Australia

Donna Endicott, MEd, RT (R)

Director, Radiologic Technology
Xavier University
Cincinnati, Ohio

Robert L. Grossman, MS, RT (R)(CT)

Instructor, Radiography
Middlesex Community College
Middletown, Connecticut

C. William Mulkey, PhD, RT(R), FASRT

Dean, Dept. of Radiological Sciences (Rtd)
Midlands Technical College
West Columbia, North Carolina

Patrick Patterson, MS, RT, (R)(N) CNMT

Director, Radiography Program
State College of Florida, manatee-Sarasota
Bradenton, Florida

Dennis Bowman, AS, RT (R)

Clinical Instructor (Rtd)
Community Hospital of Monterey Peninsula
Marina, California

Miranda Poage, PhD

Associate Professor, Biology
Midland College
Midland, Texas

Dedication

To Jason and Stephanie,
Melissa and Tim,
Chad and Sarah,
Tiffani and Nate,
Brandon, and Tyson—
a most remarkable family,
and to my cherished wife, Margaret,
who made it possible for them all
to come into my life

PREFACE

New to This Edition

The 4th edition was peer-reviewed by four colleagues who brought many valuable corrections and improvements to the textbook. Chapter 32 (now Chapter 31) on *Postprocessing Operations in Practice* was substantially rewritten with the goal of reducing dozens of differently-named features offered by the various manufacturers of x-ray equipment to a handful of generic terms for what are, after all, generic operations. Table 31-4 could be the most useful and student-friendly summary published to date of these postprocessing features; It takes six qualities of the displayed digital image (brightness, contrast, local contrast, noise, equalization, and bone/soft tissue impression), succinctly lists their primary controls (leveling, windowing, edge enhancement, smoothing, dynamic range compression, and VOI), and further connects these operations to default processing functions (rescaling, gradation LUTs, detail processing, dynamic range and histogram analysis).

True to the original spirit of this textbook to cover all pertinent material *comprehensively*, yet succinctly, in Chapter 31 a full explanation is given of how each image adjustment works as a generic concept, and then examples of the various proprietary terms used by each manufacturer are simply listed.

With the advent of digital imaging, radiographers now have *two completely different images* that we must understand. The first is the *projected image* carried by the remnant x-ray beam and impingent upon the image receptor. *This* is the image that all the conventional teachings about mAs, kVp, SID, SOD, OID and alignment apply to. The second is the *displayed digital image*, whose visibility qualities has been described by the American Association of Physicists in Medicine as completely decoupled from the original exposure conditions:

> *Unlike screen-film imaging, image display in digital radiography is independent of image acquisition. The final image brightness and contrast can be modified by digital processing of the acquired image data. Consequently, overexposed images will not necessarily be dark, and underexposed images may no appear light … Brightness of the image is controlled not by the exposure to the detector, but by postprocessing applied to the image data. This may be a new and confusing concept for operators of digital radiography systems who are accustomed to screen-film imaging.*

The postprocessing alluded to here includes *leveling* as a re-application of the rescaling operation, *windowing* as a re-application of gradation LUTs, and more advanced adjustments. For the displayed digital image, spatial resolution is now dependent on del and pixel size in addition to the original geometry of the x-ray exposure, and *display magnification* is independent of the original geometrical magnification of the x-ray beam. As technologists, these are all equipment-related concepts that we are beholden to understand. Several tables and clarifying text have been added throughout the textbook to facilitate this understanding.

Substantial material has been added to the topic of *pulsed digital fluoroscopy* in Chapters 37 and 42. Updated information has also been added on the topic of *imaging informatics* in Chapter 35. With the help of reviewers, the entire textbook has been carefully correlated to the terms and topics listed in the most recent *Radiography Curriculum Guide* published by the *American Society of Radiologic Technologists*, and due consideration given to the *Radiography Content Specifications* published by the *American Registry of Radiologic Technologists* to ensure that both material and nomenclature is up-to-date. Students and educators alike are encouraged to keep in mind the highly useful *Glossary of Radiographic Terms* at the end of the book.

