Preparation for Medical Physics Components of the ABR Qualifying (Core) Exam
ABR Physics Study Guide

The ABR Qualifying (Core) Exam for radiologists contains material on medical physics. This content is based on medical physics that is used in practice by working radiologists. Thus, the best preparation for the exam is to learn to use medical physics in your routine practice. If you do that well, you should have no problems with medical physics on the Qualifying (Core) Exam. It is the position of the ABR and all professional radiological organizations that an understanding of this material is crucial to the safe and effective practice of radiology.

We recognize, however, that candidates would like additional guidance to assist them with preparation for the exam. While it is impossible to provide the details on the content that many candidates would desire, this document explains how the material is structured and how candidates should prepare for the exam during their years of residency.

General Content

The purpose of examining the candidate about fundamentals is to determine that the candidate has knowledge of:

• Basic concepts of x-ray production and x-ray interactions
• Basic physics concepts, quality assurance, and common artifacts (for all modalities)
• Image quality
• Informatics, image display, reading room monitors
• Radiation dose metrics and units
• Regulatory, accreditation, and advisory agencies
• Radiation, ultrasound, and MRI safety
• Radiation biology

Category-based Questions

On average, the distribution of questions by imaging modality on the exam is as shown in Figure 1. Please note that this is a general guide and there may be variation from exam to exam.
Figure 1: The approximate distribution of medical physics questions by imaging modality.

These modality-based questions are divided into three main categories:

- Application of medical physics in the effective use of the modality
- Safety related to the imaging modality
- Understanding the causes and methods to reduce artifacts associated with a particular modality

These questions are distributed approximately as shown in Figure 2.

Figure 2: Distribution of the modality-based question categories

Application of Medical Physics to the Effective Use of the Modality

Each imaging modality has certain characteristics that the radiologist must understand to create effective protocols, help technologists adjust imaging technique, and compensate for the size of a patient (e.g., pediatric or obese patients). For example, increasing the amount of a PET radiopharmaceutical to a patient does not necessarily improve image quality but often degrades the image. The questions of this type focus on how the physics
characteristics of the modality relate to provide optimal images.

Questions in the “Effective Use” section are designed to determine if the candidate understands how the fundamental physics principles affect the everyday practice of radiology. Emphasis is on principles rather than the memorization of facts that are not directly relevant or that could be easily looked up online. For example, there would be no questions about the relationship \( c = \lambda \cdot \nu \) as it applies to electromagnetic radiation since there is no practical application in radiology. However, that same relationship, as it applies to ultrasound, is of interest since it affects resolution and penetration of the ultrasound beam.

**EXAMPLE of Effective Use of the Modality Items**

1. In a fast-spin-echo (FSE) pulse sequence (TR = 4000 ms, TE = 100 ms, ETL = 12, field of view \([\text{FOV}] = 30 \text{ cm}, 256 \times 256\)), which of the following modifications would reduce imaging time? *(Answer is highlighted yellow.)*

   A. Reduce TE to 50 ms
   B. Reduce FOV to 25 cm
   C. Reduce ETL to 10
   D. **Reduce TR to 3000 ms**

2. What CT acquisition factor will provide the greatest patient radiation dose reduction? *(Answer is highlighted yellow.)*

   A. Change helical pitch from 1.2 to 0.9
   B. **Reduce kV from 120 to 80**
   C. Reduce mA from 400 to 200
   D. Increase rotation speed from 0.5 sec/rot to 0.3 sec/rot

**Safety as It Relates to Specific Modalities and Categories**

While there is a general quality and safety category on the Qualifying (Core) Exam, there are also safety questions as they relate specifically to medical physics in each category and modality. These questions may involve tissue effects possibly encountered when using ionizing radiation, specific concerns about appropriate thermal index (TI) or mechanical index (MI) in ultrasound, and keeping patients and staff safe in an MRI environment. These safety questions are tied specifically to the modality used. Additional safety questions may be asked regarding radiologist personal safety, such as annual exposure limits for radiation workers, or regarding radiation safety personal protective equipment (PPE).
EXAMPLES of Safety as It Relates to Specific Modalities Items

1. Patient burns in MRI are usually associated with which of the following? (Answer is highlighted yellow.)
   
   A. Long TR pulse sequences  
   B. Loops in EKG leads  
   C. Patient touching wall of scanner  
   D. Patients weighing less than 20 kg

