CANADIAN COLLEGE OF PHYSICISTS IN MEDICINE

LE COLLÈGE CANADIEN DES PHYSICIENS EN MÉDECINE

MEDICAL PHYSICS QUESTIONS

FOR

MEMBERSHIP EXAMINATION

Edition 13.0

Canadian College of Physicists in Medicine

CANADIAN COLLEGE OF PHYSICISTS IN MEDICINE

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CCPM Membership Examination **Edition 13.0**

Medical Physics Questions For Membership Examination (Edition 13.0)

Questions de Physique Médicale pour L'Examen d'Admission (Édition 13.0)

Available from the:

Canadian College of Physicists in Medicine

Disponible de:

Le Collège canadien des physiciens en médecine

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Electronic version: ISBN: 0-9684873-3-5

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FOREWORD TO THE THIRTEENTH EDITION

This is the thirteenth edition of the published question bank for the Canadian College of Physicists in Medicine (CCPM) membership exam. This is an exam to enable the CCPM to certify that those who pass the four-part written exam and three-part oral exam are competent in their medical physics subspecialty. Combined with credentialing for the exam, this is an exhaustive process into which a candidate is entering.

All question banks underwent significant updates in 2015 and are reviewed annually for suitability of the exam material. The Magnetic Resonace Imaging question bank was further updated in 2016, the Diagnostic Radiological Physics question bank was further updated in 2021. Significant updates to the Nuclear Medicine subspecialty exam were completed in 2023 with several redundant and/or out-dated questions removed and replaced with current/relevant questions; all the questions were reorganized to improve clarity. Smaller updates have been made to the current version of the Radiation Oncology question bank. Note that it is important to ensure that the correct question bank is downloaded when exam preparation begins! Much work has been invested in producing a comprehensive set of questions since 1984 thanks to the hard work of Past Chief Examiners: Ervin B. Podgorsak, Terry M. Peters, Gino Fallone, Ting-Yim Lee, Katharina E. Sixel, Michael D.C. Evans, Robert Corns, Boyd McCurdy, Renée Larouche, Alasdair Syme and Geneviève Jarry and all those who helped them.

A Preparation Guide now exists and is posted on the CCPM website. The Preparation Guide discusses time management strategies and the typical expected length of hand-written answers.

The College wishes to thank Alexandre Bourque, deputy examiner, as well as the many volunteers that help each year. A special thanks goes to Erin Niven and Marjorie Gonzalez who helped with the comprehensive revision of the Nuclear Medicine question bank.

Candidates preparing for their exam who have comments about the question bank are invited to contact me (chiefexaminer@ccpm.ca).

Best of luck to all of the candidates,

Marcus Sonier
Abbotsford, BC, Canada
September 30th 2024

SUGGESTED TEXTS FOR PREPARATION OF THE EXAMINATION.

It must NOT be assumed that questions will be based solely on materials from these texts.

A: Radiation Oncology

1. The physics of radiation therapy: F. M. Khan; Williams and Williams, Baltimore.
2. Introduction to radiological physics and radiation dosimetry: P.H. Attix; Wiley, New York.
3. The physics of radiology (Fourth Edition.): H.E. Johns and J.R. Cunningham; Charles C. Thomas, Springfield Ill.
4. Modern technology of radiation oncology: J. Van Dyk (Editor); Medical Physics Publishing, Madison Wisconsin.
5. Radiation physics for medical physicists: E.B. Podgorsak; Springer, New York.
6. Radiation oncology physics: a handbook for teachers and students: E.B. Podgorsak (Editor); IAEA, Vienna.
7. Radiobiology for the radiobiologist: E.J. Hall; Lippincott Williams & Wilkins, New York.
8. ICRP publication 103: 2007 recommendations of the international commission on radiological protection, The International Commission on Radiological Protection; New York, 2007
9. NCRP report 147: Structural shielding design for medical x-ray imaging facilities: National Council on Radiation Protection and Measurements; Bethesda MD.
10. NCRP report 151: Structural shielding design and evaluation for megavoltage X- and gamma-ray radiotherapy facilities: National Council on Radiation Protection and Measurements; Bethesda MD.
11. CPQR Technical Quality Control Guidelines. http://www.cpqr.ca/programs/technical-quality-control/
12, ICRP publication 112: Preventing Accidental Exposures from New External Beam Radiation Therapy Technologies, The International Commission on Radiological Protection; New York, 2009

