WJEC EDUQAS A-LEVEL PHYSICS · COMPONENT 3

PHYSICS



EXAM QUESTION PACK

3.5 LASERS

SCORE	PERCENTAGE
/60	%

STEMUP

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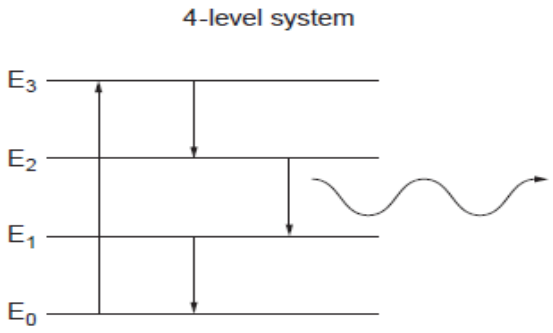
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#1

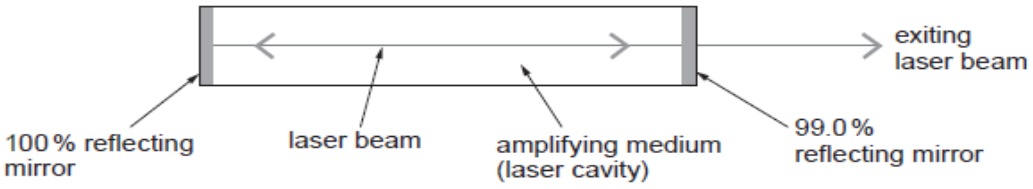
(a) Explain what is meant by stimulated emission of radiation. [2]

(b) The energy levels of a 4-level laser system are shown.



Give **two** reasons why energy level E_1 is always nearly empty. [2]

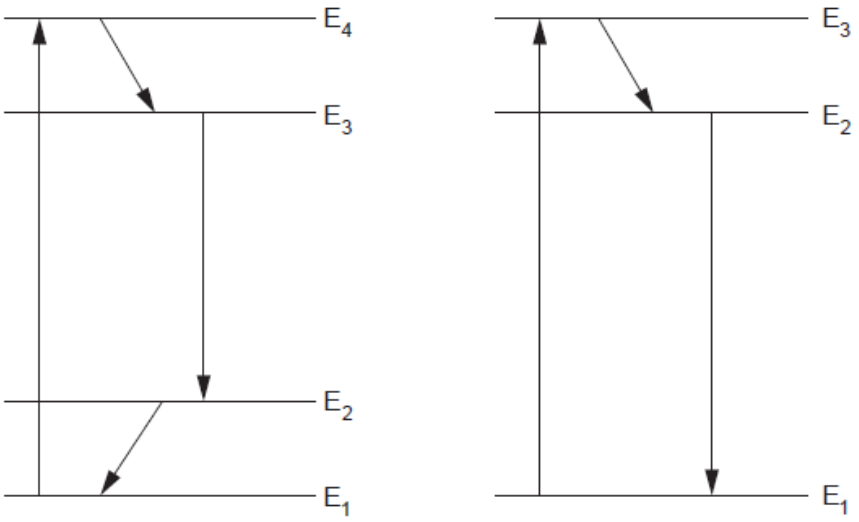
(c) Victoria claims that when the laser system shown below **is in equilibrium**, the amplifying medium provides only a 0.5 % increase in intensity of the beam each time it travels across the cavity. Her research partner, David, insists that the exponential increase in light intensity provided by the amplifying medium means that the beam intensity is increased by a factor of thousands for each pass even when the laser is in equilibrium. Discuss whether Victoria or David is correct. [3]



Question taken from Eduqas examination paper 842103, November 2020

#2

(a) **Label** the pumping and stimulated emission transitions in the four **and** three level laser systems shown below. [2]



(b) Explain why a population inversion can be achieved far more easily in a four level system than in a three level system. [4]

(c) Give **two** reasons why the top level (E4 in the four level system and E3 in the three level system) must have a short lifetime. [2]

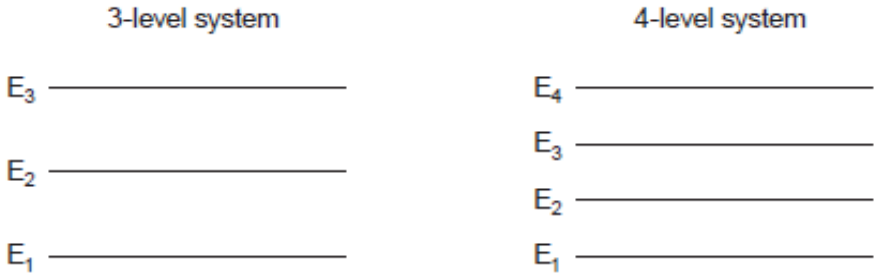
Question taken from Eduqas examination paper 842103, June 2017

