PRIFYSGOL ABERYSTWYTH UNIVERSITY

ADRAN FFISEG

DEPARTMENT OF PHYSICS

SEMESTER 1 EXAMINATIONS, JANUARY 2026

PH32410 – Concepts in Condensed Matter

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**

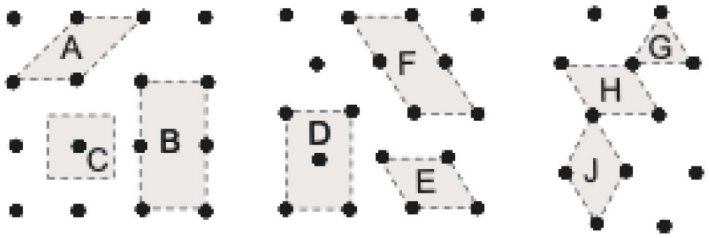
Once seated, students may complete the front cover of the answer book(s) and the attendance slip ONLY.

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

Section A

Attempt ALL questions in the booklets provided

1 State, for the following 2-dimensional lattices, which of the unit cells (A-J) are primitive unit cells. [5]



2 Explain briefly, with reference to Stokes and anti-Stokes scattering of light, how the experimental technique of Raman spectroscopy is used to measure the frequency of vibrational waves in solids. [5]

3 A crystal of sodium chloride can be considered, in one dimension, as a series of masses connected by identical springs as shown below. [5]



The frequencies of allowed vibrational modes at the edge of the Brillouin zone, are given, in the usual notation, by the equation,

$$\omega\left(\frac{\pi}{a}\right) = \sqrt{\frac{C}{mM}(m + M \pm M \mp m)}$$

Given the following values, calculate the frequency of the optical and acoustic modes at the edge of the Brillouin Zone: mass of the sodium ion, $m = 3.82 \times 10^{-26}\ kg$, mass of the chloride ion. $M = 5.89 \times 10^{-26}\ kg$, spring constant, $C = 1.00 \times 10^{3}\ Nm^{-1}$.

4 Give one example of a technological application/use for each of the following- [5]

i) High purity monocrystalline silicon

ii) Polycrystalline silicon

iii) Organic (polymeric) semiconductors

iv) "III-V" semiconductors (e.g. GaAs)

v) Ferroelectric materials (e.g. Lead Titanate).

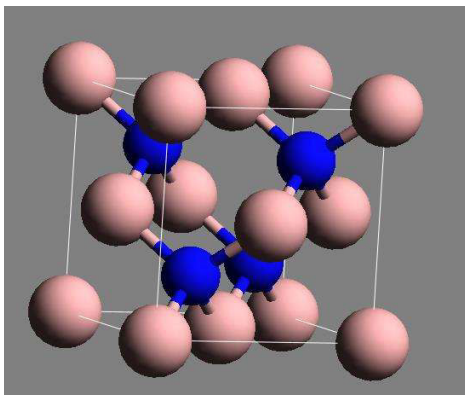
5 In the context of electrons in solids, what is meant by the *Fermi Energy*? Make a simple sketch of the energy band diagram of a bulk semiconductor, illustrating the position in energy of the Fermi level relative to the conduction and valence bands. [5]

6 Make an outline sketch of the dispersion (E-k or energy-momentum) relations, showing both the conduction and valence bands, for an *indirect* bandgap semiconductor with a bandgap energy of 1.5 eV and effective masses such that the ratio m^*(electrons)/m^*(holes) ≈ 0.5. [5]

Section B

Answer TWO questions

7 Boron nitride is a wide-band gap semiconductor that exists in cubic and hexagonal forms. The cubic crystalline form has the zincblende structure with a 3-dimensional unit cell as shown in the diagram below. The larger atoms are boron and the four smaller atoms within the unit cell are nitrogen.



a) Given that the lattice constant is 0.362 nm, calculate the volume of this unit cell and the volume occupied by each atom.

