

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 $I = I_0 e^{-\mu x}$ with half-value layer $\ln 2 / \mu$.

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 $N_2 > N_1$, which equilibrium forbids, so pumping through extra levels is required.

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

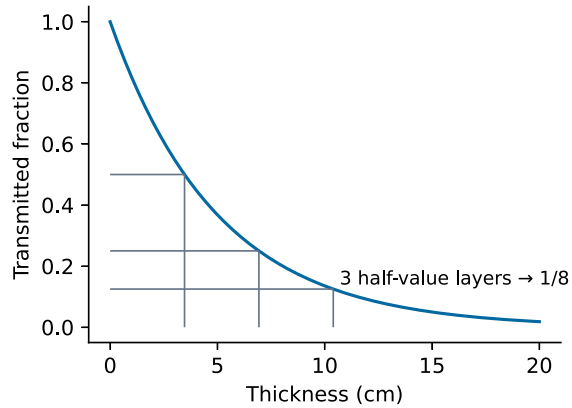
■ Worked method

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

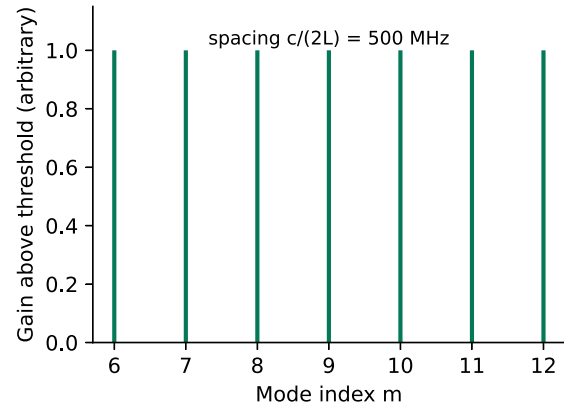
$$x_{1/2} = (\ln 2) / (0.20 \text{ cm}^{-1}) = 3.47 \text{ cm}.$$

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.

Photons: exponential, no definite range ($\mu = 0.2$ /cm)



Cavity $L = 30$ cm: $\nu = m \times 500$ MHz



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]

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 $N_2 < N_1$, 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. $c/(2L)=3 \times 10^8/0.5=6 \times 10^8$ 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 $R_1 R_2 e^{2(g-\alpha)L}$. Threshold requires that factor equal one, so $g_{th} = \alpha + \ln[1/(R_1 R_2)]/(2L)$. 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.