#3

3. *(a)* (i) Explain why a population inversion is not usually possible with a 2-level energy system pumped using light. [2]

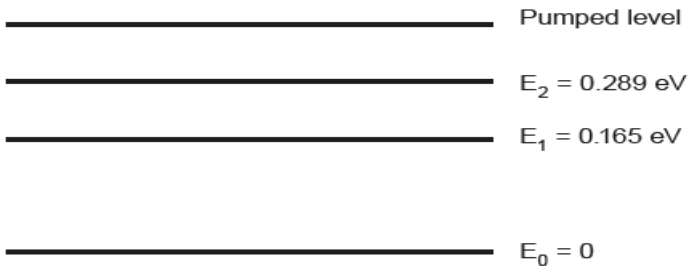
(ii) State an advantage of semiconductor lasers and an example of their use. [2]

(b) Explain how 3-level and 4-level laser systems work and the advantages of a 4-level system. Refer to the diagrams in your answer. [6 QER]



#4

When sunlight shines on the atmosphere of Mars, carbon dioxide molecules at a height of 75 km behave like the amplifying medium in a laser. The energy levels involved are shown in the following diagram. A population inversion occurs between energy levels E_1 and E_2.



(a) (i) State what is meant by a population inversion. [1]

(ii) Explain why a population inversion is needed for laser action. [2]

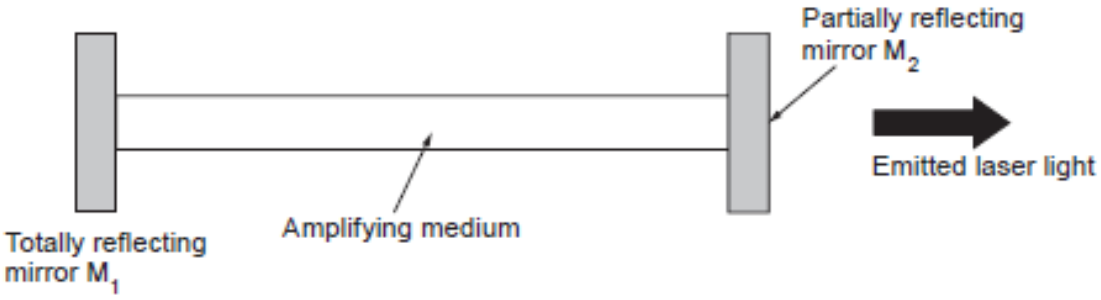
(b) Calculate the output wavelength of this naturally occurring laser and determine the region of the electromagnetic spectrum in which it lies. [3]

(c) The Llanesco crater is on the surface of Mars and has a cross-sectional area of 2290 km^2. Carbon dioxide molecules in the Mars atmosphere collide with the surface and give rise to a surface pressure of 600 Pa. The mass of a carbon dioxide molecule is 7.3×10^{-26} kg and the perpendicular component of the speed of the molecules to the surface is 550 $m\,s^{-1}$ **before** and **after** they collide with the surface. Calculate the number of carbon dioxide molecules that collide with the Llanesco crater in 1 s. [5]

#5

5. *(a)* Explain how a 3 level laser operates, explaining also why a 2 level laser is not possible. [6 QER]

(b) The simplified diagram shows the cavity of a laser.



(i) The wavelength of light from the laser is 633 nm. Calculate the energy of a photon of light emitted by the laser. [2]

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(ii) The power output of the laser is 1.0 mW. Mirror M_2 transmits 1 in 500 photons. Determine the number of photons per second incident on mirror M_2. [3]

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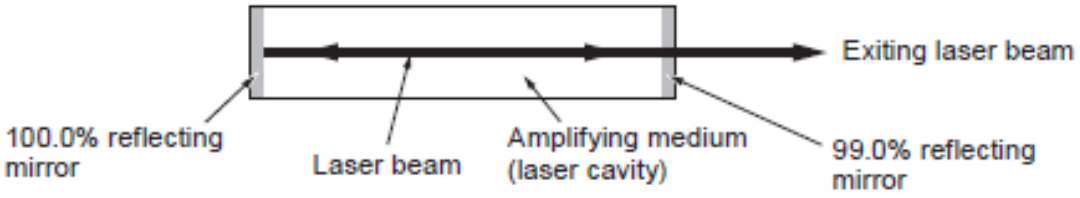
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Question taken from Eduqas examination paper 842002, June 2018

