PRIFYSGOL ABERYSTWYTH UNIVERSITY

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DEPARTMENT OF PHYSICS

SEMESTER 1 EXAMINATIONS, JANUARY 2026

PH34510 – Lasers & Photonics

Time allowed – 2 hours

- **Full marks can be attained for complete answers to ALL six questions in Section A and TWO questions from Section B**
- **The numbers in brackets after the questions indicate the allocation of marks for each question.**
- **Only calculators from the Casio FX83, FX85 or FX991 range may be used.**
- **A booklet of mathematical formulae and standard constants will be provided.**
- **Only a 1 side of A4 size Summary Sheet is allowed.**
- **MAE MODD I FYFYRWYR GYFLWYNO ATEBION I'R PAPUR HWN NAILL AI YN Y GYMRAEG NEU'R SAESNEG**
- **STUDENTS MAY SUBMIT ANSWERS TO THIS PAPER IN EITHER WELSH OR ENGLISH**

Once seated, students may complete the front cover of the answer book(s) and the attendance slip ONLY.

DO NOT TURN THE EXAMINATION QUESTION PAPER OVER UNTIL INSTRUCTED TO DO SO.

Section A

Attempt ALL questions in the booklets provided

1 Suggest suitable common laser sources for each of the applications listed in i) through to v). [5]

i) A monochromatic source for a desktop Raman spectrometer.

ii) A blue-green laser pointer.

iii) A tuneable visible source for atomic-line spectroscopy.

iv) A high-power UV-C source for use in a photo-oxidation stress test.

v) A source for generating a white-light continuum in a non-linear optical crystal.

2 A Nd:YAG laser delivers pulses of duration 1 nanosecond, repetition rate 100 Hz and single-pulse energy of 0.1 J. What is the most likely method of pulse generation for such a system? Also, calculate- [5]

i) The time-averaged power of the laser output.

ii) The average power output during each pulse.

3 A Ti:Sapphire laser, delivering pulses of duration 100 fs and λ = 800 nm, is used for harmonic frequency generation. Calculate- [5]

i) The frequency bandwidth of the fundamental laser output

ii) The wavelengths of the 3rd and 4th harmonics produced.

4 An acousto-optic modulator (AOM) cell is operating in the Bragg regime. Light of wavelength λ = 700 nm is incident at an angle θ_I on the medium [5]

relative to a travelling longitudinal acoustic wave of speed 4,000 m/sec, frequency ν, and wavelength Λ.

i) Calculate the value of Λ needed to give a deflection θ_d of 10 milli-radians at the m = 20 order.

ii) Calculate the frequency (ν) of the acoustic waves.

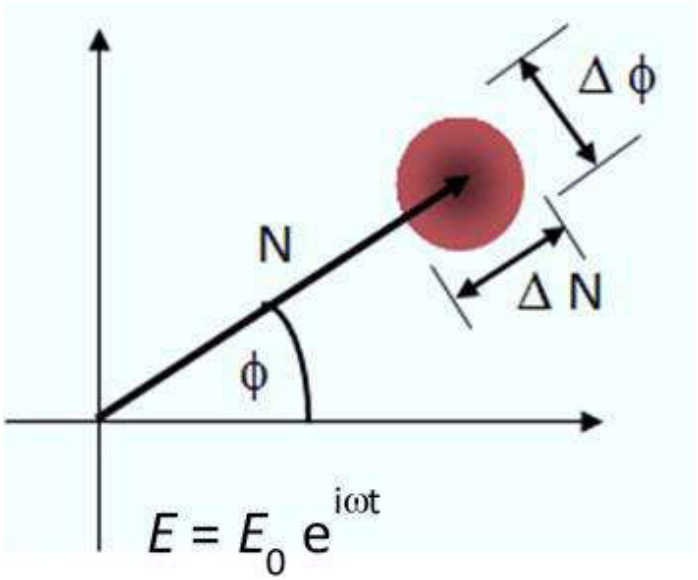
iii) Briefly describe one application of such an AOM.

5 Describe the advantages of *Off-axis* holography over the original Gabor holographic method. [5]

6 The figure below shows the *phasor* diagram for a coherent light source, such as an ideal laser. [5]

i) What are the meanings of the terms ΔN and $\Delta\phi$ in this context, and how are they related in the case of a minimum uncertainty state?

ii) How would the appearance of the shaded area in the figure change in the case of a "phase squeezed" state?



