Name	Date started	Target end date

GCE AS / A LEVEL — LASERS QUESTION PACK

Legacy PH2 · New spec Unit 2 Topic 8 · AS unit, 20% of A-level

REVISE
.wales

PHYSICS — UNIT 2 · LASERS

PH2.8 Lasers — population inversion & semiconductor lasers

Stimulated emission, requirements for sustained lasing (population inversion, optical pumping, cavity), 3- and 4-level laser systems, and the structure of semiconductor lasers and their applications.

NEW 2015 SPEC · UNIT 2 TOPIC 8

Estimated time for entire question pack: ~3 h 43 min

Derived from the legacy PH2 paper's pace of 80 marks in 1¼ hours.

*You are advised to **not** attempt to complete all of this in one sitting.*

ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every question from the legacy WJEC PH2 papers (2008 modular spec) that maps onto new-spec Unit 2 Topic 8 (2.8).

Questions are ordered chronologically within each section.

INSTRUCTIONS

Use black ink or black ball-point pen. Answer all questions in the spaces provided.

The number of marks is given in brackets at the end of each question or part-question. A calculator is required. The Data Booklet is allowed.

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Q	Source	Max	Mark
1	PH2 Jan 10 Q5	11	
2	PH2 Jan 12 Q5	11	
3	PH2 Jan 13 Q5	11	
4	PH2 Jun 12 Q7	13	
5	PH2 Jun 09 Q5	12	
6	PH2 Jun 10 Q5	12	
7	PH2 Jun 13 Q6	10	

Q	Source	Max	Mark
8	PH2 Jan 14 Q6	12	
9	PH2 Jun 14 Q6	11	
10	PH2 Jun 15 Q6	12	
11	PH2 Jun 16 Q5	11	
12	PH2 Jan 11 Q6	13	
13	PH2 Jun 11 Q4	12	
14	PH2 Jun 12 Q3	8	
Total		159	

Lasers — what the new spec asks

WJEC GCE AS / A Level Physics (from 2015) · Unit 2: Electricity & Light · Topic 2.8.

Spontaneous & stimulated emission A

- Define spontaneous and stimulated emission of photons.
- In stimulated emission, incident and emitted photons are coherent.

Population inversion B

- More electrons in upper energy state than lower ⇒ net amplification.
- Achieved by optical pumping or electrical excitation.

Energy-level systems B

- Three-level vs four-level laser schemes.
- Metastable states extending photon lifetimes.

Semiconductor lasers C

- p-n junction lasers; band-gap controls emitted wavelength.
- Threshold current and the role of the cavity.

Applications C

- Optical-fibre communication, CD / DVD reading.
- Medical and industrial uses (cutting, welding).

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Lasers in one page

Quick-reference notes — revisit before each section.

Emission types

Spontaneous: random direction, phase — ordinary fluorescence.

Stimulated: incident photon triggers identical emitted photon (same f, phase, direction).

Lasing conditions

1. Population inversion (more upper than lower).
2. Optical cavity (mirrors) for feedback.
3. Gain medium with appropriate energy levels.

Three-level laser

Pump $E_0 \Rightarrow E_2$; fast decay to E_1 (metastable).

Lasing transition: $E_1 \Rightarrow E_0$.

Needs >50% atoms pumped to invert.

Four-level laser

Lower laser level depopulates quickly — easier inversion.

Lower pump-power threshold.

Semiconductor laser

Forward bias injects carriers into junction.

Recombination across band gap emits photons.

Cleaved facets form the cavity.

Applications

Fibre comms (1.55 µm).

CD / DVD / Blu-Ray reading.

Surgery, cutting, welding, distance measurement.

Section index

Use this index to jump straight to the section you need.

