With effect from 2004 the format of Third Year exam papers has changed. Students must answer EVERY question from section A and TWO questions from section B. You may assume that section B questions will be broadly similar questions from previous years, but here are some sample section A questions to show roughly what you can expect.

The numbers in square brackets in the right-hand margin indicate the provisional allocation of maximum marks per sub-section of a question.

Mass of the electron	m_{e}	=	9.11×10^{-31} kg
Charge on the electron	e	=	-1.602×10^{-19} C
Permittivity of free space	ϵ_0	=	8.854×10^{-12} F m^{-1}
Permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
Boltzmann's constant	k_{B}	=	1.38×10^{-23} J K^{-1}
Planck's constant/2π	$\hbar$	=	1.05×10^{-34} J s

SECTION A

[Part marks]

1. Define the terms *lattice* and *basis* as applied to the structure of crystals. Sketch a unit cell of the sodium chloride crystal, and state what lattice and basis will form the structure. **[5]**

   The nearest-neighbour separation of ions in sodium chloride is 0.28 nm. Make an order-of-magnitude estimate of the binding energy per ion pair by computing the electrostatic energy of one pair of ions at that separation. **[2]**

2. Write down an expression for the separation of the (hkl) planes in a cubic crystal with lattice parameter a. **[2]**

   In an x-ray diffraction experiment on a crystal of the alkali-buckminsterfullerine $\mathrm{Rb_3C_{60}}$ using a wavelength of 0.09 nm peaks were seen at angles of 6.19, 7.15, 10.12, 11.86 and 12.40 degrees away from the straight-through direction. The crystal is known to be face-centred cubic: what is its lattice parameter? **[4]**

3. Write down an expression for the group velocity of an electron in a crystal in terms of its energy and wavevector. **[2]**

   An electron in a band in a one-dimensional metal in which the energy depends on the wavevector according to $E(k) = -2A\cos(ka)$ is subjected to a small electric field $\mathcal{E}$. Write down the equation of motion of the electron in the absence of scattering, integrate it with respect to time, and hence describe the motion of the electron under the influence of the field under these conditions. **[5]**

4. Sketch the variation of the number of carriers with temperature in a doped semiconductor. What experiment would you carry out to determine the sign of the majority carriers? **[5]**

The band gap of silicon is 1.1 eV. Estimate the ratio of the electrical conductivity of undoped silicon at 373 K to that at 273 K. **[2]**

5. Sketch the variation of magnetisation $\mathcal{M}$ as a function of applied field $\mathcal{B}$ for an assembly of non-interacting spins at a fixed temperature. On the same diagram sketch the corresponding variation for a higher temperature, taking care to label your graph clearly. **[3]**

At high temperatures, T, the susceptibility of a paramagnet may be written as C/T. The effect of exchange interactions may be represent by an internal field $\mathcal{B}_{\text{int}} = \lambda\mathcal{M}$. Derive an expression for the susceptibility of a ferromagnet at high temperatures. **[3]**

6. According to the London equation, the current density $\mathcal{J}$ is related to the flux density $\mathcal{B}$ in a superconductor containing n carriers, each of charge q and mass m, per volume by $\nabla \times \mathcal{J} = -\frac{nq^2}{m}\mathcal{B}$. Show how this leads to a penetration depth $\lambda = \sqrt{\frac{m}{\mu_0 n q^2}}$. You may use the fact that for any vector field $\mathbf{f}$, $\nabla \times \nabla \times \mathbf{f} = \nabla(\nabla.\mathbf{f}) - \nabla^2\mathbf{f}$. **[4]**

Use reasonable values of the parameters involved to make an estimate of the value of λ. **[3]**

SECTION B

7. .. **[30]**

8. . **[30]**

9. . **[30]**

10. . **[30]**

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END OF PAPER