2. What is the minimum radiation dose threshold that typically results in epilation? (Answer is highlighted yellow.)
   
   A. 1 Gy  
   B. 3 Gy  
   C. 10 Gy  
   D. 15 Gy

Artifacts

All modalities produce imaging artifacts. Radiologists need to be able to recognize these artifacts, separate them from normal/abnormal pathology, and recommend to technologists how to modify the imaging procedure to minimize them. The artifact-related questions may ask the candidate to identify the artifact, to distinguish the artifact from normal or abnormal findings on the image, or to recommend strategies to reduce or eliminate the artifact.
EXAMPLES of Artifact-Related Items

1. What is the cause of the ultrasound artifact shown by the arrow? *(Answer is highlighted yellow.)*


   A. Ring down
   B. Reverberation
   C. Mirror image
   **D. Side lobe**

2. In the CT image of the head, what is the most likely cause of the “streak” artifact (arrow)? *(Answer is highlighted yellow.)*

   A. Partial volume effect
   B. Wrong reconstruction filter
   C. Low tube current (mA) selection
   **D. Partial data loss**
Summary

The medical physics content on the Qualifying (Core) Exam is intended to reflect the medical physics that is commonly encountered by radiologists in image interpretation, executing procedures, and consulting with colleagues, staff, and patients. It addresses basic material only to the extent that fundamental knowledge is necessary to practice effectively.

Study Guide

The ABR Physics Study Guide aims to give the diagnostic radiology resident an idea of the underlying physics topics and principles that a radiologist should know when graduating from an accredited radiology residency program.

The guide is not a comprehensive list of all topics possible under the realm of medical imaging physics but some core topics to give the resident guidance for preparation for the ABR Qualifying (Core) Exam. For further guidance, the resident can refer to the AAPM curriculum designed for the radiology residents. The AAPM curriculum also contains additional test questions which a resident may find helpful.

1. Basic Science
   a. Structure of the atom
      i. Nuclear structure & interactions
      ii. Electron cloud structure & interactions
   b. Electromagnetic radiation
      i. Properties and origins of photons
      ii. Electromagnetic spectrum used in imaging
   c. Particle radiation
2. Interactions of ionizing radiation with matter
   a. Charged particle interactions
      i. Ionization
      ii. Excitation
      iii. Bremsstrahlung
      iv. Positron annihilation
   b. Photon interactions
      i. Coherent scattering
      ii. Photoelectric effect
      iii. Compton effect
   c. Photon attenuation
      i. Linear & Mass attenuation
      ii. Half-value layer (HVL) and Beam Hardening
   d. Methods of interaction
i. Exposure
ii. Kinetic energy released in matter (KERMA)
iii. Absorbed Dose
iv. Equivalent Dose
v. Effective Dose

3. X-ray Production
   a. X-ray tube cathode and anode
      i. Filament and focusing cup
      ii. Anode angle and Line focus principle
      iii. Anode heel effect
   b. Electron interactions with the anode
      i. Probability of interactions
      ii. Contributions to the x-ray beam spectrum
   c. X-ray beam characteristics
      i. Quality
      ii. Quantity
   d. Technique factors and their effect on image quality (kV, mA, exposure time, focal spot size)
   e. X-ray beam filtration
   f. Beam collimation

4. Image Quality Metrics
   a. Generation of image contrast
   b. Factors that affect visibility of contrast (low-contrast resolution)
      i. Image Noise (quantum and electronic)
      ii. Signal-to-noise ratio and Contrast-to-noise ratio
      iii. Scatter
      iv. Contrast agents
   c. Spatial resolution and sources of blur
   d. Temporal resolution

5. Image Processing, Informatics & Display
   a. Signal sampling
      i. Nyquist limit
      ii. Aliasing
   b. Image matrix
   c. Pixel size and bit depth
   d. Image processing
      i. Reconstruction methods
      ii. Smoothing
      iii. Edge enhancement
      iv. Window and level adjustments
   e. DICOM
   f. PACS
   g. Image compression (lossy, lossless)
h. Computer-aided detection (CAD)
i. Basic concepts of artificial intelligence (i.e., machine learning and deep learning)
j. Display monitor characteristics
k. Optimal image viewing conditions

