44.1 Radiation attenuation, laser gain and cavity modes

Name: _____ Class: _____ Date: _____ **Total: 10 marks**

KEY WORDS half-value layer • population inversion

Objective

Distinguish charged-particle stopping and range from exponential photon attenuation ; Compute attenuated intensity and detected counts with stated coefficients; Explain stimulated emission, population inversion and optical cavity resonance conditions. Original public practice; not an ETS paper.

1 Key knowledge and worked examples

Charged particles have an approximate range from continuous energy loss; narrow photon beams attenuate as I=I0 e^(−μx) with half-value layer ln2/μ.

Recorded counts multiply attenuation by efficiency. Broad-beam build-up exceeds the narrow-beam exponential; state the geometry.

Stimulated emission copies the stimulating photon; net gain needs N2/g2>N1/g1 (N2>N1 for equal degeneracies), which equilibrium forbids, so pumping through extra levels is required.

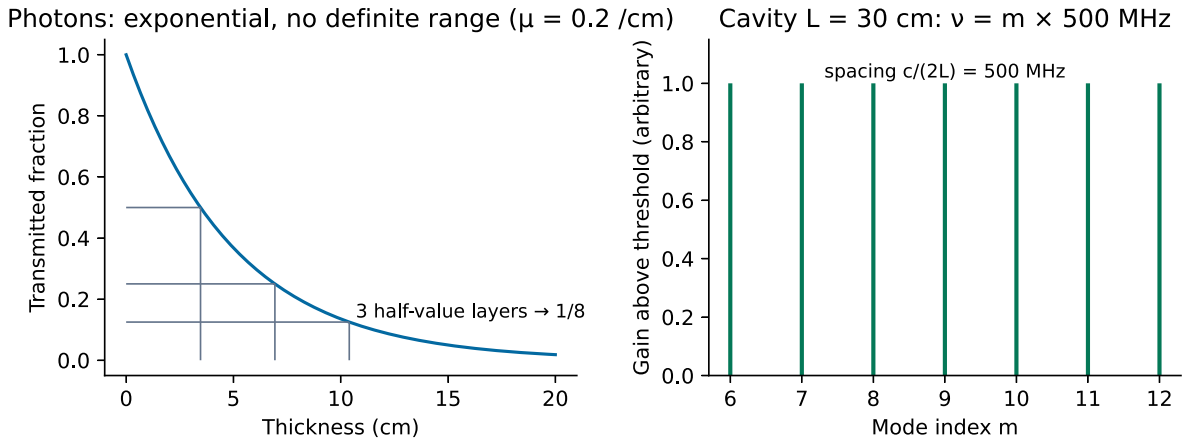
Cavity modes satisfy L=mλ/2 with spacing c/(2L); gain must exceed round-trip loss. Interferometer fringes use the same coherence.

■ Worked method

A narrow beam has attenuation $I = I_0 e^{-\mu x}$ and half-value layer $x_{1/2} = \ln 2/\mu$.

$$x_{1/2} = (\ln 2)/(0.20\,\mathrm{cm}^{-1}) = 3.47\,\mathrm{cm}.$$

Three half-value layers transmit 1/8. This model excludes scattered build-up into the detector. For a linear vacuum laser cavity, adjacent longitudinal modes are separated by $c/(2L)$. Net stimulated gain requires $N_2/g_2 > N_1/g_1$; the simpler $N_2 > N_1$ assumes equal degeneracies.



2 Practice

2.1 Choose one answer. A narrow photon beam passes through three half-value layers. The transmitted fraction is: [1]

- **A** 1/3
- **B** 1/6
- **C** 1/8
- **D** 1/9
- **E** 1/16

2.2 Choose one answer. Continuous laser action requires population inversion because in thermal equilibrium: [1]

- **A** the upper level is always more populated
- **B** the lower level is more populated, so absorption exceeds stimulated emission
- **C** spontaneous emission is forbidden
- **D** the cavity modes vanish
- **E** photons cease to be coherent

2.3 A linear laser cavity of length 25 cm has adjacent longitudinal-mode spacing _____ MHz. Show your relation and units. [2]

2.4 Decide whether this claim is true. Justify it: Broad-beam shielding transmits exactly the narrow-beam exponential intensity. [2]

3 Exam-style questions

3.1 A cavity of length L contains a gain medium over its entire length with intensity gain coefficient g, distributed intensity loss coefficient alpha, and mirror intensity reflectivities R1 and R2. Derive the threshold gain. State the intensity/amplitude convention. [4]

Solutions

2.1 C Each half-value layer halves the intensity: $(1/2)^3$=1/8.

Compare the rejected options: 1/3; 1/6; 1/9; 1/16. Use the stated model and conditions.

2.2 B Boltzmann populations give N2<N1, so absorption wins without pumping.

Compare the rejected options: the upper level is always more populated; spontaneous emission is forbidden; the cavity modes vanish; photons cease to be coherent. Use the stated model and conditions.

2.3 600. c/(2L)=$3\times10^8/0.5=6\times10^8$ Hz=600 MHz.

2.4 False. Scattered build-up adds transmission; the exponential assumes narrow-beam geometry.

3.1 One round trip multiplies intensity by $R_1R_2e^{2(g-\alpha)L}$. Threshold requires that factor equal one, so $g_{th} = \alpha + \ln[1/(R_1R_2)]/(2L)$. Above threshold unsaturated gain must exceed this loss; steady lasing involves saturation. Award round trip, threshold condition, logarithmic result and convention/saturation. An amplitude coefficient convention would introduce a factor of two and must be declared.