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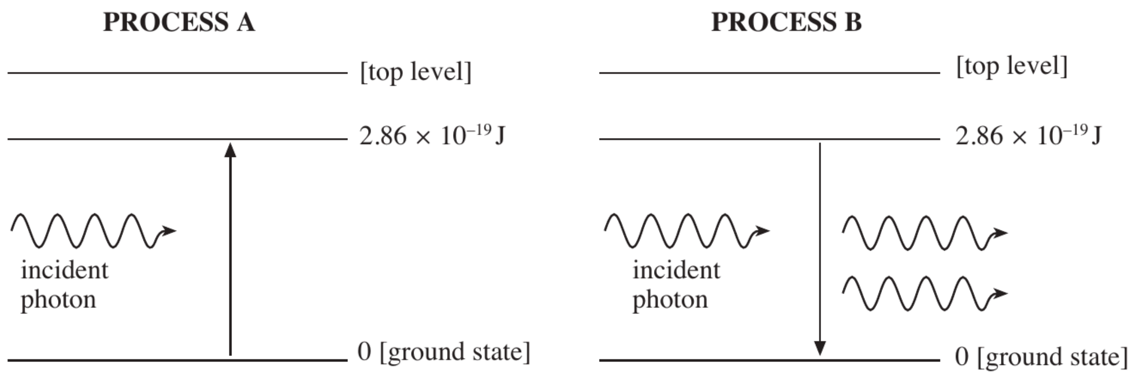
5. A *ruby laser* is classed as a *3-level system*. The amplifying medium is a ruby, which is a crystal containing chromium ions. The diagram shows two processes, **A** and **B**, which could occur when a photon of a certain wavelength is incident on a chromium ion.



(a) Calculate the *wavelength* of the incident photon. [2]

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(b) (i) What name is given to process **A**? .... [1]

(ii) State what happens to the energy of the incident photon in process **A**. [1]

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(c) (i) What name is given to process **B**? .... [1]

(ii) State **two** things which the emerging photons in process **B** have in common. [2]

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(d) For the laser to work, process **B** must happen more often than process **A**. This requires a *population inversion*.

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

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(ii) The population inversion is achieved in the ruby laser by *optical pumping* (shining a very bright light on the ruby). **Draw an arrow** on the right hand diagram on page 10 to represent the energy level transition associated with the pumping. [1]

(iii) How must the typical time an electron spends at the top level compare with the typical time it spends at the middle level? Give a reason for your answer. [2]

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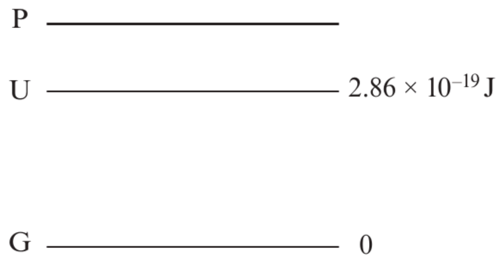
Examiner only

5. The first laser used *ruby*, a crystal containing chromium ions, as its amplifying medium. A simplified energy level diagram is given for the chromium ions.



(a) Calculate the wavelength, λ_{UG}, of radiation associated with transitions between levels U and G. [2]

(b) For the laser to work there needs to be a *population inversion* involving levels U and G.

(i) What does this statement mean? [1]

(ii) What would happen to photons of wavelength λ_{UG} present in the ruby if there were **no** population inversion, and what would become of their energy? [2]

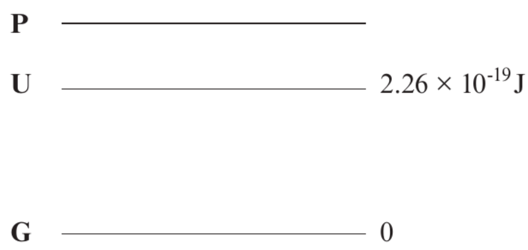
(iii) *Pumping*, involving level P, is used to cause a population inversion. **Add arrows** to the diagram to show the transitions by which the inversion is achieved. [1]

(iv) The population inversion makes possible light amplification by stimulated emission (from the chromium ions). Explain what is meant by *stimulated emission* and explain how this leads to *light amplification*. [3]

(c) State three properties of the **light** from a laser which distinguish it from light from an 'ordinary' source, such as a filament lamp. [2]

Examiner only

5. A simplified diagram of the energy levels in a 3-level laser system is given alongside.



(a) Calculate the wavelength of a photon associated with a transition between levels **U** and **G** (the ground state). [2]

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(b) Explain in terms of electrons and photons what happens in the three possible processes listed below, in which photons are involved in transitions between levels **U** and **G** (or **G** and **U**). [Assume in each case that the levels are suitably populated.]

