Note that these are answers to the exam questions, not complete solutions. Answers provided to questions requiring explanations do not represent complete solutions, and would not necessarily receive the full marks allocated on the exam paper. Many marks are given on the exam for ‘working’ (i.e. for showing that you understand the relevant physics), and a numerical answer alone is not always sufficient to gain full marks.

1.
(a) No. (Explanation required.)
(b) Yes. (Explanation required.)
(c) (i) \( E = 0 \).
(ii) \( |E| = \frac{Q}{2\pi \varepsilon_0 r^2} \), directed towards the central sphere.
(iii) \( E = 0 \).
(iv) \( |E| = \frac{3Q}{4\pi \varepsilon_0 r^2} \), directed towards the central sphere.
(d) \( +2Q \).
(e) \( \sigma = \frac{Q}{2\pi \alpha} \).
(f) Proof required.

2.
(a) Proof required.
(b) Proof required.
(c) \( V = \frac{\rho w^2}{2\kappa \varepsilon_0} + \frac{\rho wd}{\kappa_{SiO_2} \varepsilon_0} \).

3.
(a) Positive.
(b) Diagram required. (Hint: Don’t forget the force due to the induced electric field.)
(c) Proof required.
(d) Proof required.
4. (a) The magnetic field direction is parallel to the electron’s velocity (i.e. vertical).
(b) The magnetic field will be in the +x direction above the sheet, and in the −x direction below.
(c) (i) \( \mu_0 (2 \text{ mA}) = 2.5 \times 10^{-9} \text{Tm} \).
(ii) Zero.
(d) (i) Out of the page.
(ii) Proof required.
(iii) \( B = \frac{\mu_0 I}{2R} \).
(iv) 12.5 T.

5. (a) (i) Explanation required.
(ii) Explanation required.
(b) (i) Proof required.
(ii) \( \xi = -\frac{\mu_0 b}{2\pi} \ln \left( \frac{x + a}{x} \right) \alpha_0 \cos(\alpha t) \).
(iii) \( L = \frac{\mu_0 b}{2\pi} \ln \left( \frac{x + a}{x} \right) \).

6. Essay-type answer required.

7. (a) Explanation required.
(b) 16.
(c) Explanation required.
(d) States \((n, l, m_l)\) for \( n = 3, l = 0 \): (3,0,0) 
\( n = 3, l = 1 \): (3,1,-1), (3,1,0), (3,1,1) 
\( n = 3, l = 2 \): (3,1,-2), (3,1,-1), (3,1,0), (3,1,1), (3,1,2) 
Since all these states have the same energy, the degeneracy is 9.
(e) Proof required.
(f) (i) Explanation required. Need to explain why Bohr assumed that \( 2\pi r = n\lambda \), and how treating the electron as a de Broglie wave leads to \( L = n \hbar \).
(ii) In the ground state \( L = \hbar = pr \), so \( p = \hbar / r \). Need to show how this leads to an inconsistency with the uncertainty principle.
8.

(a) Proof required.

(b) 4.07 m/s.

(c) 2.225 MeV. The binding energy of the electron in hydrogen is 13.6 eV. Typical nuclear binding energies are thus much larger than atomic binding energies. This is due to the much greater strength of the strong nuclear force, compared to the electromagnetic force.

(d) (i) $X = ^4_2He$ (i.e. X is an alpha particle).
(ii) $1.68 \times 10^{19}$.
(iii) $2.99 \times 10^9$ years.