B: Diagnostic Radiology

1. Physics of radiology (2nd Ed.): A. Wolbarst, Medical Physics Publishing, Madison, WI; 2005
2. Review of Radiological Physics (3rd Ed.): W. Huda, R.M. Slone; Lippincott Williams & Wilkins; 2010
3. Essential Physics of Medical Imaging (2nd Ed.): J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, J.M. Boone; Lippincott Williams & Wilkins; (2001)
4. Medical Imaging Signals and Systems: J.L. Prince, J. Links; 2005
5. Medical Imaging Physics (4th Ed.): W.R. Hendee, E.R. Ritenour; Wiley-Liss; 2002
6. Computed Tomography: Fundamentals, System Technology, Image Quality, Applications (2nd Ed.): W.A. Kalender; Wiley-VCH; 2006
7. Ultrasound Physics and Instrumentation (4th Ed): W.R. Hedrick, D.L. Hykes, D.E. Starchman; Mosby; 2004
8. Guidelines for the safe use of diagnostic ultrasound equipment. Prepared by the Safety Group of the British Medical Ultrasound Society Ultrasound 2010; 18: 52–59.
9. Medical electrical equipment – Characteristics of digital X-ray imaging devices – Part 1: Determination of the detective quantum efficiency. International Standard IEC 62220-1

C: Nuclear Medicine

1. Physics in nuclear medicine (4th Ed): S.R. Cherry, J.A. Sorenson and M.E. Phelps; W.B. Saunders, Philadelphia; 2012
2. Nuclear medicine physics: L.E. Williams (Ed); CRC Press, Boca Raton.
3. The physics of radiology (4th Ed.): H.E. Johns and J.R. Cunningham; Charles C. Thomas, Springfield Ill.
4. Introductory physics of nuclear medicine, R. Chandra; Lea & Febiger, Philadelphia.
5. Radiation detection and measurement, G. F. Knoll; John Wiley and Sons, Third Edition, 2000.
6. Basic science of nuclear medicine, R.P. Parker, P.H.S. Smith, D.M. Taylor; Churchill Livingston, New York.

D: Magnetic Resonance

1. Nuclear magnetic resonance imaging in medicine and biology: P.G. Morris; Oxford University Press, Oxford.
2. Magnetic resonance imaging: physical principles and sequence design, R.W. Brown, YN Cheng, E.M. Haacke M.R. Thompson, and R. Venkatesan, A. John Wiley & Sons, 2014.
3. In vivo NMR Spectroscopy: principles and techniques, R. A. de Graaf, John Wiley and Sons, 2007.
4. Questions and answers in magnetic resonance imaging, Second Edition, A.D. Elster and J. H. Burdette, Mosby, 2001.
5. Handbook of MRI pulse sequences, M. A. Bernstein, K. F. King, and X. J. Zhou, Elsevier Academic Press, 2004.
6. MRI: Basic Principles and Applications (4th Ed.); M.A. Brown, R.C. Semelka; Wiley-Blackwell; 2010
7. Principles of Magnetic Resonance Imaging: A Signal Processing Perspective, Z.P. Liang and P.C. Lauterbur, Wiley-IEEE, 1999

Section B: Diagnostic Radiology Specialty

You will be required to answer **FIVE** questions from Part III and **FIVE** questions from Part IV. Total time to complete these questions is 2.5 hours. Each question is worth an equal percentage, totaling to 100% for each Part.

PART III. DIAGNOSTIC RADIOLOGY SPECIALTY

1. Define or explain:
   (a) photoelectron
   (b) Auger effect
   (c) internal conversion
   (d) annihilation quantum
   (e) characteristic radiation
   (f) electron-hole pair
   (g) recoil electron
   (h) absorption edge

2. List three ways in which x-rays in the diagnostic energy range interact with matter and discuss their dependence on photon energy and atomic number.