The chapter (28) on "Computer Basics" was deleted from this edition on the assumption that today's students have already covered all this material well enough in school. So we begin the digital section with "Creating the Digital Image" and go from there. Several crisp new illustrations and helpful tables have been added, along with refinements to the text designed to reduce what can be complicated topics to clear and concise explanations. While an effort has been made to reduce the size and weight of the book, its overall objective is to serve those programs with the philosophy that radiography education should be about understanding the how and why of our equipment rather than rote memorization. Those who prefer a more cursory treatment of digital radiography are referred to my textbook, *Digital Radiography in Practice* also published by Charles C. Thomas.

Scope and Philosophical Approach

The advent of digital radiographic imaging has radically changed many paradigms in radiography education. In order to bring the material we present completely up-to-date, and in the final analysis to fully serve our students, much more is needed than simply adding two or three chapters on digital imaging to our textbooks:

First, the entire emphasis of the foundational physics our students learn must be adjusted in order to properly support the specific information on digital imaging that will follow. For example, a better basic understanding of waves, frequency, amplitude and interference is needed so that students can later grasp the concepts of spatial frequency processing to enhance image sharpness. A more thorough coverage of the basic construction and interpretation of graphs prepares the student for histograms and look-up tables. Lasers are also more thoroughly discussed here, since they have not only medical applications, but are such an integral part of computer technology and optical disc storage.

Second, there has been a paradigm shift in our use of image terminology. Perhaps the most disconcerting example is that we can no longer describe the direct effects of kVp upon image contrast; Rather, we can only describe the effects of kVp upon the subject contrast in the remnant beam signal reaching the image detector, a signal whose contrast will then be drastically manipulated by digital processing techniques. Considerable confusion continues to surround the subject of scatter radiation and its effects on the imaging chain. Great care is needed in choosing appropriate terminology, accurate descriptions and lucid illustrations for this material.

The elimination of much obsolete and extraneous material is long overdue. Our students need to know the electrical physics which directly bear upon the production of x-rays in the x-ray tube - they do not need to solve parallel and series circuit problems in their daily practice of radiography, nor do they need to be spending time solving problems on velocity. MRI is briefly overviewed when *radio* waves are discussed under basic physics, sonography is also discussed under the general heading of *waves,* and CT is described along with attenuation coefficients under digital imaging. But, none of these subspecialties has a whole chapter devoted to it.

It is time to bring our teaching of image display systems up to date by presenting the basics of LCD monitors and the basics of quality control for electronic images. These have been addressed in this work, as *part of ten* full chapters dealing specifically with digital and electronic imaging concepts. If you agree with this educational philosophy, you will find this textbook of great use.

Organization

The basic layout is as follows: In Part I, *The Physics of Radiography,* ten chapters are devoted to laying a firm foundation of math and basic physics skills. The descriptions of atomic structure and bonding go into a little more depth than previous textbooks have done. A focus is maintained on *energy* physics rather than mechanical physics. The nature of electromagnetic waves is more carefully and thoroughly discussed than most textbooks provide. Chapters on electricity are limited to only those concepts which bear directly upon the production of x-rays in the x-ray tube.

Part 2, *Production of the Radiographic Image*, presents a full discussion of the x-ray beam and its interactions within the patient, the production and characteristics of subject contrast within the remnant beam, and the proper use of radiographic technique. Image qualities are thoroughly covered. This is conventional information, but the terminology and descriptions used have been adapted with great care to the digital environment.

Part 3, *Digital Radiography*, includes nine chapters covering the physics of digital image capture, extensive information on digital processing techniques, and the practical application issues of both CR and DR. PACS and medical imaging informatics are included. There is a chapter on mobile radiography, fluoroscopy, and digital fluoroscopy, and an extensive chapter on quality control which includes digital image QC.

Finally, Part 4 consists of five chapters on *Radiation Biology and Protection*, including an unflinching look at current issues and practical applications including an unflinching look at current issues and practical applications.