Section B

Answer TWO questions

7 a) In the context of the possible light-matter interactions of a generic 2-level atom system, describe what is meant by a *population inversion.*

[2]

b) Briefly explain why a *population inversion* is necessary for light amplification by stimulated emission.

[3]

c) Sketch an energy level diagram for a generic 3-level laser system, illustrating the *pumping* and *lasing* transitions involved. Explain the crucial role of the transition rates, from levels 3 → 2 and levels 2 → 1, in the attainment of population inversion.

[5]

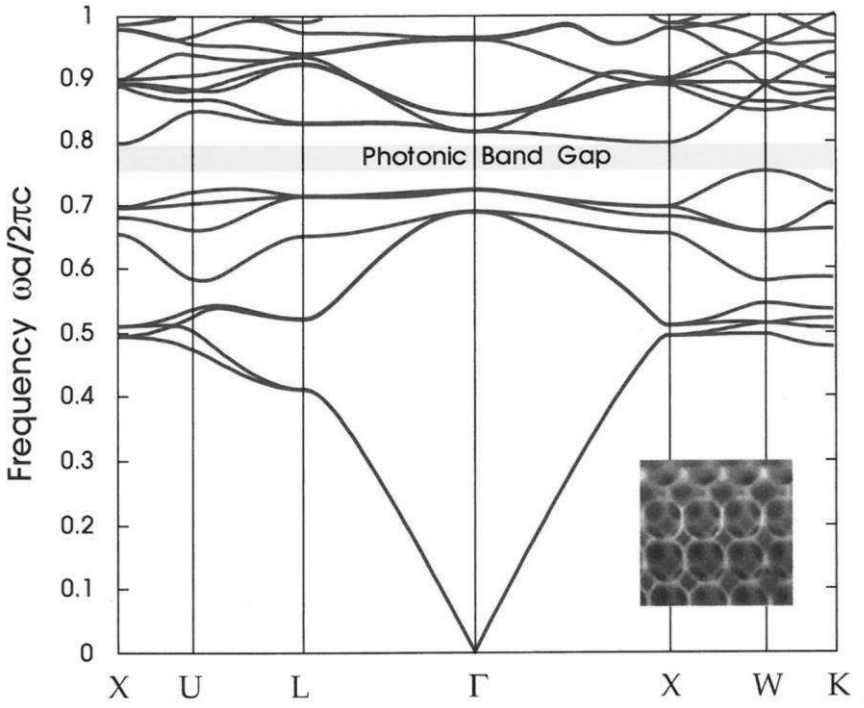
d) Sketch an energy level diagram for a generic 4-level laser system, again illustrating the *pumping* and *lasing* transitions involved, and also the relative transition rates, from levels 4 → 3, levels 3 → 2, and levels 2 → 1. What are the intrinsic advantages of this system over the 3-level system above, in the attainment of population inversion?

[5]

8 a) Describe what are meant by *Photonic Crystals*, outlining their key structural and optical properties

[5]

b) Below, a simulation of the dispersion (ω - k) characteristics of propagating light is shown for a cubic lattice of air holes in a 3D dielectric medium; an "inverse opal", as shown in the inset. The lattice parameter, a, is 1 μm.



i) Briefly explain why the dispersion curves are linear at low normalised frequencies.

[2]

ii) How is the group velocity of light propagating within bands related to the dispersion plots shown? What is the physical interpretation of the "flat-band" conditions which exist for frequencies immediately above and below the photonic band gap?

[4]

iii) From the information provided, estimate the wavelength range over which a complete photonic bandgap exists for incident light, giving full indication of your working.

[4]

9 a) In the context of pulsed optical signals transmitted along an optical fibre, describe what is meant by the *modal* (*multipath*) *dispersion* and also the *material dispersion*.

[4]

b) Show that the broadening (Δt) of an optical pulse per unit length of fibre due to multipath dispersion is given, by the equation,

$$\Delta t/L = \frac{n_1}{n_2 c}\Delta n.$$

(The fibre core and cladding indices are n_1 and n_2 respectively, and $n_1 - n_2 = \Delta n$)

[6]

c) Optical pulses of time-width 100 ns are sent down a standard step-index optical fibre with a core of refractive index 1.55 and a cladding of refractive index 1.49. Calculate the time-broadening due to multipath dispersion if the pulse travels 50 km along the fibre. Hence, estimate the upper limit for the pulse frequency that could be usefully transmitted over this length of fibre.

[5]

END OF PAPER