3. Plot the mass attenuation coefficients for tissue, bone and lead in the diagnostic energy range and discuss the key characteristics of these curves.

4. What is the relationship between the linear attenuation coefficient, mass attenuation coefficient and mass energy absorption coefficient? Plot these three coefficients for air in the diagnostic energy range.

5. Derive an expression for converting exposure to absorbed dose (*f*-factor). Describe the *f*-factor energy dependence for bone, soft tissue and fat in the diagnostic x-ray energy range.

6. Briefly define or explain:
   (a) Roentgen
   (b) KERMA
   (c) electrode
   (d) W for air
   (e) mass attenuation coefficient
   (f) collection efficiency
   (g) recombination
   (h) electronic equilibrium

7. Sketch and explain the functioning of the following:
   (a) a free air ionization chamber;
   (b) a typical thimble ionization chamber;
   (c) a typical saturation curve for an ionization chamber.

8. In X-ray radiology
   (a) Explain how tube output depends on kVp, anode material and tube filtration
   (b) Discuss kVp ranges, anodes and filters employed in general X-ray, CT and mammography

9. Describe the spectrum obtained using a tungsten target x-ray tube operated at a 100 kVp tube potential. Describe how the spectrum is altered by the following changes:
   (a) tube potential is lowered to 60 kV,
   (b) mAs is doubled,
   (c) 0.5 mm Cu filtration is added.

10. Briefly define or explain:
   (a) inherent filtration
   (b) added filtration
   (c) compound filter
   (d) K-edge filter
   (e) beam hardening
   (f) homogeneity coefficient
   (g) effective energy
   (h) broad beam attenuation

11. Outline an experimental method for the determination of the Half Value Layer of a diagnostic x-ray system. What information does the HVL provide about a diagnostic x-ray system? List typical HVL values for CT (120 kVp), radiography (80 kVp) and mammography (28 kVp).

12. Briefly define or explain the following with respect to x-ray tubes:
   (a) thermionic emission
   (b) space charge effect
   (c) focusing cup
   (d) line focus principle
   (e) rotating anode
   (f) blooming
   (g) filtration
   (h) beam quality

13. Draw a schematic diagram of a typical x-ray tube, clearly identifying the component elements. Describe how the heel effect arises, using the diagram to illustrate.

14. Discuss in detail the two types of x-ray production resulting from an electron beam with a given kinetic energy incident on a tungsten target. Describe their relative contributions to the emitted radiation.

15. Define the terms *anode heat storage capacity* and *maximum anode cooling rate* and explain their significance with respect to the clinical usage of x-ray tubes in CT and interventional fluoroscopy.

16. Discuss the variation of the focal spot size with x-ray tube current and x-ray tube potential. Discuss the "*NEMA*" specifications for focal-spot sizes.

17. Discuss and illustrate how scatter from fluoroscopy examinations varies with exam parameters, distance from the table and direction from the primary x-ray beam. Discuss the implications for radiation protection of staff and give 3 examples of how staff doses can be reduced.

18. Describe quantitatively when possible, the factors that affect the quantity and distribution of scattered radiation in diagnostic radiology.

19. Define or explain the following with respect to anti-scatter grids:
    (a) grid ratio
    (b) scatter reduction software
    (c) focused grid
    (d) convergent line
    (e) parallel grid
    (f) moving grid
    (g) Bucky factor
    (h) primary grid transmission

20. Discuss contrast reduction and image artifacts caused by scattered radiation and quantify the contrast improvement achieved using anti-scatter grids.

21. Discuss in detail the relationship between grid parameters and patient dose.

22. Describe two practical methods for reducing scatter in diagnostic radiology other than anti-scatter grids. Compare their advantages and limitations with the use of anti-scatter grids.

23. Outline an experimental method to determine the ratio of scatter to primary radiation for a diagnostic x-ray system. Discuss the difference between the scatter fraction and the scatter-to-primary ratio.