Feedback

For a textbook to retain enduring value and usefulness, professional feedback is always needed. Colleagues who have adopted the text are invited to provide continuing input so that improvements might be made in the accuracy of the information as well as the presentation of the material. Personal contact information is available in the *Instructor Resources* (below) on disc or download.

This is intended to be a textbook written "by technologists for technologists," with proper focus and scope for the practice of radiography in this digital age. It is sincerely hoped that it will make a substantial contribution not only to the practice of radiography and to patient care, but to the satisfaction and fulfillment of radiographers in their career as well.

Instructional Resources

Instructor Resources for Radiography in the Digital Age, 4th Ed.: This disc includes over 1500 multiple-choice questions *with permission* for instructors' use. Answer keys for all chapter-end review questions in the textbook are included, along with keys to the multiple-choice question banks. Also included are 15 laboratory exercises demonstrating the applications of digital equipment. *Instructor Resources for Radiography in the Digital Age* is available on disc or download from Charles C Thomas, Publisher, Ltd. The website is *www.ccthomas.com*.

PowerPoint™ Slides on Disc for Radiography in the Digital Age, 4th Ed.: *PowerPoint™* slides are available for classroom use. These are high-quality slides with large text, covering every chapter of the textbook, and including additional illustrations for each lecture. They cover as many as four courses in the typical radiography curriculum: Physics and Equipment, Principles of Radiographic Imaging, Digital Radiography, and Radiation Biology and Protection. Available from Charles C Thomas, Publisher Ltd. The website is *www.ccthomas.com*.

Student Workbook for Radiography in the Digital Age, 4th Ed.: This classroom supplement is exactly correlated with the *PowerPoint™* slide series for in-classroom use. Although it can be used for homework assignments, it is designed to deliberately provoke student participation in classroom instruction while avoiding excessive note-taking that distracts the student from the lecture. All questions are in "fill-in-the-blank" format, focusing on key workds that correlate perfectly with the slides. Available from Charles C Thomas, Publisher, Ltd. The website is *www.ccthomas.com*.

ACKNOWLEDGMENTS

Many thanks to the reviewers for the 4th Edition, Meg Rollins Petty, Kelli Haynes, Robert L. Grossman, and Shane Mountain, who provided many improvements for content, organization and readability. Reviewers for previous editions have continued to be supportive and provide input. They include Ajesh Singh Dip, Patrick Patterson, Donna Endicott, and C. William Mulkey. Physicists Charles Willis, Phil Heintz and Dan Sandoval have all contributed to the accuracy of physics content, and Miranda Poage to the accuracy of biological content.

Special thanks to Georg Kornweibel and Dr. Ralph Koenker at Philips Healthcare, and to Gregg Cretellen at FujiMed for their sustained assistance. Thanks also to Lori Barski at Carestream Health, (previously Kodak). All were extremely helpful in obtaining images and a good deal of information related to digital imaging and processing. Dr. J. Anthony Seibert at the University of California Davis Medical Center was generous with his time and expertise, as well as providing energy-subtraction images. His help was greatly appreciated.

Some material was adopted and adapted from contributing authors to my textbook, *Practical Radiographic Imaging*, (previously *Fuchs's Radiographic Exposure, Processing and Quality Control*). They include Robert DeAngelis, BSRT in Rutland, Vermont, Robert Parelli, MA, RT(R) in Cypress, California, and Euclid Seeram, RTR, MSc, in Burnaby, British Columbia, Canada. Their contributions are still greatly valued.

Many photographs and radiographs were made available by Kathy Ives, RT, Steven Hirt, RT, Jason Swopes, RT, Trevor Morris, RT, and Brady Widner, RT, all graduates whom I proudly claim, by Fyte Fire and Safety in Midland, Texas and Apogee Imaging Systems in Roseville, California, and made available in the public domain by the U.S. Army and U.S. Navy. Thanks, in particular to William S. Heathman, BSRT, my colleague in radiography education for many years, for his support and assistance.

Without the gracious assistance of all these individuals and companies, the completion of this work would have been impossible.

