

Alkalmazott fizikai módszerek laboratórium

III.: Folyadékszintillációs Spektroszkópia - Ellenőrző kérdések

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1. MAGYAR VERZIÓ

1. Q: Miért használunk folyadékszintillációs detektort a triton bomlásának detektálásához?
A:
2. Q: Milyen folyamat elnevezése a „szintilláció”?
A:
3. Q: Mit tartalmaz egy folyadékszintillációs detektor?
A: Folyadékot.
4. Q: Mi az a fényhozam¹ és hogyan változik az elnyelődés² jelenségének hatására?
A:
5. Q: Milyen bomlás jellemzi a radiokarbont és a tríciumot?
A:
6. Q: Hogyan keletkezett a radiokarbon és a trícium a Földön?
A:
7. Q: Miért folytonos a β -spektrum?
A:
8. Q: What is the spectrum of the amplitude of the electric pulses during a triton measurement?
A:
9. Q: How can the scintillation light be quenched?
A:
10. Q: How can we determine the efficiency of a triton measurement from the measured value of the quench?
A:
11. Q: Why is the amplitude of the electric signal proportional to the energy deposited in the vial?
A:
12. Q: What are the operating purposes of the cocktail ingredients?
A:
13. Q: How does the photomultiplier work?
A:
14. Q: How can we discriminate the triton counts from the radiocarbon counts?
A:

¹Angol szaknyelvben „light output”

²Angol szaknyelvben „quenching”

2. ENGLISH VERSION

1. Q: Why do we use liquid scintillator for detecting the decay of triton³?

A: The triton is a β -decaying nuclei, which decay's products⁴ mean free path is simply way too short to reach a regular encapsulated detector from a separated source. Using a liquid scintillator allows us to use liquid samples, which are directly mixed with the scintillation-capable fluid. In this case, the decaying particles are right next to the scintillating particles, thus making it possible to detect decays with lower energies and shorter mean free paths.

2. Q: What process is called scintillation?

A: The scintillation is the process when the scintillator material emits visible or UV photons just after one radioactive decay. The β -particle after decay, excites the nearby atoms as it travels away from the decayed nuclei. When they return to their ground state, they emit these UV photons.

3. Q: What does a liquid scintillator contain?

A: It literally just contains such a liquid, which capable of scintillation. Then, this scintillation is amplified by a photomultiplier tube and converted to electrical pulses, which are finally detected by a multi-channel analyzer and it creates an energy-histogram of these detected events.

4. Q: What is the light output and how does it change in case of quenching?

A: The ionizing electrons are losing kinetic energy by colliding with the scintillator liquid's particles. This energy – denoted by E_d – is proportional to the number of excited atoms or molecules in the scintillator, which is also proportional to the number of scintillation photons. This number is called the light output. Measuring the distribution of this quantity gives us insights about the β -decay of the sample inside the detector. To be more precise, light output is defined as the ratio of the number of total measured photons and number of 1 keV photons. Quenching slightly "squeezes" the light output distribution along the X-axis, while pushing its maximum value a bit higher.

5. Q: How do the radiocarbon and the triton decay?

A: By β^- -decay: in their nuclei a neutron decays into a proton, emitting an electron (e^-) and an electron antineutrino ($\bar{\nu}_e$). In terms of equations we can describe them as follows for the ^3H :



And for the ^{14}C :



6. Q: How do the radiocarbon and the triton is created in our planet?

A: They're both created in the upper atmosphere by cosmic neutrons hitting ^{14}N isotopes. If a neutron hits an ^{14}N nuclei, it can either hit out a proton, and build into the place of it, or it can pull a proton and a neutron out with itself⁵. In the first case the following reaction will take place:



While in the second case, the cosmic neutron will form a tritium nuclei with the swept away proton and neutron from the ^{14}N nuclei. In the formalism of chemical equations:



7. Q: Why is the beta-spectrum continuous?

A: The main difference between the β -decay and other decays, that in the β -decay, there are two particles emitted instead of one: one β -particle and a corresponding neutrino or anti-neutrino. However the total released energy is discrete, it is continuously split between the two emitted particles. Due to the very low mass of the neutrino, only the β -particles energy could be effectively detected, which spectrum thus indeed will be continuous.

8. Q: What is the spectrum of the amplitude of the electric pulses during a triton measurement?

A: It is the distribution of the quenched light output.

³Another name for tritium

⁴ β -particle

⁵This is not totally true. There are some other scenarios, but these two are the most dominant ones.

9. Q: How can the scintillation light be quenched?

A: Quenching can occur as the result of many processes. Eg. the liquid, or the container glass vial can contain contamination. But there are several ways for this.

10. Q: How can we determine the efficiency of a triton measurement from the measured value of the quench?

A: By measuring a so called "tSIE" (denoted by L) parameter. It is a proportion of the light output at lower and at higher light levels:

$$L = \frac{N_{\text{high}}}{N_{\text{low}}} \quad (5)$$

For unquenched sample, this ratio is an exact number. If the sample is quenched, then this value will decrease by a known amount. Measuring this deviation, it directly provides us information about the efficiency.

11. Q: Why is the amplitude of the electric signal proportional to the energy deposited in the vial?

A: The energy originates from the β -particle. When it releases its energy, it excites the neighboring atoms and molecules. When they return to their ground state, they emit a photon, which energy is proportional to the excitation energy. This photon's energy then absorbed by the primer and secuder scintillators and totally emitted back into the photomultiplier tube. At the other end, we detect this energy. That's why it is proportional to the energy of the β -particle.

12. Q: What are the operating purposes of the cocktail ingredients?

A: The largest part of this cocktail is the solvent. It is the medium, where the β -particle releases its kinetic energy. The solvent then emits photons, which wavelength are not optimal for the photomultiplier tube. To solve this issue, there are two more ingredient mixed into the cocktail, which absorbs these useless photons, and emits them on a much more optimal wavelength, which are now can be used for measurements.

13. Q: How does the photomultiplier work?

A: If a scintillation photon enters the photocathode, it will hit out a "photoelectron", which is then focused into a metal layer, so called "dynode". If a fast photoelectron hits a dynode, 3 "slow" electron will be generated. Then they're accelerated with an electric voltage of about 300 V and focused into another dynode. The process then starts over, and a beam of exponentially more and more photoelectrons are created by consecutive dynodes. A photomultiplier tube usually contains 10-12 dynodes, which are capable of creating 3^{12} electrons at the end of the tube.

14. Q: How can we discriminate the triton counts from the radiocarbon counts?

A: The maximal energy of β -particles for ^3H and ^{14}C are differs greatly. For ^3H $E_{\text{max}} = 18.6 \text{ keV}$, and for ^{14}C $E_{\text{max}} = 156.5 \text{ keV}$. If we measure an energy over 18.6 keV, we can be sure, that it isn't originated from a ^3H decay, but from the background radiation, or from another isotope (in this case from ^{14}C).