[4]

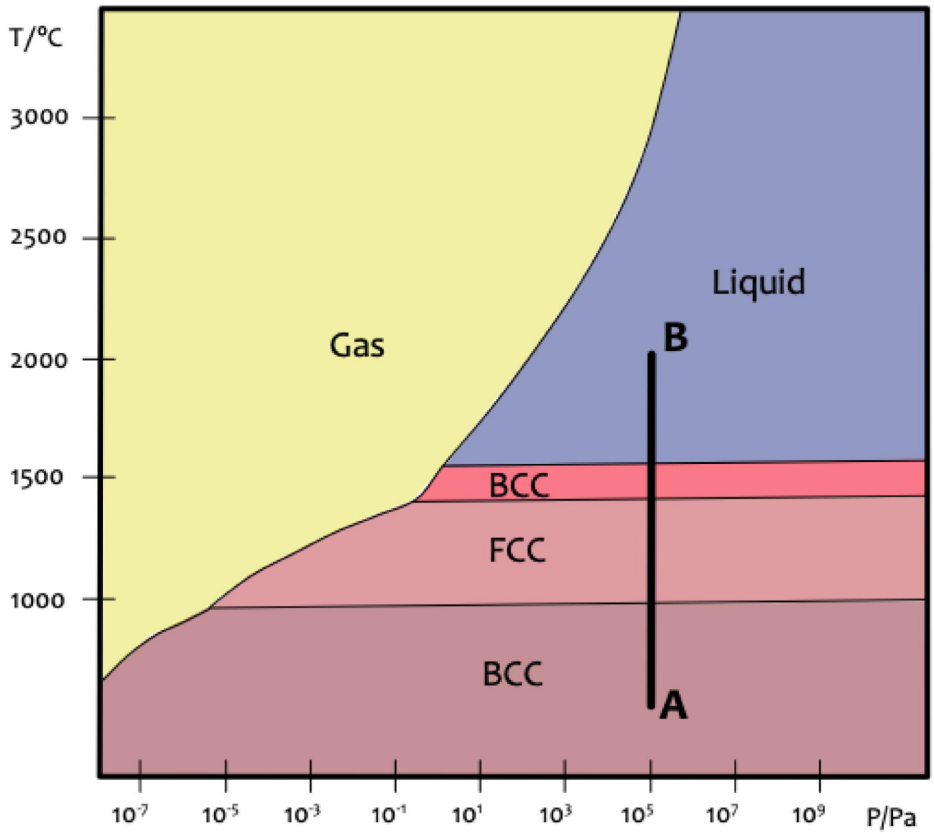
b) Sketch the atoms in the (110) plane and draw a suitable unit cell for this 2-dimensional lattice, showing two lattice vectors. Calculate the length of each of these lattice vectors

[5]

c) Briefly describe an experimental method for measuring the lattice constant of cubic boron nitride.

[6]

8 The phase diagram for iron (Fe) is given in the diagram below.



a) Describe the phase transitions as the temperature is varied along the line AB.

[3]

b) Briefly explain, giving reasons and numerical values, which of the two solid crystalline phases, Body Centred Cubic (BCC) and Face Centred Cubic (FCC) has the lowest volume per atom. Take the lattice constant for BCC iron to be, $a_{BCC} = 0.286\ nm$ and the lattice constant for FCC iron to be, $a_{FCC} = 0.367\ nm$.

[5]

c) Below the Curie temperature (T_c), the BCC phase of iron behaves as a ferromagnet. In terms of the magnetic structure of the material, explain the transition which occurs as the temperature is increased above T_c and the temperature dependence of the magnetisation above this temperature.

[4]

d) Given that the Curie temperature of Iron is 770ºC, and considering the energetic balances in the magnetic structure at $T \approx T_c$, estimate the internal exchange field (B_{ex}) of mutually interacting magnetic moments. (The magnetic moment of one atom, p_m, is $\approx 2 \times 10^{-23}$ Am^2)

[3]

9 a) Describe what is meant by *extrinsic* and *intrinsic* charge carriers in a semiconductor. Which of these carrier types is expected to be prevalent at low temperatures?

[5]

b) A silicon sample is doped with 5×10^{19} donors per cm^3. Assuming that the intrinsic carrier density, n_i, at room temperature is 1.5×10^{16} per cm^3, and that all impurities are shallow, calculate both the resultant electron (n) and hole (p) concentration densities.

[5]

c) Considering the contributions of both *extrinsic* and *intrinsic* charge carriers, sketch a graph of how the electron density (n) and hole density (p) would thus vary as a function of temperature in such a semiconductor, going from 0K up to several hundred degrees K.

[5]

END OF PAPER