24. Define or explain the following with respect to digital image receptors:
    (a) pixel
    (b) dark field
    (c) exposure index
    (d) scintillator
    (e) direct detection (DR)
    (f) amorphous silicon
    (g) dose creep
    (h) flat field

25. Compare and contrast the performance of cesium iodide (CsI) and gadolinium oxysulfide (Gd_2O_2S) scintillators used in indirect flat panel detectors.

26. Describe the regular quality control tests you would perform for a digital radiography system, including their frequency.

27. Specify and explain the focal spot size requirements for the following examinations:
    (a) fluoroscopy
    (b) chest radiographs
    (c) magnification neuroradiography
    (d) magnification mammography.
    (e) skeletal radiography.

28. Explain the procedure and equipment used for quality control tests of an x-ray generator.

29. With regard to digital radiography systems:
    (a) Define and explain the Exposure Index (EI) and image receptor air kerma (K_{IND})
    (b) Define and explain the Deviation Index (DI), and its relationship to EI and K_{IND}
    (c) Describe how the use of DI could be implemented in clinical practice, and how the monitoring of DI could be included in a quality assurance program.

30. Briefly compare both the clinical and technical merits and limitations of Computed Radiography (CR) vs. Digital Radiography (DR) including the performance evaluations of both CR and DR image receptors

31. Outline the acceptance tests that should be performed on a newly installed CR system.

32. Describe the unsharp mask image processing technique currently used by most commercial CR systems.

33. Sketch a computed radiography system including the CR reader. Describe the image formation process.

34. Sketch a diagram of a dedicated mammographic system and indicate how it differs from a general radiographic unit.

35. Indicate the settings or choices of technical parameters in a mammographic unit for the following:
    (a) tube potential (kV)
    (b) focal spot size
    (c) anode material
    (d) filter material
    (e) source to image distance (SID)
    (f) breast compression
    (g) DBT angle
    (h) HVL

36. Outline procedures for acceptance testing of a newly installed digital mammography system and give typical values for any measured parameters.

37. Discuss the factors that affect radiation dose in digital mammography and give typical values of the mean glandular dose (MGD) normally encountered on state-of-the-art systems.

38. Discuss the risk-benefit ratio associated with screening mammography.

39. Discuss the variation of subject contrast in mammography with x-ray energy.

40. Briefly explain using sketches the following technology as applied to mammography. Describe the functions of the major components.
    (a) photon-counting detectors
    (b) digital breast tomosynthesis.

41. Discuss the primary sources of image blur and image noise in digital mammography.

42. Describe and compare digital breast tomosynthesis to general 2D mammography including detector requirements.

43. As it relates to diagnostic displays, briefly explain the following. In your answers, please include any differences between both mammography diagnostic displays and non-mammography diagnostic displays.
    (a) L'min
    (b) L'max
    (c) contrast ratio
    (d) luminance ratio
    (e) GSDF calibration
    (f) pixel pitch.

44. Outline the differences in recommended specifications for primary displays used for general radiology and mammography. List and briefly describe the key elements of a QC program for primary displays.

45. Sketch an image intensifier tube and clearly label and discuss its components.

46. Define the following image intensifier parameters, and provide representative values:
    (a) brightness gain
    (b) minification gain
    (c) electronic or flux gain
    (d) contrast ratio
    (e) conversion factor
    (f) electronic zoom

47. Sketch a block diagram showing the major components of the image chain in a fluoroscopy system and briefly describe the function of each.

48. Briefly define or explain the following with respect to CCD detectors:
    (a) frame rate
    (b) saturation
    (c) flat field correction
    (d) dark noise
    (e) readout noise
    (f) quantum detection efficiency
    (g) temporal lag
    (h) blooming

49. Compare and contrast image quality and dose efficiency of image intensifier systems versus flat panel detector systems when used for fluoroscopy.