#6

4. A laser has two mirrors either side of the amplifying medium as shown.



(a) Explain the purpose of the 99.0% reflecting mirror and the 100.0% reflecting mirror. [2]

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(b) Explain the purpose of a population inversion in the laser cavity. [3]

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(c) (i) The light intensity inside a powerful laser is 2.0×10^{15} W and its wavelength is 1.05 μm. Show that this corresponds to approximately 1×10^{34} photons per second. [2]

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(ii) Show that the momentum of a 1.05 μm photon is approximately 6×10^{-28} kg m s^{-1}. [1]

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(iii) Show that the force exerted on a 100.0% reflecting mirror by a beam of power 2.0×10^{15} W is approximately 1×10^{7} N. [2]

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(iv) Calculate the strain produced in a laser structure if the power of the beam between the mirrors is 2.0×10^{15} W. You may assume that the structure of the laser cavity has a cross-sectional area of 43 cm^2 and is made of a material with Young modulus 2.8×10^{11} Pa. [3]

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Question taken from Eduqas examination paper 842103, June 2018

Marking Scheme

#1

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
	(a)		Electron drops giving 2 photons (1) (Stimulated by) incoming photon of correct energy / wavelength (1)	2			2		
	(b)		Short lifetime (1) Above ground level **OR** level above is metastable / long T (1)	2			2		
	(c)		1 % lost each round trip (due to transmission) (1) Equilibrium requires 1 % gain or WTTE (1) Which is 0.5 % each length & Victoria is correct (or similar) (1) **Award a maximum of 2 marks -** David is correct because large amplification (1) must counteract other losses (1)			3	3		
			Question total	**4**	**0**	**3**	**7**	**0**	**0**

#2

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
	(a)		• In 4-level E3 to E2 • In 3-level E2 to E1 • Pumping is upward in **both** diagrams All 3 correct award 2 marks 1 or 2 correct award 1 mark 0 correct award 0 marks	2			2		
	(b)		E2 is [initially] nearly empty or empties quickly or has a short half-life or lifetime [in 4 level] (1) E1 is [initially] occupied or ground state or full [in 3-level] (1) More pumping needed for 3 level or converse (1) At least 50% of electrons need pumping in 3 level or any pumping produces population inversion in 4 level (1)	1 1	1 1		4		
	(c)		Cannot pump a full energy level or pumping not as effective if level is fuller etc (1) Electrons need to go to next level down [E3 or E2 for population inversion] (1)		2		2		
			Question total	**4**	**4**	**0**	**8**	**0**	**0**

#3

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
3	(a)	(i)	Stimulated emission also happens [1] Decreasing the upper population (accept 50 % population is greatest possible or equal probability of absorption / dropping) [1]	2			2		
		(ii)	Greater efficiency or requires less energy / small pumping voltage / larger population inversions / less pumping / cheaper and mass produced [1] Don't accept lower current CD / DVD / Blu ray / pointers / laser fusion / anything sensible [1]	2			2		
	(b)		**3-level system** Pumping E1-E3 E3-E2 quick E2 metastable E2-E1 laser output E1-E2 population inversion **4-level system** Pumping E1-E4 E4-E3 quick E3 metastable E3-E2 laser output E2-E3 population inversion E2-E1 quick **Advantages / Disadvantages** E1 ground so usually full in 3-level More than 50% pumping required in 3-level E2 normally empty in 4-level Minimum pumping required in 4-level	6			6		
			5-6 marks Comprehensive description of how a 3-level works, how a 4-level works and its advantages. *There is a sustained line of reasoning which is coherent, relevant, substantiated and logically structured.* **3-4 marks** Comprehensive description of 2 from: how a 3-level works, how a 4-level works and its advantages or limited description of all 3. *There is a line of reasoning which is partially coherent, largely relevant, supported by some evidence and with some structure.* **1-2 marks** Comprehensive description of 1 from: how a 3-level works, how a 4-level works and its advantages or limited description of 2. *There is a basic line of reasoning which is not coherent, largely irrelevant, supported by limited evidence and with very little structure.* **0 marks** *No attempt made or no response worthy of credit.*						
			Question 3 total	**10**	**0**	**0**	**10**	**0**	**0**