On a more personal note, I owe an eternal debt of gratitude to my sweet wife, Margaret for her acceptance, support and love throughout my life. I wish to express appreciation for the professional support and loyal friendship of Dr. Eileen Piwetz, which never waivered over 25 years, along with my love and admiration for all my colleagues in health sciences education, who, often against all odds, make miracles happen on the "front line" every day.

CONTENTS

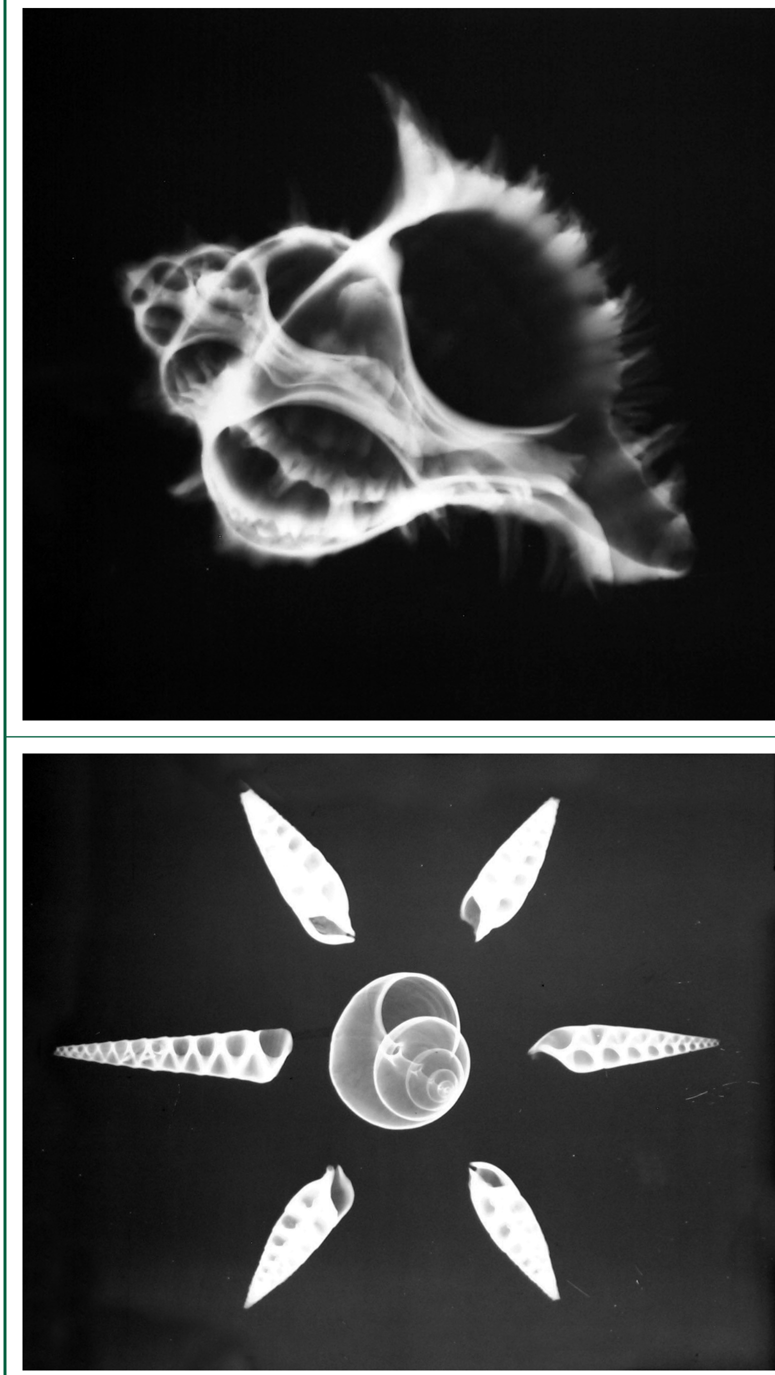
PART II: PRODUCTION OF THE RADIOGRAPHIC IMAGE

PART IV: RADIATION BIOLOGY AND PROTECTION

RADIOGRAPHY IN THE DIGITAL AGE

Part I

THE PHYSICS OF RADIOGRAPHY



Radiographs of various seashells.

