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| **1.** | (a) | M1: E = hf = $\frac{hc}{λ}$M2: = (6.63 x 10-34 x 3 x 108)/0.002 = 9.9 x 10-23 J |
|  | (b) | M3: λ = $\frac{hc}{E}$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 mM5: both answers to 2 – 3 sf with no rounding errors[5] |
| **2.** | (a) | M1: hf = E + $\frac{mv^{2}}{2}$ so E = hf - $\frac{mv^{2}}{2}$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 JM3: Per mole = 5.92 x 10-19 x 6.02 x 1023 = 356 kJmol-1 (2 – 3 sf, no rounding errors) |
|  | (b) | M4: $\frac{hc}{λ}$ = E + $\frac{mv^{2}}{2}$ but maximum wavelength gives $\frac{mv^{2}}{2}$ = 0 so $\frac{hc}{λ}$ = E so λ = $\frac{hc}{E}$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 JM2: For photon original p = $\frac{h}{λ}$ = 1.275 x 10-27M3: so final p = 1.275 x 10-27 - 4.55 x 10-28 = 8.2 x 10-28M4: so final λ = $\frac{h}{p}$ = 8.09 x 10-7 m = 809 nmMAX 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 particlesM5: 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 electronsM2: hence electrons have wave-like properties |
|  | (b) | M3: $ΔpΔx\geq \frac{h}{4π}$; M4: this means that it is not possible to know the precise position and momentum of a particle at the same timeM5: showing that electrons do not obey classical mechanics[5] |
| **5.** | (a) | M1: λ = $\frac{h}{mv}$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 propertiesM4: Electrons in atoms behave as standing wavesM5: The de Broglie wavelength is used to derive the Schrodinger equation[5] |
| **6.** | (a) | M1: mvr = $\frac{nh}{2π}$ |
|  | (b) | M2: F = $\frac{mv^{2}}{r}$M3: F = $\frac{ze^{2}}{4πε\_{0}r^{2}}$ so $\frac{mv^{2}}{r}$ = $\frac{ze^{2}}{4πε\_{0}r^{2}}$M4: so r = $\frac{ze^{2}}{4πε\_{0}mv^{2}}$ M5: and KE = $\frac{mv^{2}}{2}$ = $\frac{ze^{2}}{8πε\_{0}r}$M6: PE = -$\frac{ze^{2}}{4πε\_{0}r}$ M7: so U = KE + PE = $\frac{ze^{2}}{8πε\_{0}r}$ - $\frac{ze^{2}}{4πε\_{0}r}$ = -$\frac{ze^{2}}{8πε\_{0}r}$M8: so U = -$\frac{z^{2}e^{4}m}{8ε\_{0}^{2}h^{2}}$($\frac{1}{n^{2}}$)M9: clarity and layout |
|  | (c) | M10: ΔU = $\frac{z^{2}e^{4}m}{8ε\_{0}^{2}h^{2}}$($\frac{1}{n\_{f}^{2}}$) - $\frac{z^{2}e^{4}m}{8ε\_{0}^{2}h^{2}}$($\frac{1}{n\_{i}^{2}}$) = $\frac{z^{2}e^{4}m}{8ε\_{0}^{2}h^{2}}\left(\frac{1}{n\_{f}^{2}}-\frac{1}{n\_{i}^{2}}\right)$M11: = $\frac{hc}{λ}$ so $\frac{1}{λ}$ = $\frac{z^{2}e^{4}m}{8ε\_{0}^{2}h^{3}c}\left(\frac{1}{n\_{f}^{2}}-\frac{1}{n\_{i}^{2}}\right)$ so $R\_{H}$ = $\frac{z^{2}e^{4}m}{8ε\_{0}^{2}h^{3}c}$ |
|  | (d) | M12: $\frac{1}{λ}= R\_{H}\left(\frac{1}{n\_{f}^{2}}-\frac{1}{n\_{i}^{2}}\right)$ = RH$\left(\frac{1}{4}-\frac{1}{36}\right)$ = $\frac{2R\_{H}}{9}$M13: So λ = $\frac{9}{2R\_{H}}$ = 4.1 x 10-7 m (must be 2sf) |
|  | (e) | M14: In He, z = 2 so z2 = 4M15: so RHe = 4 x RH = 4.4 x 107 m-1[15] |
| **7.** | (a) | **M1:** $∇$**2**ψ = 2nd derivative of ψ in 3D or $\frac{d\_{2}Ψ}{dx^{2}}$ + $\frac{d\_{2}Ψ}{dy^{2}}$ + $\frac{d\_{2}Ψ}{dz^{2}}$M2: Ψ = wavefunction AND λ = wavelength of wave |
|  | (b) | M3: KE = $\frac{mv^{2}}{2} $ and PE = -$\frac{ze^{2}}{4πε\_{0}r}$M4: so U = KE + PE = $\frac{mv^{2}}{2}$ - $\frac{ze^{2}}{4πε\_{0}r}$M5: U + $\frac{ze^{2}}{4πε\_{0}r}$ = $\frac{mv^{2}}{2}$ so v2 = $\frac{2\left(U + \frac{ze^{2}}{4πε\_{0}r}\right)}{m}$**M6:** $∇$**2**ψ + $\frac{4π^{2}}{λ^{2}}$ ψ = 0**M7:** $∇$**2**ψ + $\frac{4m^{2}v^{2}π^{2}}{h^{2}}$ = 0M8: λ = $\frac{h}{mv}$ **so** $∇$**2**ψ + $\frac{4m^{2}v^{2}π^{2}}{h^{2}}$ = 0$M9: ∇$2ψ + $\frac{8\left(U + \frac{ze^{2}}{4πε\_{0}r}\right)mπ^{2}}{h^{2}}$ = 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 3M13: If l = 0, ml = 0 If l = 1, ml = -1, 0 or 1M14: if l = 2, ml = -2, -1, 0, 1 or 2, if l = 3, ml = -3, -2, -1, 0, 1, 2 or 3M15: total number of eigenfunctions = 16[15] |
| **8.** | (a) |  | M1: potential energy on y-axis and internuclear distance on x-axisM2: E = 0 when r approaches infinity, reaches a minimum and then approaches infinity as r approaches 0M3: large distance: zero attraction; as distance increases, attraction increases until the most stable distance is reached, then repulsion between electrons dominates and potential energy increasesM4: bond energy = minimum value of E on graphM5: bond length = value of r when E is at minimum value[5] |
| **9.** | (a) |  | M1: evidence of a σ-bondM2: evidence of a π-bond above and below the internuclear axisM3: evidence of a π-bond in front of and behind the internuclear axisM4: σ-bond = overlap of orbitals along the internuclear axisM5: π-bond = overlap of orbitals either side of the internuclear axis |
|  | (b) |  | M6: Hybridisation = mixing of atomic orbitals to improve bonding efficiencyM7: I promotes 2 electrons from p into empty d to increase bonding capacity from 1 to 5M8: so 6 occupied orbitals = sp3d2 hybridisationM9: 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**