6. Radiation Biology
   a. Molecular and cellular effects of radiation
      i. Direct vs. Indirect Effects
      ii. Cell type and cell cycle radiosensitivity
      iii. Cell damage, survival, repair, and death (apoptosis)
b. Tissue reactions (Deterministic) effects
      i. Skin
      ii. Eye lens
      iii. Gonads
c. Stochastic effects
      i. Epidemiological Studies
      ii. Radiation induced cancer
d. Teratogenesis
      i. Developmental effects
      ii. Childhood Leukemia
      iii. In-utero Sensitivity
e. Acute Radiation Syndromes
      i. Hematopoietic
      ii. Gastrointestinal
      iii. Neurovascular
      iv. LD50/60
f. Radiation risk and dose response models
   i. Benefit vs. Risk in Radiology (BIER VII)
   ii. Relative and Absolute Risk
   iii. Dose-Response Models

7. Radiation Protection
   a. Sources of radiation to the U.S. population
      i. Natural
      ii. Medical
b. Patient and fetal doses from imaging procedures
c. Monitoring and management of patient and fetal dose
   i. Diagnostic Reference Levels (DRL)
   ii. Joint Commission Sentinel Events
   iii. Nuclear Regulatory Commission (NRC) Medical Event
   iv. Patient Dose Tracking
d. Occupational and public dose regulatory dose limits
   i. Effective dose and organ dose
   ii. Declared pregnant workers
   iii. Members of the public
iv. Personnel dosimeters

e. Radiation protection principles and methods
   i. Time, distance, shielding
   ii. As Low as Reasonably Achievable (ALARA)

f. Regulatory, accreditation, and advisory agencies

8. General Radiography
   a. X-ray tube, filtration, and collimation
   b. Scatter reduction and grids
      i. Grid ratio
      ii. Bucky factor
   c. Radiographic detector systems (CR, DR, etc.)
      i. Basic design and operation
      ii. Sensitivity and spatial resolution
   d. System geometry and magnification
   e. Applications, acquisition modes, and protocols
      i. Typical technique factors for common examinations
      ii. Pediatric, adult, and bariatric patients
      iii. Automatic exposure control operation
      iv. Mobile/portable examinations
      v. Exposure index
      vi. Deviation index
   f. Patient radiation dose
      i. Factors that affect entrance skin air KERMA and absorbed dose
      ii. Average effective dose for common exams
   g. Image quality and factors that affect
      i. Subject contrast
      ii. Low contrast visibility
      iii. Geometric blur
      iv. Detector blur
      v. Motion blur
   h. Common artifacts and artifact mitigation

9. Mammography
   a. X-ray tube targets and filtration materials
   b. Tube alignment and collimation
   c. Breast compression
   d. Scatter reduction and grids
   e. Mammography detectors (CR and DR)
      i. Basic design and operation
      ii. Sensitivity and spatial resolution
      iii. Automatic exposure control
   f. Contact vs magnification mammography
   g. Digital breast tomosynthesis
      i. Sweep angle and acquisition time
ii. Number of acquisitions and image reconstruction  
iii. In plane and z-axis spatial resolution  
iv. Synthetic 2D images  

h. Stereotactic breast biopsy systems  
i. System configuration  
ii. Principles of lesion localization  
i. Dose  
   i. Typical values for the standard breast (average glandular and effective dose)  
   ii. MQSA requirements for 2D and 3D mammography  

j. Common 2D and 3D artifacts and artifact mitigation  

k. Quality assurance and quality control  
i. MQSA standards  
ii. Accreditation requirements  
 iii. Common quality control testing requirements  
 iv. Radiologist workstation display and viewing requirements  

10. Fluoroscopy and Interventional Imaging  
a. X-ray tube and filtration  
b. Collimation and grids  
c. Automatic exposure rate control system  
d. Fluoroscopic detectors  
i. Image Intensifier and Flat panel  
   ii. Field of View (FOV), Binning and Electronic Magnification  

e. System geometry and geometric magnification  
i. Geometric Magnification  
ii. System Configurations (c-arm, under table tube, over table tube, etc.)  