Chapter 1

INTRODUCTION TO RADIOGRAPHIC SCIENCE

Objectives:

Upon completion of this chapter, you should be able to:

1. List the foundational principles of the scientific method and how they relate to the standard of practice for radiographers.
2. Describe landmark events in the development of medical radiography, with particular focus on those that brought about reductions in patient exposure.
3. Overview landmark events in the development of modern digital radiographic imaging.
4. Present a scientifically balanced perspective on the hazards of radiation in our environment and workplace.
5. Understand and appreciate the ALARA philosophy in modern radiographic imaging.

THE SCIENTIFIC APPROACH

Radiography is a branch of the modern *science* of medicine. Science is objective, observable, demonstrable knowledge. Try to imagine your doctor engaging in practices that were not grounded in scientific knowledge! What is it that sets science apart from art, philosophy, religion and other human endeavors? There are actually several foundational principles to scientific method. It is worthwhile to give a brief overview of them. They include:

Parsimony: The attempt to simplify concepts and formulas, to economize explanations; the philosophy that simple explanations are more likely to be true than elaborate, complex ones.

Reproducibility: The requirement that proofs (experiments) can be duplicated by different people at different times and in different locations with precisely the same results.

Falsifiability: The requirement that any theory or hypothesis can logically and logistically be proven *false*. Anything that cannot be proven false is not science, but belongs in another realm of human experience.

Observation: The requirement that experiments and their results can be directly observed with the human senses.

Measurability: The requirement that results can be quantified mathematically and measured.

As a fun practice exercise, consider the following three statements. Which one is scientific?

1. *The moon is made of green cheese.*
2. *Intelligent life likely exists elsewhere in the universe.*
3. *Albert Einstein was the greatest physicist in the twentieth century.*

The most scientific statement is No. 1. Even though it may not be a true statement, it is nonetheless a statement that can be (and has been) proven false with modern travel technology, it is simple, and experiments proving that moon rocks do not consist of green cheese can be reproduced by anyone, anywhere on earth with the same, observable, measurable results. Statement No. 2 may be true or false, but *cannot be proven false*, because to do so would require us to explore every planet in the entire universe, documenting that we have looked in every crevice and under every rock. It may be classified as a philosophical statement, but not as a scientific one. Statement No. 3 is, of course, a simple matter of personal opinion that depends upon how one defines the word "greatest." It is a historical statement that defies standardized measurement or observation.

Perhaps the strongest aspect of the scientific method is that when it is used properly, it is *self-correcting*. That is, when a theory is found to be wrong, that field of science is expected to be capable of transcending all politics, prejudice, tradition and financial gain in order to establish the new truth that will replace it. Sometimes this process is painful to the scientific community, and it has been known to take years to complete. But, at least it presupposes a collective willingness to accept the *possibility* that a previous position may have been wrong, something one rarely sees in nonscientific endeavors.

This principle of *self-correction* is nicely illustrated in the story of Henri Becquerel and the discovery of natural radioactivity, related in the next section. Also demonstrated in both his story and that of Wilhelm Roentgen, the discoverer of x-rays, is the fact that many scientific truths are discovered by accident. Nonetheless, it is *because* scientific method is being followed, not in spite of it, that they have occurred, and *through* scientific method that they come to be fully understood.

How does this scientific approach apply to radiography, specifically? Even though some aspects of radiography, such as positioning, are sometimes thought of as an art, the end result is an image that contains a quantifiable amount of diagnostically useful details, a measurable amount of information. Image qualities such as contrast, brightness, noise, sharpness and distortion can all be mathematically measured. Even the usefulness of different approaches to positioning are subject to measurement through repeat rate analysis. In choosing good radiographic practices, rather than relying on the subjective assertion from a cohort that, "It works for me," important matters can be objectively resolved by simply monitoring the repeats taken by those using the method compared to those using another method. By using good sampling (several radiographers using one method and several using another over a period of weeks), reliable conclusions can be drawn.

