University of Pittsburgh
Department of Bioengineering

BIOE 1330
Biomedical Imaging
Homework #4 Solns

1. What two physical characteristics cause an atom (nucleus really) to be unstable? How does each type of instability become stable? i.e. what changes, what is emitted?

   Ans: Too many neutrons results in a neutron converting to a proton and an electron, and yields a gamma photon. Too few neutrons results in a proton converting to a neutron, releasing a positron and two gamma photons.

2. What are gamma rays? X-rays? What's the difference between them?

   Ans: Gamma rays and x-rays are both forms of electromagnetic radiation with similar energy levels. Gamma rays are produced from radioactive decay, and x-rays are produced by electron interactions.

3. High speed electrons interacting with a target material can result in three types of radiation. Briefly describe them.

   Ans: Collision transfer: a fraction of the electron's energy is transferred to another electron
   Radiative transfer: the excited electron from collision transfer returns to its original state, producing infrared radiation
   Delta Ray: occasionally enough energy is transferred by collision transfer to produce a second energetic electron.

4. Why do X-ray images made with higher energy tend to be more blurry.

   Ans: Higher energy x-rays tend to result in more Compton scattering interactions than PE interactions with tissues, resulting in many photons leaving the tissue in random directions.

5. Why are x-rays filtered before exposing the patient?

   Ans: Filters can be used to balance x-ray density with tissue thickness, but are also used to remove highly toxic low energy x-rays.

6. What is a "K-edge" in a contrast agent? How is it used to increase contrast?

   Ans: A K-edge is the energy level at which photon energy just exceeds the k-shell electron binding energy in the contrast media. X-rays at this energy level result in a large increase in number of x-rays absorbed by the contrast agent, but not by surrounding tissues, resulting in enhanced contrast between the two.

7. Describe the roll of a grid-screen assembly in an x-ray system.

   Ans: The grid absorbs photons that likely resulted in Compton scatter, which would add to blur in the image. The screen converts high-energy photons to large numbers of lower energy photons. This conversion greatly increases the exposure of film due to individual x-rays.

8. How many photons are created by the phosphor screen for each x-ray photon?

   Ans: about 1000.

9. What two factors increase geometric blurring of an image?

   Ans: Distance between the tissue and film, and the size of the x-ray source.

10. Infrared light is defined as having wavelengths in the range of 1 μm – 100 μm
    a. Determine the frequency range of IR light
    b. Determine the photon energy range of IR light
    c. Is IR light ionizing or not?

       $\lambda = \frac{c}{v}$

       $v = \frac{c}{\lambda}$, where $c = 3.0 \cdot 10^{-8} meters/sec$

       $$v = \frac{3.0 \cdot 10^{-8} meters/sec}{1 \cdot 10^{-6} meters} = \mathbf{3 \cdot 10^{14} Hz}$$

       $$v = \frac{3.0 \cdot 10^{-8} meters/sec}{100 \cdot 10^{-6} meters} = \mathbf{3 \cdot 10^{12} Hz}$$

       a. $3 \cdot 10^{14} - 3 \cdot 10^{12} Hz$

       $E = \hbar v$, where $\hbar = 6.626 \cdot 10^{-34} joul - sec$ (Planck's Constant)

       $$E = 6.626 \cdot 10^{-34} joul - \text{sec} \cdot 3 \cdot 10^{14} Hz \cdot \frac{1\ eV}{1.6 \cdot 10^{-19} J} = \mathbf{1.24\ eV}$$

       $$E = 6.626 \cdot 10^{-34} joul - \text{sec} \cdot 3 \cdot 10^{12} Hz \cdot \frac{1\ eV}{1.6 \cdot 10^{-19} J} = .0124\ eV = \mathbf{12.4\ meV}$$

       b. $12.4\ meV - 1.24\ eV$

       Ionizing radiation $E > 13.6\ eV$, IR is non-ionizing.