(i) absorption [1]

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(ii) stimulated emission [4]

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(iii) spontaneous emission [1]

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Examiner only

(c) (i) Explain what is meant by *pumping* in a laser. [1]

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(ii) Explain why pumping is essential to the operation of the laser. [2]

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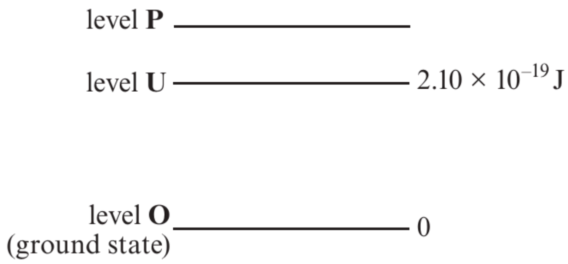
7. A simplified energy level diagram for the amplifying medium of a 3-level laser is given.



(a) Suppose that the laser is at room temperature and that it is **not being pumped**.

(i) Compare the (electron) populations of the three levels. [1]

(ii) A photon of energy 2.10×10^{-19} J in the laser cavity could interact with the amplifying medium. Name the process involved, and explain briefly what happens. [2]

(b) The laser is now pumped, to create a *population inversion* between levels **U** and **O**.

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

(ii) Draw **two** arrows on the diagram to show how the population inversion is achieved. [1]

(iii) Explain in detail how light amplification takes place. [4]

(iv) Calculate the wavelength of the radiation emitted. [2]

Examiner only

(c) In a 4-level laser the light output results from a transition to a lower level which is above the ground state. Explain the advantage over a 3-level system. [2]

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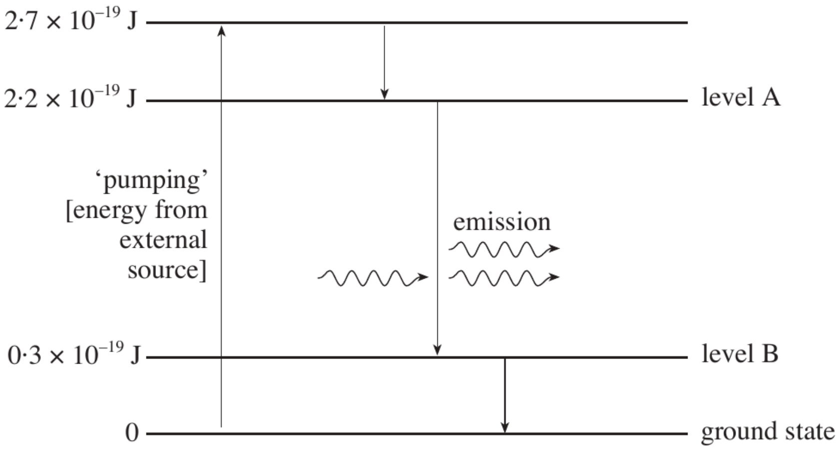
5. A simplified energy level diagram is given for the amplifying medium in a type of laser (the Nd-YAG laser).



(a) The useful output of the laser results from the transition between level A and level B.