The standard of practice for all radiographers is to use good common sense, sound judgment, logical consistency and objective knowledge in providing the best possible care for their patients.

A BRIEF HISTORY OF X-RAYS

It is fascinating to note that manmade radiation was invented *before* natural radioactivity was discovered. If this seems backward, it is partly because x-rays were discovered by accident. In the late 1800s, Wilhelm Conrad Roentgen (Fig. 1-1) was conducting experiments in his laboratory at Wurzburg University in Germany. It had been discovered that a beam of electricity (glowing a beautiful blue in a darkened room) could be caused to stream across a glass tube. With strong enough voltage, the electricity could be caused to "jump" from a negatively-charged *cathode* wire across the gap toward a positively-charged *anode* plate, although most of it actually struck the glass behind. Since they were emitted from the cathode, these streams of electricity were dubbed *cathode rays*.

Several researchers were studying the characteristics of cathode rays. These glass tubes, known as Crookes tubes, came in many configurations. Figure 1-2 shows several that Roentgen actually used in his experiments. If most of the air was vacuumed out of the tube, the cathode rays became invisible. (It was later understood that they were in fact the electrons from the current in the cathode, far too small for the human eye to see, and that the blue glow was the effect from the ionization of the air around them.)

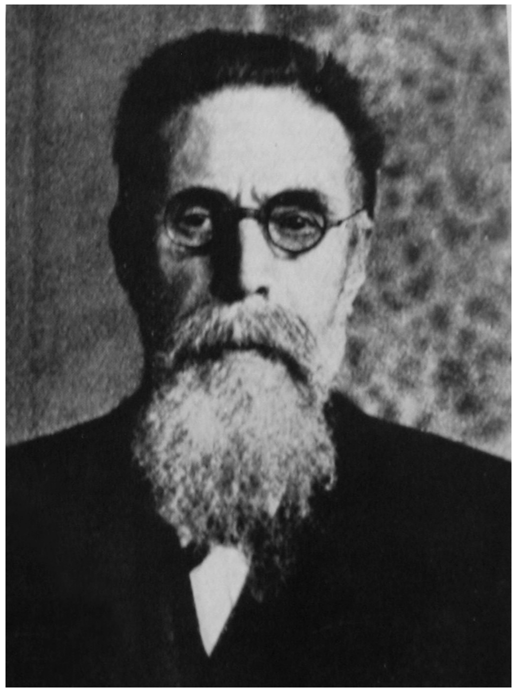
Other researchers had noticed that the glass at the anode end of the tube would fluoresce with a greenish glow when the cathode rays were flowing. They began experimenting with placing fluorescent materials in the path of the beam. They learned how to deflect the beam at right angles with a plate so it could exit the tube through a window of thin aluminum. In this way, cards or plates coated with different materials could simply be placed alongside the tube, in the path of the electron beam, to see how they fluoresced. Researchers learned to surround the tube with black cardboard so as to not confuse any light that might be generated within the tube with the fluorescence of the material outside the tube.

This was the type of experiment Roentgen was engaged with on November 8, 1895, when he noticed that a piece of paper laying on a bench nearby was glowing while the tube was activated in its black cardboard box. This paper was coated with barium platinocyanide, but it was not in the direct path of the cathode rays (electron beam).

Roentgen quickly realized that there must be some other type of radiation being emitted from the tube, other than the electron beam. He dubbed this radiation as "x" indicating the unknown. This radiation seemed to be emitted in all directions from the tube and was able to affect objects such as the plate at some distance. Placing various objects between the tube and the plate, he saw that they cast partial shadows on the glowing screen, while lead cast a solid shadow, stopping the mysterious rays altogether. He deduced that they traveled in straight lines and were able to penetrate less dense materials. During the following days, Roentgen conducted brilliant experiments delineating the characteristics of the x-rays.