#4

Question			Marking details		Marks available				
				AO1	AO2	AO3	Total	Maths	Prac
	(a)	(i)	More electrons in higher energy level [E_2] compared to lower energy level [E_1]	1			1		
		(ii)	Population inversion ensures stimulated emission [rather than spontaneous emission] (1) Produces 2 photons for 1 incoming photon (1)	2			2		
	(b)		Conversion of eV to J correct (1) Wavelength = 1.00×10^{-5} m (1) Wavelength lies in the infra-red (1)	1 1	1		3	2	
	(c)		Converting 2 290 km^2 to 2.29×10^9 m^2 (1) Force on the crater (= pressure × area **ecf**) = 1.38×10^{12} [N] (1) Momentum of each molecule calculated = 4×10^{-23} [N s] (1) Momentum change per collision = 8.03×10^{-23} [N s] **or** realisation that momentum change = initial – (-final) (1) Number of molecules = 1.71×10^{34} (1)		5		5	5	
			Question total	**5**	**6**	**0**	**11**	**7**	**0**

#5

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
5	*(a)*		**3-level energy system** E1 – Clearly labelled diagram of 3-level energy system E2 – Population inversion mentioned E3 – More electrons in higher energy levels than lower E4 – Pumping used to achieve more electrons in higher energy level / state E5 – One state is metastable or long lived **2-level energy system** E6 – Population inversion not possible in 2-level system E7 - Reference to absorption (either 2 or 3 level) **Stimulated Emission** S0 – Incident photon causes an electron to drop S2 – Photon emitted when electron drops S3 – Stimulated emission mentioned S4 – There are 2 photons instead of 1 photon (coherent) S5 – Incident photon of correct energy or frequency or wavelength **5-6 marks** 9 to 12 points from either E1 to E7 and S0 to S5 *There is a sustained line of reasoning which is coherent, relevant, substantiated and logically structured.* **3-4 marks** 5 to 8 points from either E1 to E7 and S0 to S5 *There is a line of reasoning which is partially coherent, largely relevant, supported by some evidence and with some structure.*	6			6		
			1-2 marks 1 to 4 points from either E1 to E7 and S0 to S5 *There is a basic line of reasoning which is not coherent, largely irrelevant, supported by limited evidence and with very little structure.* **0 marks** No attempt made or no response worthy of credit.						
	(b)	(i)	Substituting for wavelength into $E = \frac{hc}{\lambda}$ (1) Energy of photon = 3.14×10^{-19}J unit mark(1)	1	1		2	2	
		(ii)	Number of photons per second $= \frac{1\times10^{-3}}{3.14\times10^{-19}} = 3.18 \times 10^{15}\ s^{-1}$ (ecf on value of energy of photon) (1) Number of incident photons per second = $3.18 \times 10^{15} \times 500$ (1) Answer = 1.6×10^{18} (1) ecf power 10		3		3	3	
			Question 5 total	**7**	**4**	**0**	**11**	**5**	**0**

#6

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
4	*(a)*		{Multiple passes of beam / reflection / keeps most of the light} for more amplification / stimulated emission or increased collimation (1) Some light (1%) transmitted by 99% mirror (1)	2			2		
	(b)		Increase of stimulated emission (1) Compared with absorption (1) [Exponential] increase in intensity or amplification or more power] (1) NB Stimulated emission > absorption → 2 marks	3			3		
	(c)	(i)	Energy of photon = 1.89×10^{-19} [J] seen or implied (1) $\frac{2 \times 10^{15}}{1.89 \times 10^{-19}}$ seen or implied (1.056×10^{34}) (1) [no e.c.f.]		2		2	2	
		(ii)	$p = \frac{6.63 \times 10^{-34}}{1.05 \times 10^{-6}}$ [kg m s^{-1}] seen or implied [= 6.314×10^{-28} N s]		1		1	1	
		(iii)	$1.06 \times 10^{34} \times 6.31 \times 10^{-28}$ [N] seen or implied (1) 2 × due to reflection stated (1) [→1.33×10^{7} N] [Using the 'show that' figures → 1.2×10^{7} N]		2		2	1	
		(iv)	$E = \frac{\text{stress}}{\text{strain}}$ used (1) [or by implication] $\text{Stress} = \frac{F}{A}$ used (1) [or by implication] Answer = 0.0083 or 0.011 (or 0.0105) seen (depends on (iii) but check) (1) [0.83% ✓]	1 1	1		3	3	
			Question 4 total	**7**	**6**	**0**	**13**	**7**	**0**