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| **1.** | (a) | M1: E = hf =  M2: = (6.63 x 10-34 x 3 x 108)/0.002 = 9.9 x 10-23 J |
|  | (b) | M3: λ =  M4: = (6.63 x 10-34 x 3 x 108)/(9.9 x 10-19) = 9.9 x 10-19 J = 2.01 x 10-7 m  M5: both answers to 2 – 3 sf with no rounding errors  [5] |
| **2.** | (a) | M1: hf = E + so E = hf -  M2: = (6.63 x 10-34 x 9.5 x 1014) – 0.5 x 9.11 x 10-31 x (2.9 x 105)2 = 5.92 x 10-19 J  M3: Per mole = 5.92 x 10-19 x 6.02 x 1023 = 356 kJmol-1 (2 – 3 sf, no rounding errors) |
|  | (b) | M4: = E + but maximum wavelength gives = 0 so = E so λ =  M5 = (6.63 x 10-34 x 3 x 108)/(5.92 x 10-19) = 3.37 x 10-7 m (2 – 3 sf, no rounding errors)  Max 1 mark lost for sf or rounding errors  [5] |
| **3.** | (a) | M1: For electron Δp = mΔv = +4.55 x 10-28 so Δp of photon = -4.55 x 10-28 J  M2: For photon original p = = 1.275 x 10-27  M3: so final p = 1.275 x 10-27 - 4.55 x 10-28 = 8.2 x 10-28  M4: so final λ = = 8.09 x 10-7 m = 809 nm  MAX 3; -1 per error, max -1 if answer not 2-3 sf or rounding errors) |
|  | (b) | M4: Compton effect shows that photons (waves) have momentum, which is a property of particles  M5: Photoelectric effect shows that photons act individually, which is a characteristic of particles  [5] |
| **4.** | (a) | M1: Davisson-Germer observed a diffraction pattern from a beam of electrons  M2: hence electrons have wave-like properties |
|  | (b) | M3: ;  M4: this means that it is not possible to know the precise position and momentum of a particle at the same time  M5: showing that electrons do not obey classical mechanics  [5] |
| **5.** | (a) | M1: λ =  M2 = 6.63 x 10-34 / (9.11 x 10-31 x 150,000) = 4.85 x 109 m (2 – 3 sf, no rounding errors) |
|  | (b) | M3: The de Broglie wavelength shows that all particles have wave-like properties  M4: Electrons in atoms behave as standing waves  M5: The de Broglie wavelength is used to derive the Schrodinger equation  [5] |
| **6.** | (a) | M1: mvr = |
|  | (b) | M2: F =  M3: F = so =  M4: so r =  M5: and KE = =  M6: PE = -  M7: so U = KE + PE = - = -  M8: so U = -()  M9: clarity and layout |
|  | (c) | M10: ΔU = () - () =  M11: = so = so = |
|  | (d) | M12: = RH =  M13: So λ = = 4.1 x 10-7 m (must be 2sf) |
|  | (e) | M14: In He, z = 2 so z2 = 4  M15: so RHe = 4 x RH = 4.4 x 107 m-1  [15] |
| **7.** | (a) | **M1: 2**ψ = 2nd derivative of ψ in 3D or + +  M2: Ψ = wavefunction AND λ = wavelength of wave |
|  | (b) | M3: KE = and PE = -  M4: so U = KE + PE = -  M5: U + = so v2 =  **M6: 2**ψ + ψ = 0  **M7: 2**ψ + = 0  M8: λ = **so 2**ψ + = 0  2ψ + = 0 |
|  | (c) | M10: Eigenfunction = wavefunctions which are solutions to the Schrodinger equation (orbitals)  M11; Eigenvalue = total energy of the electron in the wavefunction |

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|  | (d) | M12: If n = 4, l can be 0, 1, 2 or 3  M13: If l = 0, ml = 0 If l = 1, ml = -1, 0 or 1  M14: if l = 2, ml = -2, -1, 0, 1 or 2, if l = 3, ml = -3, -2, -1, 0, 1, 2 or 3  M15: total number of eigenfunctions = 16  [15] | | | |
| **8.** | (a) |  | | | M1: potential energy on y-axis and internuclear distance on x-axis  M2: E = 0 when r approaches infinity, reaches a minimum and then approaches infinity as r approaches 0  M3: large distance: zero attraction; as distance increases, attraction increases until the most stable distance is reached, then repulsion between electrons dominates and potential energy increases  M4: bond energy = minimum value of E on graph  M5: bond length = value of r when E is at minimum value  [5] |
| **9.** | (a) |  | M1: evidence of a σ-bond  M2: evidence of a π-bond above and below the internuclear axis  M3: evidence of a π-bond in front of and behind the internuclear axis  M4: σ-bond = overlap of orbitals along the internuclear axis  M5: π-bond = overlap of orbitals either side of the internuclear axis | | |
|  | (b) |  | | M6: Hybridisation = mixing of atomic orbitals to improve bonding efficiency  M7: I promotes 2 electrons from p into empty d to increase bonding capacity from 1 to 5  M8: so 6 occupied orbitals = sp3d2 hybridisation  M9: so shape is a distorted octahedron with 1 lone pair (square-based pyramid)  M10: so bond angle is around 87 – 88o  [10] | |

**TOTAL 70 MARKS**