Nuclear Medicine

12.1. The gamma photon emitted by the nucleus of the cesium isotope with 137 mass number is absorbed with photoeffect. The absorbing medium is air, assume the work function to be 34 eV.
a) What will be the kinetic energy of the photoelectron in eV and
b) attojoule units?
c) What is the maximum number of ion pairs that the ejected photoelectron is able to produce during the secondary ionization process?

12.2. The energy required to produce an ion pair in the NaI crystal activated with thallium is 5 eV. In average every fourth recombination results in photon emission. The wavelength of the emitted photons is 420 nm. With what efficiency is the energy of ion pair production transformed into scintillation light?

12.3. The gamma photon emitted by the nucleus of cesium-137 is absorbed with photoeffect in the thallium-activated NaI crystal. The energy difference between the thallium energy levels is 3 eV. The crystal transforms the absorbed gamma energy into visible light with 14% efficiency.
a) How many joules will be the visible light energy emitted during the scintillation?
b) How many light photons are emitted?
c) What is the average scintillation intensity if the scintillation lasts for 0.6 microseconds and it is observed from 25 cm distance? Suppose that the scintillation is point-like and isotropic.
d) How many electrons are emitted by the photocathode as a result of the scintillation, if the photons release photoelectrons with 20% probability?

12.4. The gamma photon emitted by the ^{64}Cu isotope is absorbed with pair production.
a) What is the initial kinetic energy of the produced electron?
b) How many ion pairs may this electron produce if the average ionization energy (i.e. work function) of the medium is 34 eV?

12.5. Theoretically 2 eV would be enough to remove an electron from the surface of a dynode but only 10% of cases will result indeed in removal since most electrons loose their energy in the dynode metal.
a) What is the expected number of secondary electrons per one incident electron if the potential difference between two dynodes is 100 V?
b) What will be the amplification of the photomultiplier tube if it contains 16 dynodes?

12.6. What is the amplification of a photomultiplier consisting of ten dynodes if the number of secondary electrons is
a) 3 per dynode,
b) 4 per dynode,
c) 2.7 per dynode in average?

12.7. A blue photon colliding into the photocathode of a photomultiplier tube consisting of 12 dynodes removes a photoelectron. The number of secondary electrons per dynode is 4.
a) What is the current on the anode if the electron avalanche travels down in 1 μs?
b) What is the pulse voltage if the anode circuit resistance is 1 kΩ

12.8. A photon emitted by ^{51}Cr isotope is absorbed with Compton scattering in the thallium-doped NaI crystal.

a) What is the energy of the Compton electron (in eV and aJ units) if the wavelength of the scattered photon is 8 pm and the work function is 45 eV?

b) How many photons of 420 nm wavelength are emitted if the absorbed energy of the ionizing radiation is converted to scintillation light with 12% efficiency?

c) The photons emitted during the scintillation are directed toward the photocathode of the photomultiplier tube. How many photoelectrons do they remove if the quantum efficiency of the interaction is 10%?

d) There is 120 V voltage between each pair of dynodes, the energy required for electron exit is 2.1 eV but it occurs with only 7% probability. What is the multiplication factor of secondary electrons?

e) What is the amplification of the PM-tube if it contains 12 dynodes?

f) How many electrons arrive to the anode due to the scintillation mentioned above?

g) What is the electric current if the electron avalanche travels down in 0.5 μs?

h) What is the pulse amplitude is it is measured on a 0.4 kΩ resistor?

i) Will this pulse be counted if the baseline of the integral discriminator is set to 1.5 V?

Formulae

1 eV = $1.6 \cdot 10^{-19}$ J

$$E_{el} = q \cdot U$$

$$E_{kin} = \frac{1}{2} m v^2$$

$$\varepsilon_{ph} = hf = h\frac{c}{\lambda}$$

$$N_{photon} = \frac{E_{total}}{\varepsilon_{ph}}$$

$$N_{electron} = \frac{q_{total}}{e}$$

$$\eta = \frac{P_{\text{useful output}}}{P_{\text{input}}}$$

$$P = \frac{\Delta E}{\Delta t}$$

$$J = \frac{P}{\Delta A} = \frac{\Delta E}{\Delta t \cdot \Delta A}$$

$$A_{sphere} = 4r^2\pi$$

$$\varepsilon_{ph} = A + \varepsilon_{kin}$$

$$\varepsilon_{ph} = A + \varepsilon_{kin} + \varepsilon_{ph}'$$

$$\varepsilon_{ph} = 2\left(mc^2 + \varepsilon_{kin}\right)$$

$$I_{el} = \frac{\Delta q}{\Delta t}$$

$$R = \frac{U}{I}$$

Solutions

12.1. a) **≈ 661 000 eV**
b) **≈ 105 760 aJ**
c) **≈ 19 440 ion pairs**

12.2. **14.73%**

12.3. a) **$1.48 \cdot 10^{-14}$ J**
b) **30 847 photons**
c) **$3.14 \cdot 10^{-8}$ W/m^2**
d) **6170 electrons**

12.4. a) **159 keV**
b) **4676 ion pairs**

12.5. a) **5**
b) **$5^{16} \approx 1.53 \cdot 10^{11}$**

12.6. a) **$3^{10} = 59\,049$**
b) **$4^{10} = 1\,048\,576$**
c) **$2.7^{10} = 20\,599$**

12.7. a) **2.68 µA**
b) **2.68 mV**

12.8. a) **26 450 aJ; 165 300 eV**
b) **6734 photons**
c) **673 electrons**
d) **4 ×**
e) **16 777 216 ×**
f) **$11.3 \cdot 10^9$ electrons**
g) **3.615 mA**
h) **1.446 V**
i) **not**