11. Compare and contrast characteristic radiation and Bremsstrahlung radiation

    Ans: Characteristic radiation is produced when an electron drops from an excited energy state to a lower energy and gives of an x-ray. Since electrons can exist in only discrete energy states, characteristic radiation is only emitted at discrete levels

Bremsstrahlung radiation is the result of an electron interacting with a nucleus. As the electron is slowed and deflected from its original path and produces an x-ray with energy equal to the lost energy

12. Calculate the thickness of shielding material needed to block out 95.0 % of the incident radiation for a material with linear attenuation coefficient μ.

$$\frac{I_x}{I_0} = 1 - .95 = 0.05$$

$$I_x = I_0 e^{-\mu x}$$

$$\frac{I_x}{I_0} = 0.05 = e^{-\mu x}$$

$$x = -\frac{1}{\mu} ln(0.05) = \frac{\ln(20)}{\mu} = \frac{3}{\mu}$$

13. An x-ray tube fires on average, 10000 photons per seconds at an x-ray image intensifier. If the detector provides an average count of 10000 photons per second, calculate and plot the variance of the detector's output as a function of DQE. What DQE value is required for an output variance of 2000?

λ_d Number of photons detected at the detector every second

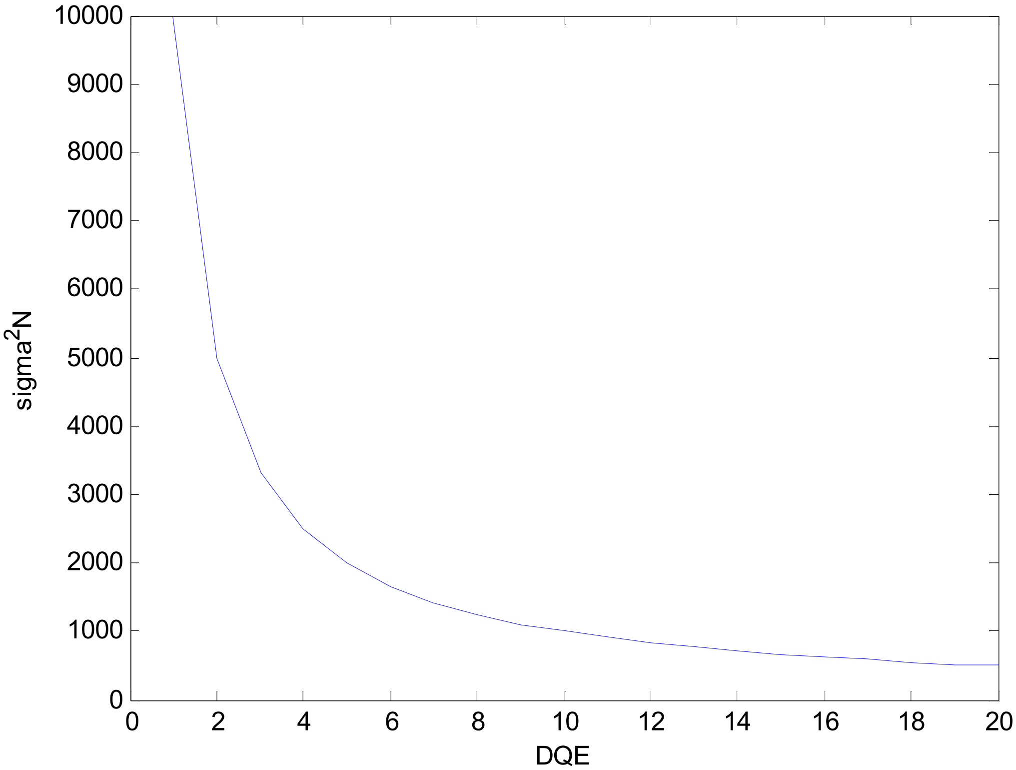
σ_N^2 Variance of the noise

$$DQE = \frac{\hat{\lambda}}{\lambda}$$

$$\hat{\lambda} = \left[\frac{\lambda_d}{\sqrt{\sigma_N^2}}\right]^2$$

$$DQE = \frac{\lambda_d^2}{\sigma_N^2 \lambda} = \frac{10000}{\sigma_N^2}$$

$$\sigma_N^2 = \frac{10000}{DQE}$$



$\sigma_N^2 = \frac{10000}{2000} = 5$ This is better than an ideal detector.