(i) Calculate the wavelength of the radiation emitted. [3]

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(ii) Name the region of the electromagnetic spectrum in which the radiation lies. [1]

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(iii) This radiation is produced by stimulated emission. Explain what is meant by stimulated emission. [Your answer should include statements about photon energy and phase.] [3]

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(iv) Explain briefly, in terms of photons, why stimulated emission gives rise to 'light amplification'. [1]

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(b) (i) Referring to levels A and B, explain what is meant by a population inversion. [1]

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(ii) Explain why a population inversion is needed for the laser to work. [1]

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(iii) In this 4-level laser system, level B is above the ground state. How does this make the population inversion easier to establish than in a 3-level system? [2]

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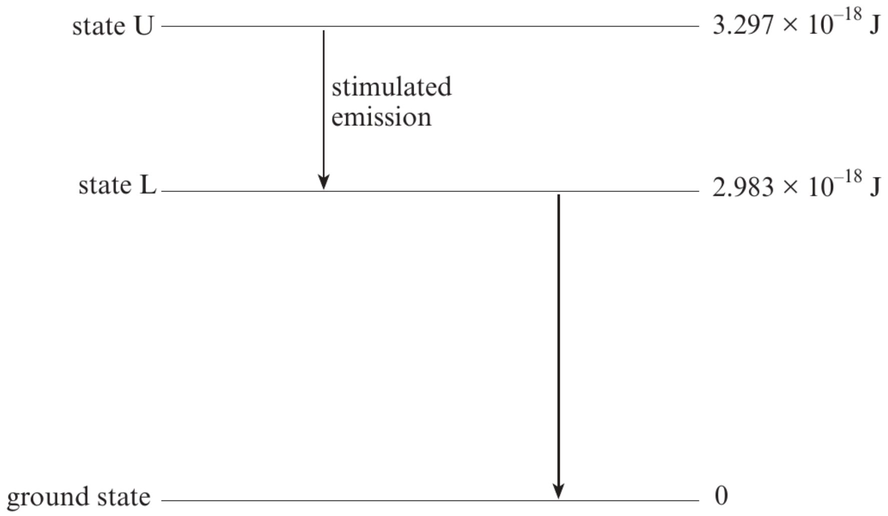
5. In the helium-neon laser, excited helium atoms collide with neon atoms and transfer energy to them. This raises neon atoms from the ground state to the excited *metastable* state, U (see diagram).



Photons are emitted by stimulated emission involving an electron transition between state U and state L.

(a) (i) Calculate the fraction

$$\frac{\text{photon energy}}{\text{energy used to excite atom to level U}}\ .$$ [2]

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(ii) Calculate the wavelength of the light emitted. [2]

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(b) (i) What causes a stimulated emission event to occur? [2]

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(ii) Describe carefully, in terms of photons, the outcome of such an event. [2]

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Examiner only

(iii) An electron stays in level L for only a very short time, spontaneously dropping to the ground state. Explain why this feature is important to the operation of a laser. [2]

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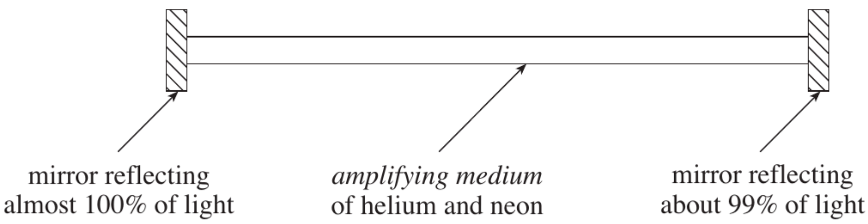
(iv) The mixture of helium and neon is contained in a long cavity with mirrors, as shown in the simplified diagram.



How does this cavity design promote laser operation? [2]

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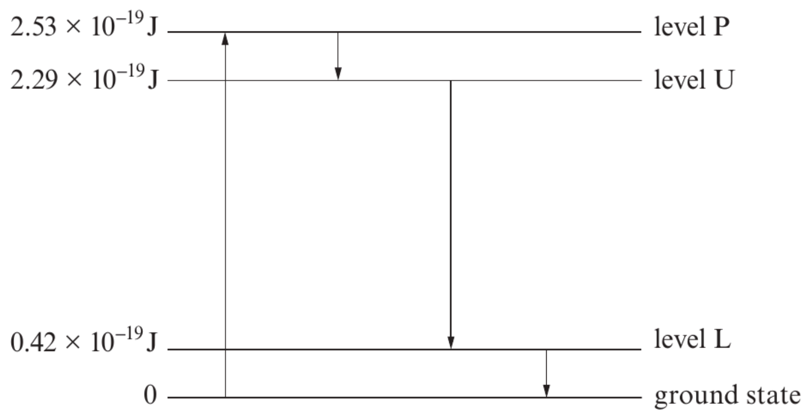
6. A simplified energy level diagram is given for the amplifying medium of a 4-level laser. The useful output of the laser is due to the 'lasing' transition between level U and level L. The laser is *pumped* using photons from an external source.



