



# Modern Atomic Physics Mid-Term Exam

**Course Code:** PHYS5102P

**Date:** Apr. 24, 2026

**Note:** Fundamental constants are listed on the inside of the back cover of the textbook. All numeric answers should reach an accuracy better than **10%**.

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## 1. (15 points) Tritium Beta Decay

Tritium ( ${}^3\text{H}$ ), a radioactive isotope of hydrogen, beta decays to  ${}^3\text{He}^+$ . The nuclear decay process is so fast that, in atomic physics studies, it can be assumed to take place instantaneously. This is the so-called **sudden approximation**, which assumes that the electron wavefunction of the ground state H atom remains unchanged immediately after the decay.

Find the probability of the resulting  ${}^3\text{He}^+$  in the following states after the decay:

(Useful integral:  $\int_0^{+\infty} r^n e^{-r} dr = n!$ )

**1) (10 points)** In the **2s state** of  ${}^3\text{He}^+$ .

**2) (5 points)** In the **2p state** of  ${}^3\text{He}^+$ .

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## 2. (20 points) Nuclear Magnetic Resonance (NMR)

A nuclear magnetic resonance experiment is conducted on a water sample in a magnetic field of **1 Tesla** along the z-axis generated by a superconducting solenoid. A pair of Helmholtz-coils is placed around the water sample to generate a transverse oscillatory magnetic field along the y-axis. This field is used to manipulate the proton spins in water, whose relaxation

times are  $T_1 = 100$  s and  $T_2 = 1$  s.

**1) (10 points)** We plan to use the **Ramsey method** to achieve the maximum probability of spin flip and the narrowest resonance peak in the frequency spectrum. Design the transverse magnetic field, including the oscillation amplitude and frequency, and the pulse structure.

**2) (10 points)** Instead of the Ramsey method, we plan to use the **adiabatic fast passage method** to achieve the maximum probability of spin flip. Design the transverse magnetic field, including the oscillation amplitude and frequency, and the pulse structure.

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### 3. (20 points) Cesium Atomic Fountain Clock

The definition of the second is based on the frequency of the hyperfine transition in the ground-level of the cesium atom ( $^{133}\text{Cs}$ ,  $6^2\text{S}_{1/2}$ ,  $I = 7/2$ ). In a cesium atomic fountain clock, atoms are launched up through the microwave cavity. The active area of the clock is filled with a uniform magnetic field of **10 mGauss** along the vertical z-axis.

**1) (5 points)** Which  $(F, m_F)$  state or states in the ground-level experience the **largest Zeeman shift**? Calculate this maximum shift.

**2) (5 points)** Which  $(F, m_F)$  state or states in the ground-level experience the **smallest Zeeman shift**? Estimate this minimum shift.

**3) (10 points)** Draw the ground-level hyperfine structure including all  $(F, m_F)$  states. The microwave oscillatory magnetic field is also directed along the z-axis. Label all the transitions that can be induced by the microwave field.

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**Total of 7 pages**