50. Describe quality control tests for a flat panel detector fluoroscopy system. Name equipment used for these tests.

51. With regards to digital subtraction angiography (DSA), answer the following:
    (a) Outline the physics of image acquisition;
    (b) Why are patients imaged using DSA?
    (c) List and briefly explain factors which affect patient dose in an interventional procedure using DSA.

52. Describe how the image processing techniques available with current DSA systems are used when performing interventional procedures.

53. Define or explain the following with respect to computed tomography:
    (a) bowtie filter
    (b) Hounsfield unit
    (c) axial scan mode
    (d) helical scan mode
    (e) flying focal spot
    (f) third-generation scanner
    (g) isocenter
    (h) tube current modulation

54. Sketch and describe the major components of a modern third-generation multislice CT scanner.

55. Qualitatively describe and compare the different approaches to CT image reconstruction available in modern CT scanners.

56. Discuss the following CT artefacts, including methods implemented to minimize them:
    (a) beam hardening,
    (b) partial volume effects,
    (c) streak artifacts, and
    (d) ring artifacts.

57. Describe the radiation detector arrays in use in current multislice CT scanners, including representative technical specifications and performance criteria.

58. Compare and contrast multislice and cone-beam CT scanners, including advantages and disadvantages and clinical applications.

59. Describe a comprehensive quality assurance program for a CT scanner, including the relative importance and frequency of test procedures.

60. Discuss the clinical efficacy of Iterative reconstruction in Computed Tomography. Discuss how key features of IR can be evaluated both quantitatively and qualitatively.

PART IV. DIAGNOSTIC RADIOLOGY SPECIALTY

1. Briefly define or explain the following with respect to radiation detectors:
   (a) photo-peak
   (b) dynode
   (c) stopping power
   (d) Compton edge
   (e) electronic avalanche
   (f) quenching
   (g) paralyzable system

2. Describe the following radiation detectors based on gas ionization and discuss their relative merits in radiation protection:
   (a) ionization chamber
   (b) Geiger-Mueller (G-M) counter

3. Describe how film and optically stimulated luminescence dosimeters may be used for personnel dosimetry and discuss their relative advantages and limitations.

4. Describe three common personnel dosimeters and explain how the dose is estimated for each one.

5. Briefly define or explain:
   (a) indirect action
   (b) non-stochastic
   (c) directly ionizing
   (d) chromosome aberration
   (e) linear quadratic model
   (f) absolute/relative risk models

6. Discuss why it is difficult to obtain accurate information about the biological effects on humans of low doses (e.g. 10 mGy) of low-LET radiations delivered over extended periods of time.

7. Briefly define or explain:
   a) LET
   b) RBE
   c) latent period
   d) deterministic effect
   e) radiation weighting factor
   f) equivalent dose
   g) effective dose
   h) GSD

8. Discuss the potential detrimental effects of ionizing radiation at the exposure levels encountered in diagnostic radiology with respect to:
   (a) stochastic effects;
   (b) deterministic effects.

9. Quantitatively discuss sources of natural background radiation (including medical exposure). Describes how it varies across North America.

10. Discuss typical doses to staff working in Radiology and compare these with dose limits for occupationally exposed individuals and members of the public.

11. Estimate the radiation doses to key organs (gonads, hands, thyroid, eye lens) and the corresponding effective dose for a radiologist performing percutaneous transluminal coronary angioplasty (PCTA) using fluoroscopic guidance.

12. Discuss the radiation risks associated with a typical barium enema study and an interventional cardiac catheterization procedure.

13. For a 20 cm thick female patient receiving an AP abdominal radiograph, show how you could roughly estimate organ doses for liver, kidneys, and ovaries if the incident air kerma was 1.5 mGy at 80 kVp. How much would these organs contribute to an effective dose estimate? State all assumptions.

14. Give typical doses to pregnant women from abdominal radiographs and abdominal CT examinations and discuss the corresponding radiation risks to the embryo/fetus.

15. For a typical PA chest examination, give estimates of the following:
    (a) entrance exposure
    (b) entrance skin dose
    (c) dose to lungs, breast, ovaries and gonads
    (d) effective dose (E)
    (e) image receptor entrance air kerma.