(a) Calculate the wavelength of

(i) the radiation emitted in the lasing transition, [3]

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(ii) the radiation needed for pumping. [1]

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(b) Pumping is needed to produce a population inversion.

(i) State what is meant by *a population inversion* **for this system**. [1]

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Examiner only

(ii) Explain carefully why a population inversion is needed for light amplification to take place. [3]

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(iii) In a *three* level laser system, level L would be the ground state. Explain why it is an advantage for level L to be *above* the ground state. [2]

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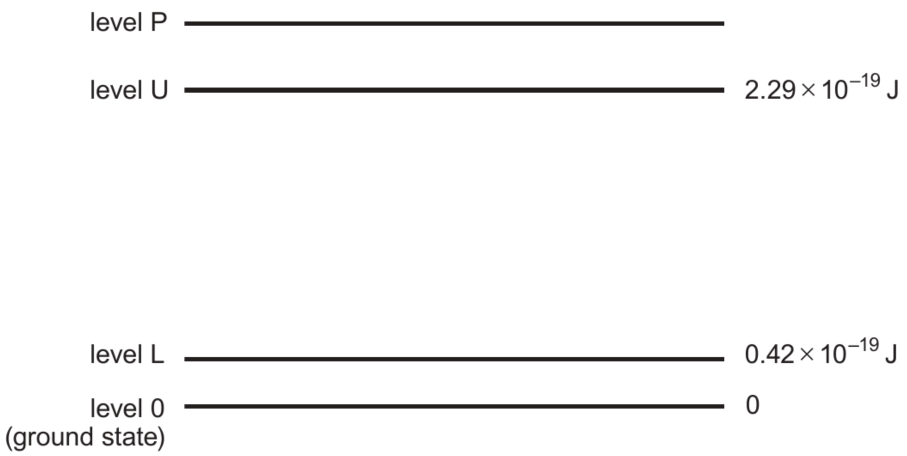
Examiner only

6. *(a)* A simplified energy level diagram is given for a four level laser system.



(i) Calculate the wavelength of photons involved in transitions between levels U and L. [2]

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(ii) Photons of this wavelength, present in the laser cavity, may be absorbed. Explain what this means, adding an arrow to the diagram to assist your explanation. [2]

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(iii) In a laser the probability of a photon producing stimulated emission must be greater than the probability of it being absorbed.

(I) Explain what is meant by stimulated emission, referring to levels U and L. [3]

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(II) Referring to all four levels, explain how the greater probability of stimulated emission over absorption is achieved in a four level laser system. [3]

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(b) Light from a laser is coherent. Explain what this means. [2]

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Examiner only

6. *(a)* A laser emits 25 W of coherent infra-red radiation of wavelength 1 064 nm.

(i) Explain what 'coherent' means in this sentence. [2]

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(ii) Calculate the photon energy. [2]

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(iii) Calculate the number of these photons leaving the laser per second. [1]