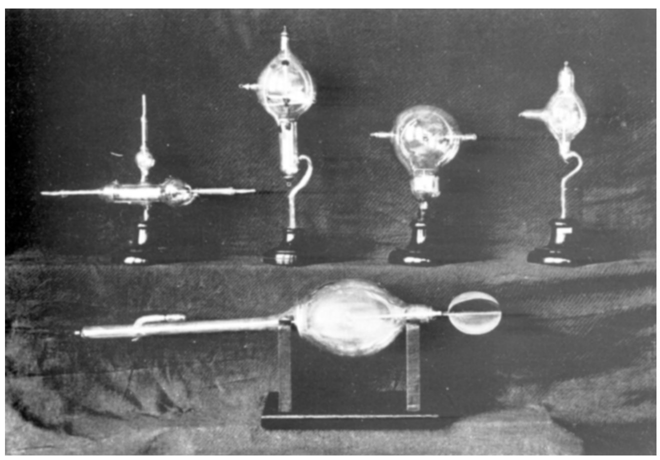
Early in his experiments, he was astonished to see the image of the bones in his own hands on the screen, while the flesh was penetrated through by the x-rays. The field of radiography was born when he placed his wife's hand in front of the screen and allowed the screen's fluorescent light to expose a photographic film for about four minutes (Fig. 1-3). Along with three other radiographs, this image was

Figure 1-1



Wilhelm Conrad Roentgen, discoverer of x-rays.

Figure 1-2



Photograph of Crookes tubes employed by Roentgen in his experiments on cathode rays, which led to the discovery of x-rays. (From Quinn B. Carroll, *Practical Radiographic Imaging*, 8th ed. Springfield, IL: Charles C Thomas, Publisher, Ltd., 2007. Reprinted by permission.)

Figure 1-3

The first radiograph, showing the hand of Marie Roentgen with her wedding band, took over 4 minutes to expose.

published two months later in his paper, "On a New Kind of Rays," introducing the process of radiography to the world. With uncommon modesty, Roentgen refused to patent his radiographic process for commercial gain, showing great character to match his tremendous scientific acumen.

However, the discovery was truly accidental, as many scientific discoveries have been, taking an unexpected turn even while scientific method is rigorously followed. It was accidental because Roentgen was investigating the effects of the *cathode rays* or electron beam upon fluorescent materials, and was not expecting to find an object fluorescing outside of that beam of electrons.

It was in the following year, 1896, that Antoine Henri Becquerel, a French physicist, discovered natural radioactivity. Inspired by Roentgen, he hypothesized that crystals which phosphoresce ("glow in the dark") after absorbing light might also emit x-rays at the same time. He thought he had proven his theory when a phosphorescing crystal exposed a photographic plate wrapped in black paper. He wanted to repeat the experiment with a crystal known to phosphoresce for only 1/100th second, but was frustrated when cloudy weather prevented him from letting the crystal absorb some sunlight to begin. He placed the wrapped-up photographic plate and the crystal in a dark drawer. Later, on a pure whim, he developed the old plate. To his great surprise, it was darkened with exposure. He realized that "x-rays" must have been continuously emitted by the stone while it was in the drawer, rather than being emitted only along with phosphorescent light. Thus, another happy accident led to more accurate knowledge.

As the process of self-correcting scientific investigation continued in the following years, it was found that Becquerel's natural radiation consisted not strictly of x-rays, but of *three* distinct types of radiation. These were named *alpha*, *beta* and *gamma* rays. Using magnets and electrodes to deflect their paths, physicists were able to prove that alpha rays consisted of extremely heavy particles with positive electric charge, and beta rays consisted of very light particles with negative charge (electrons). Gamma rays were, in their nature, essentially the "x-rays" that Becquerel was looking for, but they had far higher energy than those produced by Roentgen's x-ray machines. These high energies gave them different abilities than x-rays, and made them unsuitable for producing radiographs, warranting their own distinct name, *gamma rays*.

Because of their brilliant investigative work, both Roentgen and Becquerel received Nobel Prizes. Our understanding of the atom developed hand-in-hand with our understanding of radiation. Ernest Rutherford, a New Zealand physicist, found that the alpha particle was identical to the nucleus of a helium atom. He proved the existence of the proton and predicted the neutron. Einstein discovered the photoelectric effect and much of his work built upon Roentgen, Becquerel, Rutherford and others. Thus, Wilhelm Roentgen "began a revolution in modern physics that was to include the quantum theory, radioactivity, relativity, and the new Bohr atom."[1] Figure 1-4 shows one of the first x-ray machines, installed at Massachusetts General Hospital in 1896.

