

Exercise walk-through

44.1

Radiation attenuation, laser gain and cavity modes

GRE · GRE Subject Test · GRE Physics

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**

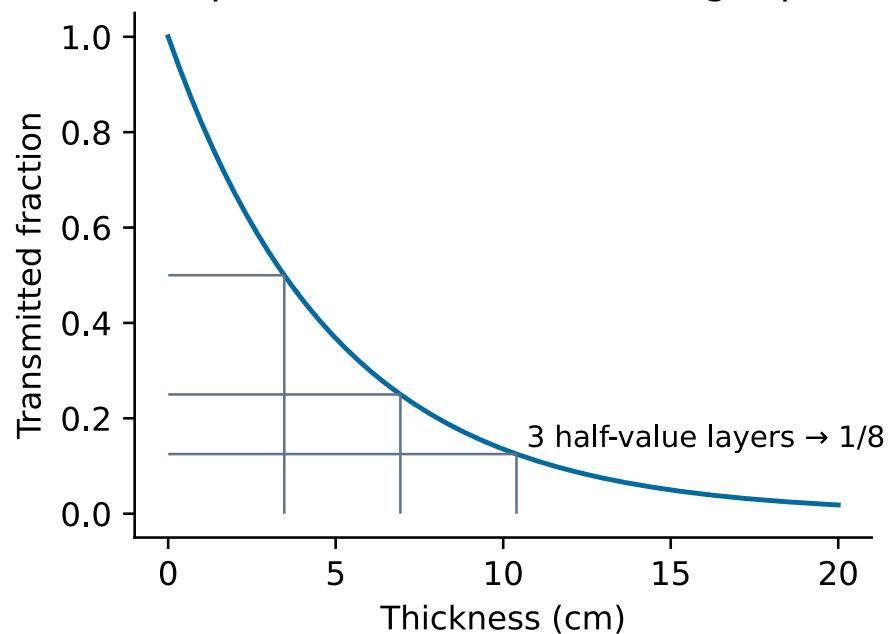
A narrow beam has attenuation $I = I_0 e^{-\mu x}$ and half-value layer $x_{1/2} = \ln 2 / \mu$.

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

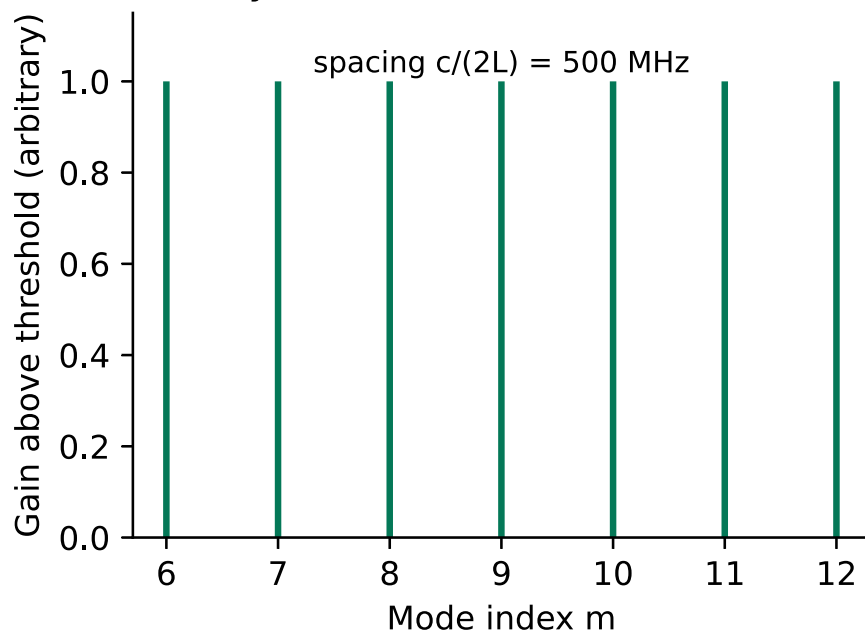
Three half-value layers transmit $1/8$. This model excludes scattered build-up into the detector. For a linear vacuum laser cavity, adjacent longitudinal modes are separated by

$c/(2L)$. 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



Exercise 2.1

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** $1/16$

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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.

Exercises 2.2-2.3

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]

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

2.3 600. $c/(2L) = 3 \times 10^8 / 0.5 = 6 \times 10^8 \text{ Hz} = 600 \text{ MHz}$.

Exercises 2.4·3.1

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

3.1 A cavity of length L contains a gain medium over its entire length with intensity gain coefficient g , distributed intensity loss coefficient α , and mirror intensity reflectivities R_1 and R_2 . Derive the threshold gain. State the intensity/amplitude convention. [4]

Exercises 2.4·3.1

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

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

3.1 A cavity of length L contains a gain medium over its entire length with intensity gain coefficient g , distributed intensity loss coefficient α , and mirror intensity reflectivities R_1 and R_2 . Derive the threshold gain. State the intensity/amplitude convention. [4]

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.