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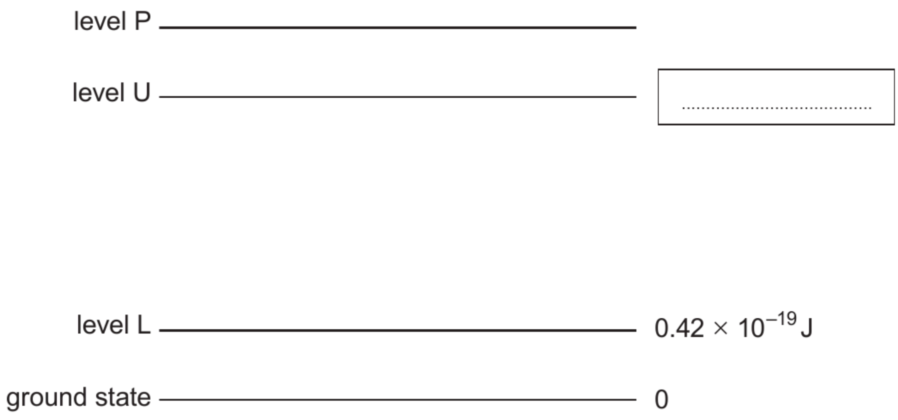
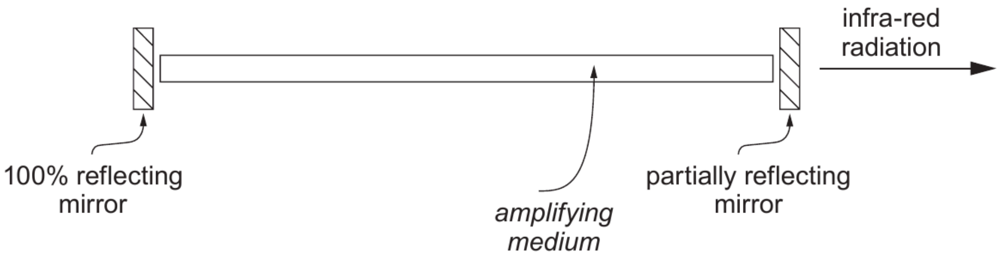
(iv) A simplified energy level diagram for this (four level) laser is given.



(I) **Show, with an arrow,** on the diagram the transition associated with emission of the infra-red radiation. [1]

(II) In the box provided in the diagram above, **write** the energy of level U. [1]

(b) 'Light' amplification occurs as the radiation passes through the amplifying medium in the laser cavity.



Explain how light amplification occurs. Start by explaining what is meant by *stimulated emission,* referring to the diagram in *(a)*(iv). [4]

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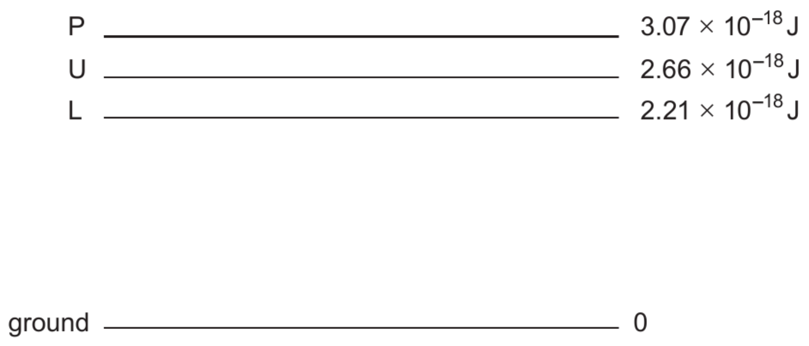
6. A simplified energy level diagram is given for a four level laser system.



(a) Calculate:

(i) the wavelength of radiation emitted by stimulated emission; [3]

(ii) the number of photons of this radiation emitted per second if the output power of the laser is 15 mW; [2]

(iii) the energy of a photon emitted in a stimulated emission event as a **percentage** of the energy needed for a pumping event. [2]

(b) As light goes from one end of the laser cavity to the other, its intensity increases.