f. Image quality and factors that affect  
i. Low-Contrast Resolution  
ii. Spatial Resolution  
   iii. Temporal Resolution  

g. Operating modes  
i. Continuous Fluoroscopy  
ii. High-Dose Rate Fluoroscopy  
iii. Variable Frame-Rate Pulsed Fluoroscopy  
iv. Digital Spot  
v. Cine/Fluorography  
vi. Digital Subtraction Angiography (DSA)  
vii. Cone-beam CT Imaging (3D Rotational Angiography)  

h. Applications  
i. Conventional Fluoroscopy  
ii. Interventional Fluoroscopy  
iii. Pediatric  
i. Protocol optimization
i. Acquisition Parameters (e.g., kV, Pulse Rate)
ii. Patient Positioning/Geometry
iii. Acquisition mode
iv. Dose saving options (last image hold, beam-on time etc.)
j. Artifacts and artifact mitigation
   i. Image Intensifier (II) (e.g., Pincushion etc.)
   ii. Flat Panel (e.g., Dead Pixels etc.)
k. Patient dose, dose metrics and dose tracking
   i. Dose Rate Limits
   ii. Audible Alarms
   iii. Minimum Source-to-Patient Distance
   iv. Interventional Reference Point
   v. Dose Metrics (peak skin dose, air KERMA, DAP etc.)
   vi. Sentinel Event
   vii. Personnel Protection (time, distance, shielding, optimization)

11. Computed Tomography
   a. X-ray tube, beam filtration, and bow-tie filters
   b. System geometries and operating modes
      i. Gantry/Beam Geometry
      ii. Localizer Radiograph, axial, helical etc.
      iii. Cardiac/Respiratory Gated
      iv. CT Fluoroscopy
      v. Dual Source and Dual Energy
   c. Acquisition parameters
      i. Tube Voltage (kV) and Automatic kV Selection
      ii. Tube Current-Time Product (mAs) and Effective mAs
      iii. Automatic Tube Current Modulation
      iv. Organ Dose Modulation
      v. Pitch
      vi. Detector Configuration, Beam Width
      vii. Scan Field of View
   d. Image formation and reconstruction
      i. Sinogram
      ii. Reconstruction Methods (FBP, Iterative and AI)
      iii. Reconstruction Filters/Convolution Kernels
      iv. CT Number/Hounsfield Unit
      v. Reconstruction Thickness (slice) and Interval
      vi. Reconstruction Field of View
   e. Image quality and Artifacts
      i. Spatial, Contrast, and Temporal Resolution
      ii. Common Artifacts and Mitigation
   f. Adult, Pediatric, and Bariatric Protocol Applications and Optimization
      i. Single vs. Multi-Phase Exams
ii. Perfusion CT
iii. Pediatric CT
iv. Cardiac CT
v. CT Angiography
vi. Dual Energy CT
g. Patient dose metrics and typical values
   i. Computed Tomography Dose Indices (CTDIvol, etc.)
   ii. Dose-Length Product (DLP)
   iii. Organ and Effective Dose
   iv. Size-Specific Dose Estimate (SSDE)
12. Ultrasound
   a. Properties of ultrasound waves
   b. Beam formation and characteristics
      i. Near and Far Fields
      ii. Side and Grating Lobes
      iii. Linear and Sector Scanning
      iv. Transmit and Receive Focusing
      v. Beam Steering and Shaping
   c. Interactions of sound waves with tissue
      i. Acoustic Impedance
      ii. Density, Speed, and Compressibility
      iii. Reflection, Refraction, and Transmission
      iv. Scattering, Absorption, and Attenuation
   d. Transducer components and Arrays
      i. Backing material, piezoelectric, matching layer, acoustic lens
      ii. Types of transducer arrays (Linear, Curvilinear etc.)
   e. Pulse-echo imaging principles
      i. Pulse-Repetition Period, Frequency, and Duty Cycle
      ii. Field of View and Maximum Depth
      iii. Frame Rate
      iv. Time Gain compensation
      v. Power, gain and dynamic range
   f. Display modes (A-mode, B-mode etc.)
   g. Doppler imaging principles
      i. Flow Dynamics (e.g., Laminar etc.)
      ii. Continuous Wave, Pulsed
      iii. Power, Spectral, Color Doppler
   h. Special imaging techniques
      i. Harmonic Imaging
      ii. Compound Imaging
      iii. Contrast-enhanced
      iv. Elastography
   i. Image quality and common artifacts
i. Spatial Resolution: Axial, Lateral, Elevational
ii. Temporal Resolution
iii. Image Contrast, Noise, CNR
iv. Transducer artifacts (e.g., Grating Lobes, etc.)
v. Propagation artifacts (e.g., Shadowing, Ring Down, etc.)
vi. Doppler artifacts (e.g., Twinkle, Flash, Flow Ambiguity, etc.)
j. Safety and typical limiting values
   i. Heating and Thermal Indices (TI)
   ii. Cavitation and Mechanical Index (MI)
   iii. Acoustic Power
   iv. Pregnant Patient and Pediatric Protocols