16. Discuss the merits and limitations of expressing patient doses in terms of:
    (a) entrance skin dose
    (b) effective dose (E)

17. Discuss the patient doses and potential risks associated with the following diagnostic examinations:
    (a) skull radiographs
    (b) abdominal radiographs
    (c) IVP examinations
    (d) barium meals

18. Estimate the effective dose to a patient undergoing percutaneous transluminal coronary angioplasty (PCTA) with fluoroscopic guidance. State all assumptions made.

19. Discuss patient doses encountered over the range of current fluoroscopy procedures, both diagnostic and therapeutic, and describe methods used to minimize patient doses.

20. Describe the following dose parameters associated with CT scanners, and give typical values for clinical head and body scans:
    (a) weighted $CTDI_W$
    (b) volume $CTDI_{VOL}$
    (c) dose-length product
    (d) Size Specific Dose Estimate (SSDE)
    (e) effective dose

21. Outline and briefly describe five steps that can be taken to optimize patient doses in digital x-ray radiography.

22. Describe the following three accidental exposures reported in the press. For each event, list at least two strategies that, had they been in place, would have reduced the risk of this type of event.
    (a) CT brain perfusion scans at Los Angeles's Cedars-Sinai Medical Center in 2008-2009;
    (b) Multiple CT scans of the same 3 mm slice at Arcata, California in 2008;
    (c) Industrial radiography camera malfunction in Ventanilla, Peru (2014).

23. Discuss the shielding requirements for a fluoroscopic room, giving representative values for all parameters used.

24. Describe the necessary equipment and tests performed to ensure that the shielding in an x-ray room is satisfactory. Describe the information necessary to perform shielding calculations for an x-ray room.

25. With regards to X-ray measurement equipment calibration, explain the following:
    (a) Outline how a calibration is performed and with what frequency;
    (b) What are potential issues that arise if calibration is not performed?
    (c) What is cross-calibration?

26. Outline the design of a reject image analysis including the expected number of images in each major reject category.

27.
    (a) Quantitatively discuss the resolution properties for the following:
        i) x-ray focal spot
        ii) direct detection digital detector
        iii) indirect detection digital detector
    (b) How do the resolution properties of each of the above change when magnification radiography is performed?

28. Discuss the measurement of focal spot sizes using both a pinhole camera and by taking a radiograph of a star pattern. Compare the advantages and limitations of each method.

29. Discuss the image quality obtained with image intensifiers with respect to noise, contrast, resolution and image distortion.

30. Discuss and show mathematically the relationship between the Point Spread Function (PSF), Line Spread Function (LSF) and Modulation Transfer Function (MTF) of a medical imaging system.

31. Define the Nyquist frequency for a digital imaging system and explain why undersampling causes aliasing. Give representative values of the Nyquist frequency for digital image receptors used in mammography and general radiography.

32. Discuss the MTF of a digital imaging system and how this is affected by the following:
    (a) detector element size
    (b) detector element spacing
    (c) display matrix size

33. Outline a method for determining the presampling MTF of a digital imaging modality (e.g. CR) and plot a representative MTF for the chosen modality.

34. Describe the primary components of noise in the formation of a digital radiographic image, including their relative contributions to overall image noise levels.

35. Define the noise power spectrum (NPS) of a digital radiographic image receptor and explain in detail how it is measured.

36. Discuss how the noise power spectrum (NPS) for an indirect-conversion flat panel detector would change when:
    (a) a thicker scintillator is used
    (b) a scintillator with a higher conversion efficiency is used
    (c) a detector with a higher quantum detection efficiency is used.

37. Define noise equivalent quanta (NEQ) and describe the factors that influence the NEQ for a digital image.

38. Define detective quantum efficiency (DQE) and describe the factors that influence the DQE for a digital radiographic image receptor.

39. Describe the Rose criterion for detection of a uniform object in a uniform background, including assumptions used in developing the model and practical limitations.