(i) Referring to the energy level diagram, explain in terms of photons how the increase in intensity takes place. [Assume that a population inversion has already been set up.] [3]

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(ii) The pumping rate is now increased, making the population inversion greater. Suggest why this makes the output power greater than before. [2]

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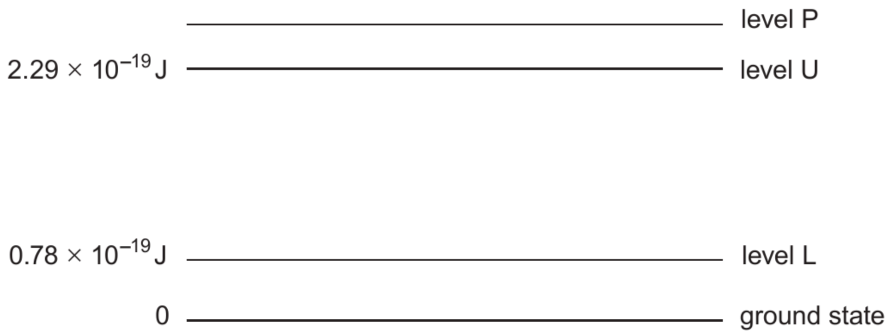
5. A simplified energy level diagram is given for the amplifying medium in a four level laser, which is pumped using light. Stimulated emission involves levels U and L.



(a) (i) Calculate the wavelength of the emitted radiation, and name the region of the electromagnetic spectrum in which it lies. [3]

(ii) The power supplied to the laser is 5.0 W, and its efficiency is 0.70%. Calculate the number of photons of this wavelength emitted per second. [3]

(b) Explain **in terms of the energy level diagram** how a population inversion between levels U and L is brought about. [3]

(c) Explain how stimulated emission differs from spontaneous emission and why stimulated emission can give light amplification. [2]

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6. *(a)* A laser emits light with a photon energy of 3.14×10^{-19} J.

(i) Calculate the wavelength of the light. [2]

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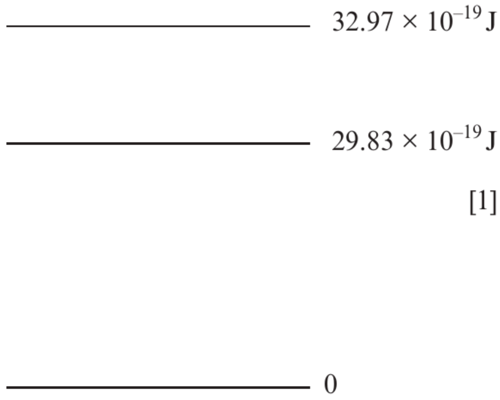
(ii) What is the colour of the light? .... [1]

(iii) A simplified energy level diagram for the amplifying medium of the laser is given.

Add an arrow to show the transition giving rise to these photons.



[1]

(b) Almost all these photons are emitted by the process of *stimulated emission.*

(i) State what triggers an atom to emit a photon by stimulated emission. [2]

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(ii) The light from the laser may be more intense than that from a light-emitting diode (LED), which emits by *spontaneous emission*. State **two** other ways in which the light emitted by the laser differs from that emitted by the LED. [2]

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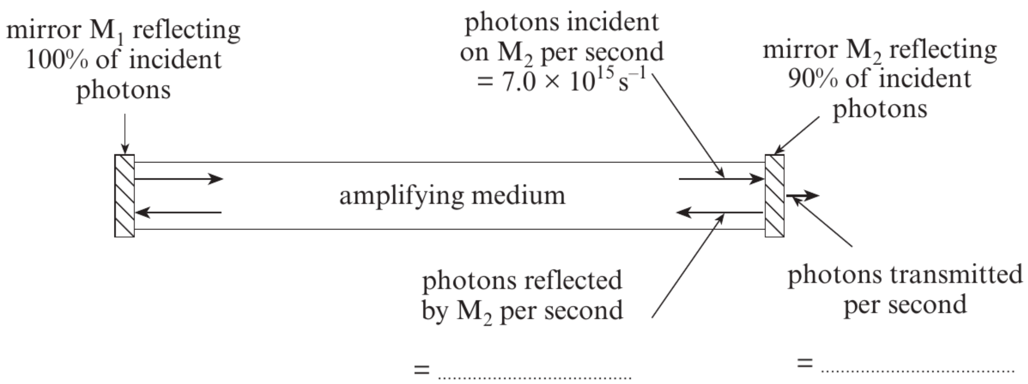
(c) The (simplified) diagram shows the cavity of the laser.