13. Magnetic Resonance Imaging
   a. MRI Instrumentation
      i. Static magnetic field (B₀-field), i.e., Fringe field
      ii. Coils (Gradient field subsystems, Shim coils, and RF coils)
      iii. Transmit/receive systems
   b. Fundamentals of magnetism
      i. Magnetic fields
      ii. Susceptibility
      iii. Magnetic moments and net magnetization
      iv. Magnetic resonance (Larmor equation)
   c. Signal generation and encoding
      i. Radiofrequency field (RF) excitation
      ii. Tissue relaxation
      iii. Signal localization (imaging gradient interactions)
   d. Pulse sequences and contrast mechanisms
      i. Tissue characteristics (i.e., T₁, T₂, proton density)
      ii. Pulse sequence parameters and timing diagrams
      iii. Spin-Echo pulse sequences (basic, fast)
      iv. Gradient-Echo pulse sequences
      v. Echo-planar imaging (EPI) and functional MRI (fMRI)
         1. Diffusion and Diffusion tensor imaging (DTI)
         2. Blood oxygenation level dependent (BOLD)
         3. Perfusion
      vi. Signal suppression
         1. Inversion recovery
         2. Spatial
         3. Spectral (or chemical)
         4. Magnetization transfer
         5. Dixon method
         6. Gradient moment nulling (GMN)
   vii. MR angiography (MRA) & cardiac
   viii. MR spectroscopy (MRS)
ix. Susceptibility weighted imaging (SWI)
x. Breast MRI
e. Image reconstruction
   i. k-space filling techniques
   ii. Parallel imaging
f. Image quality characteristics and factors that affect SNR and spatial resolution
g. Common Artifacts and artifact mitigation
h. MRI Safety and biological effects (see Non-interpretative skills study guide)

14. Nuclear Medicine
   a. Fundamentals of Nuclear Medicine
      i. Counting statistics
      ii. Nuclear transformation, radioactivity, and equilibrium
      iii. Radioisotope production (reactors, cyclotrons, and generators)
      iv. Instrumentation (well counter, dose calibrator, survey meters, thyroid probe)
b. Radiopharmaceuticals and their administration
   i. Tracer concept
   ii. Uptake, distribution, & clearance
   iii. Specific activity
   iv. Quality assurance and control procedures
c. Occupational and patient safety, quality management, and regulatory issues
   i. External exposure and internal dosimetry
   ii. Pregnancy, Fetal dose, and Breastfeeding patients
d. Nuclear medicine imaging
   i. Scintillation and solid-state camera design and operation
      1. Photomultiplier tube (PMT) and Anger logic
      2. Collimator types and characteristics
      3. Quality control
   ii. Planar imaging properties and techniques
   iii. SPECT imaging properties and techniques
   iv. Nuclear medicine therapy
      1. Radiopharmaceutical usage and regulatory considerations
      2. Written directive, patient safety, and release considerations
e. PET imaging
   i. Positron Annihilation
   ii. Scintillation and solid-state detector material
   iii. Positron emission scanner design and operation
   iv. Imaging properties and techniques
   v. Quality control
f. Use of CT in hybrid PET and SPECT imaging
   i. Attenuation correction
   ii. Radiation dose tradeoff
g. Reconstruction
i. Filtered back projection (FBP)
ii. Iterative reconstruction (i.e., MLEM & OSEM)
iii. Quantitative imaging
iv. Standardized uptake value (SUV)

h. Image quality characteristics
   i. SNR
   ii. Spatial resolution
   iii. Sensitivity and count rate
   iv. Image noise

i. Common Artifacts and artifact mitigation
j. Radioisotope Safety Content (See RISC study guide)