[1] Encyclopedia Americana, Vol. 24, p. 68, 1970.

displayed image, the *only* quality that has typically *not* been altered by digital processing is shape distortion, which is primarily determined by positioning. Brightness, contrast, noise, spatial resolution and magnification have all been "tampered with" upon final display. What role, then, *does* the original radiographic technique play in determining final image quality?

The answer is that technique plays one, and only one, very critical role, and that is to *ensure that adequate signal reaches the detector system such that computer algorithms can be successful in making corrections and refinements to the image*. In more familiar terms, the one objective for setting radiographic technique on a digital unit is to get plenty of exposure to the image receptor without unnecessary exposure to the patient. This can be directly measured by the signal-to-noise ratio (SNR) at the detector.

The mAs setting and the SID combine to determine the *quantity* or intensity of radiation incident upon the patient, but since kVp controls the percentage penetration of that radiation *through* the patient, it also has a profound effect on the final intensity of the *remnant beam reaching the detector* behind the patient. To achieve adequate exposure to the image receptor and a good SNR, mAs *and* kVp in relation to each other (along with distances, filtration and generator type) must all be taken into consideration.

We will find in this chapter that all of the physics and technique concepts related to this goal (of achieving sufficient exposure at the detector) remain critical to the practice of radiography, and have not changed. For example, the concept that *no amount of mAs can compensate for insufficient kVp* still holds true. On the other hand, particularly when discussing the qualities of the final displayed image, we find that many old concepts must be completely discarded in order to avoid confusion. This chapter will attempt to sort out which concepts belong to the "still true" group and which to the "discard completely" group.

MINIMIZING PATIENT EXPOSURE

Most early CR systems were installed and operated at a speed class of 200. This was only one-half the speed of the "regular" rare earth screens (400) that were popular over the last quarter of the twentieth century. In making the change from rare earth screen systems to CR, many radiology departments doubled the mAs values used for most Bucky procedures, with some adjustments being more than this. This resulted in an undesirable doubling of x-ray exposure to patients undergoing pelvic, abdominal and head procedures, just where the most radiosensitive organs are located.

As described in Chapter 31, operation of a CR or DR system at the 400-speed class assumes an average exposure reaching the imaging plate of 5 μGy. It is possible for this level of exposure to be insufficient in some cases, based on the *assumption* of using previously popular kVp levels. But, by increasing *kVp* rather than mAs, penetration of the x-ray beam through to the imaging plate *does* result in sufficient exposure to the receptor elements, and allows operation at the 400-speed class.

High kVp and Scatter Radiation

Figures 32-1 and 32-2 use conventional radiographs to demonstrate how the effects of higher kVp levels upon the production of scatter radiation have traditionally been over-emphasized. The primary causes of scatter radiation are *patient size* and *collimation*, both of which bear upon the *volume of exposed tissue*. The effects of kilovoltage, while important to understand, are *secondary* when compared to these issues of tissue volume. Figure 33-1 shows a pair of AP elbow exposures taken at 65 kVp and 90 kVp for comparison. While desirable penetration and gray scale are achieved in radiograph ***B***, no significant *fogging* is visible *even when 25 more kVp than usual is used*. This is because the anatomy has too small a volume of tissue to generate much scatter radiation at *any* kVp. Figure 32-2 demonstrates two abdomen radiographs of the same patient taken at 80 kVp and 92 kVp for comparison. Both were taken using the Bucky grid to attenuate scatter radiation. Again, while Radiograph ***B*** shows increased gray scale and penetration as expected, it is *not visibly fogged*—this result in spite of the fact that the abdomen is the portion of the body

[1] Shepard et al.: Exposure Indicator for DR: TG116 (Executive Summary) in *Medical Physics*, Vol. 36 No. 7, July 2009.