(i) Mirror M_2 is only partially reflecting. The light that it does not reflect is transmitted through it.



Fill in the numbers of photons per second reflected and transmitted. [1]

(ii) Calculate the ***power output*** of the laser. [2]

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(iii) Photons reflected from M_2 travel to M_1 and are reflected from it. Explain, using the concept of stimulated emission, why more photons arrive back at M_2 than are reflected from it. [2]

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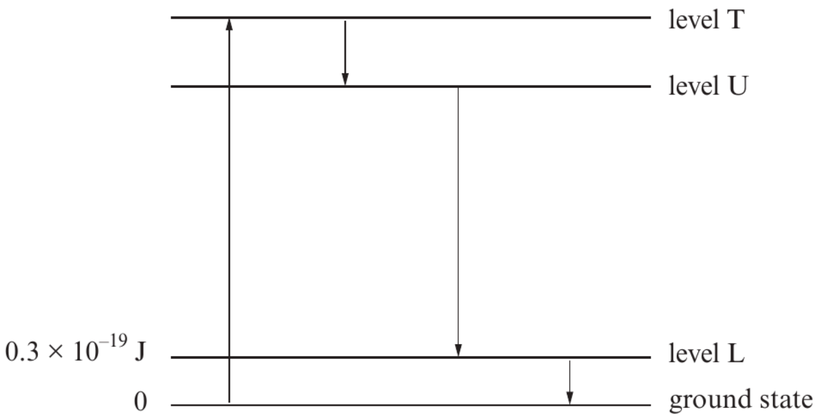
4. *(a)* A simplified energy level diagram for a 4-level laser system is given. The arrows show the sequence of transitions which electrons make between leaving the ground state and returning to it.



(i) Label the transitions associated with (I) *pumping* (II) *stimulated emission*. [2]

(ii) The wavelength of the output radiation from the laser is 1.05×10^{-6}m. Calculate the energy **above the ground state** of level U. [3]

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(iii) (I) What triggers a stimulated emission event? [2]

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(II) How does stimulated emission produce light amplification? [1]

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(III) What feature of stimulated emission makes the laser's output *coherent*? [1]

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(iv) T_U is the typical time spent by an electron in level U before spontaneously 'falling' to a lower level. T_L is the typical time spent by an electron in level L before spontaneously falling to the ground state. Explain why it is an advantage for laser operation for T_U to be much greater than T_L. [2]

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(b) Semiconductor (diode) lasers are much cheaper to make and much more compact than other types of laser. What advantage do they have in terms of *energy* over other types of laser? [1]

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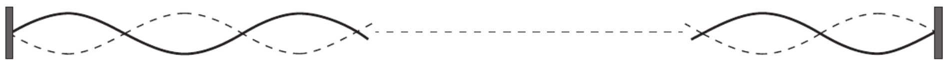
3. The cavity of a laser has reflecting ends a distance L apart. Assuming there is a node at each end, the possible wavelengths of stationary waves are given by the equation

$$\lambda = \frac{2L}{n} \quad \text{in which } n \text{ is a whole number.}$$

(a) Label relevant lengths on the diagram, and hence show how this equation arises. [The stationary wave is shown as if it were a stationary wave on a stretched string.] [2]



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(b) For a particular semiconductor laser, L = 0.2050 mm.

(i) Using the equation above, show that a stationary wave of wavelength 820.0 nm can exist in the cavity, but that a stationary wave of wavelength 821.0 nm cannot. [2]

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(ii) Find the next wavelength above 820.0 nm of stationary wave that could exist in the cavity. [2]

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(c) A stationary wave is equivalent to a superposition of progressive waves of equal amplitude travelling in opposite directions. Why is this condition not exactly met in a laser emitting a beam of light? [2]

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END OF QUESTION PACK

14 questions · 159 marks · ~3 h 43 min

Source: WJEC PH2 (2008 modular spec)

Curated for WJEC Physics 2015 spec AS Unit 2 — Topic 8 (2.8)

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