40. Draw a 2 x 2 matrix of disease (D+ or D-) and a diagnostic test (T+ or T-) for some patient population. Identify true positives, false positives, true negatives and false negatives and define the following terms:
    (a) sensitivity
    (b) specificity
    (c) accuracy
    (d) prevalence of disease
    (e) predictive value of the test

41. Sketch a Receiver Operating Characteristic (ROC) curve and indicate the operating points on the curve corresponding to strict and lax thresholds. Explain the meaning of these thresholds and of the diagonal connecting (0,0) and (1,1) on the ROC plot. Discuss the use of the area under the ROC curve as a measure of the accuracy of a diagnostic test.

42. Describe the procedure used to perform an ROC study to compare the performance of two competing imaging modalities to diagnose a specific clinical problem.

43. Compare and contrast ROC and alternative forced choice (AFC) methods for assessing observer performance in visual signal detection.

44. Compare the diagnostic information obtained, image quality parameters and patient doses of a nuclear medicine brain scan, skull x-ray and head CT examination.

45. Compare and contrast the benefits and limitations of SPECT myocardial perfusion and CT coronary angiography studies, including artifacts typically encountered.

46. How do modern dual-energy X-ray absorptiometry (DXA or DEXA) systems produce "dual energies"?

47. What is a precision study and Least Significant Change (LSC)? What is the clinical significance of having current LSC values in-place?

48. Discuss or define the following as they apply to magnetic resonance:
    (a) Larmor equation
    (b) gyromagnetic ratio
    (c) paramagnetism
    (d) 90 degree pulse
    (e) gradient echo
    (f) magnetization transfer
    (g) chemical shift
    (h) susceptibility

49. Discuss the factors that influence the signal to noise ratio in an MR image.

50. Describe, with the aid of sketches, the RF pulses, gradients and signal acquisition of the following imaging techniques:
    (a) Inversion Recovery (IR)
    (b) Spin-Echo (SE)
    (c) Gradient Echo (GE)

51. For spin-echo imaging:
    (a) use graphs to explain how image contrast can be varied by the choice of spin-echo imaging parameters.
    (b) what spin-echo imaging parameters would you use to maximize image contrast between tissues having:
        i) different T_1
        ii) different T_2
        iii) different proton density.

52. Compare the imaging aspects of an MR head scan with a CT scan of the head (including image quality, patient dose, scan time and cost).

53. Define or discuss the following with respect to ultrasound imaging:
    (a) piezoelectric effect
    (b) matching layer
    (c) acoustic impedance
    (d) scan converter
    (e) pulse length
    (f) aliasing
    (g) reverberation artifact
    (h) duplex scanning

54. Discuss the structure of an ultrasound transducer array. Describe how images are formed using linear, curved, and phased array transducers.

55. Explain what is meant by **B** and **M** mode ultrasound scans. Explain how the temporal resolution is limited for each technique.

56. Discuss the most important factors that affect the axial, lateral, and elevation resolution of an ultrasound scanner. How are these controlled on a linear array transducer?

57. For diagnostic ultrasound:
    (a) Explain the terms mechanical index (MI) and thermal index (TI).
    (b) Discuss the hazards associated with mechanical and thermal effects.
    (c) What special safety considerations are required for ultrasound contrast agents?

58. Describe the following Doppler modes:
    (a) Continuous Wave
    (b) Pulsed
    (c) Color
    (d) Power

59.
    (a) Describe how a Failure Modes and Effects Analysis could be performed in the radiology setting.
    (b) For each of the following Failure Modes, identify one possible cause and suggest, with reasons, values for Frequency (F), Severity (S) and Detectability (D) parameters
        (i) incorrect patient for procedure;
        (ii) incorrect scanning parameters used;
        (iii)exam on pregnant patient.
    (c) For each case in (b) above, what preventative measures could be employed to decrease D, (i.e. increase the detectability of the error before it reaches the patient)?

60.
    (a) Define the following health informatics terms:
        i) RIS
        ii) PACS
        iii) DICOM
        iv) HL7
        v) Structured Report (SR)
        vi) IHE
    (b) Briefly describe how the technologies listed above would work together in a hospital radiology department.