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.

**Question 1**

(a) (i) Electrons have been removed.

(ii) \(3 \times 10^{10}\) electrons removed.

(b) \(-1.1 \times 10^{-8}\) C. (Use Coulomb’s law and don’t forget the sign.)

(c) (i) Negative \(x\) direction.

(ii) Positive \(x\) direction.

(iii) In the \(+x\) or \(-x\) direction, depending on the exact point on the \(x\) axis.

(iv) \(x = -1.82\) m (where \(x = 0\) is the location of particle A).

**Question 2**

(a) (i) Zero.

(ii) \(1.0 \times 10^{-17}\) Nm.

(iii) \(-10^{-17}\) J. (The potential energy decreases.)

(b) (i) The electric field inside a conductor in electrostatic equilibrium is always zero. If it was something other than zero, the free charges in the conductor would move around and the conductor would not be in electrostatic equilibrium.

(ii) \(-2Q\). (Justification required.)

(iii) \(-5Q\). (Justification required.)

(iv) \(E = 5Q/(4\pi\varepsilon_0 r^2)\). (Derivation required.)

(v) \(-5Q\).

(vi) None.

(vii) \(-5Q\).

**Question 3**

(a) (i) Upwards (opposite to the field direction).

(ii) \(B\) is at a higher electric potential.

(iii) 5 V.
(b) (i) In the 4.00 Ω resistor: 2.00 A. In the 3.00 Ω resistor: 1.33 A. In the 6.00 Ω resistor: 0.667 A. (Use Kirchhoff’s rules.)

(ii) $V_b - V_a = -4V$.

(iii) 24.0 W.

(iv) 5.33 W.

**Question 4**

(a) $2.1 \times 10^{-13}$ N, directed out of the page.

(b) (i) $1.9 \times 10^5$ m/s.

(ii) 9.9 mm.

**Question 5**

(a) (i) Into the page.

(ii) Proof required.

(iii) Proof required.

(iv) Explanation and proof required.

(b) $b < a = c = d$

**Question 6**

(a) $1.5 \times 10^{-3}$ V.

(b) (i)

$$
\epsilon - L \frac{di}{dt} - iR = 0.
$$

(ii) Proof required. Hint: differentiate the given expression for $i(t)$ with respect to time and check that it satisfies the equation in part (i).

(iii)

$$
V = -L \frac{di}{dt} = -\epsilon e^{-(R/L)t}.
$$

(iv) Approximately one time-constant, or $\tau = L/R = 2.5 \times 10^{-11}$ s.

(c) Explanation required.

**Question 7**

(a) $3.38 \times 10^{-19}$ J, or 2.11 eV.

(b) $2.96 \times 10^{21}$ photons per second.
(c) \(1.687 \times 10^{-27}\) kg.

Question 8

(a) This is Bragg diffraction. The shaded planes represent potential surfaces within the crystal structure, from which x-rays are reflected. Use a diagram to show the path difference between two rays. (Don’t forget that \(\theta\) is the angle between the ray and the plane, not the angle between a normal to the plane and the ray.)

(b) \(\sim 30\) pm. (Could also be 15, 10, 7.5 etc. Why?)

(c) \(5.81^\circ\).

Question 9

(a) 36 pm.

(b) \(K_\alpha \approx 17\) keV, \(K_\beta \approx 19\) keV.

(c) Sketch required. Graph shows a broad continuous spectrum going to zero intensity (cutting off) at \(\lambda = 36\) pm. On top of the continuous spectrum are two sharp peaks, corresponding to the characteristic x-rays. The \(K_\alpha\) peak is at a smaller wavelength than the \(K_\beta\) peak.

(d) (i) The broad distribution is due to Bremsstrahlung or ‘braking radiation’, in which electrons emit x-rays as they are accelerated near an atomic nucleus.

(ii) The sharp peaks occur when an electron is knocked out of the K shell, leaving a gap. Electrons in higher energy levels then cascade ‘down’ to fill the gap, losing energy in the process as x-rays. Electron transitions in atoms are quantised, so the emitted x-rays have only certain specific energies that depend on the energy-level structure of the atom. For example, a \(K_\alpha\) x-ray is produced when an electron makes a transition from the \(n = 2\) level to \(n = 1\).

Question 10

(a) For hydrogen, we have

\[ E_n = -\frac{m e^4}{8\epsilon_0^2 \hbar^2} \frac{1}{n^2} = -13.6 eV \frac{1}{n^2}. \]

This expression is derived for an atom with one electron (charge \(-e\)) and one proton (charge \(+e\)). He\(^+\) has two protons and one electron. In the derivation of the above expression, both the electron charge and the total nuclear charge are squared, so to adapt the expression for He\(^+\) we must replace a factor of \(e^2\) in the expression with \((2e)^2\), to account for the increased nuclear charge. Thus, the 13.6 eV factor is multiplied by 4, to give 54.4 eV, and the energy for the \(n = 3\) level of He\(^+\) is \(-6.0\) eV. (Note that while the above formula is easily generalised for one-electron, multi-proton ions, it cannot be easily generalised for multi-electron atoms, since if we add more electrons we need to include the electrostatic potential energy between each pair of electrons in deriving an appropriate formula.)
(b) Energy: 40.8 eV. Wavelength: $3.05 \times 10^{-8}$ m.

(c) Sketch required. (6 different transitions are possible.)

**Question 11**

(a) 24.8 MeV.

(b) Explanation required.

(c) $\frac{4}{3}$He. (i.e. element X is an alpha particle – a Helium nucleus.)

(d) (i) $2.0 \times 10^{20} + 1.4 \times 10^{21} = 1.6 \times 10^{21}$.

(ii) 13.5 billion years ($1.35 \times 10^{10}$ yr.)