Q1 (i) True (Kinetic energy of electrons gets converted to heat energy of work piece)

(ii) ~~True~~ False (Energy gets absorbed and melts and vaporizes the workpiece at a certain distance from the top)

(iii) True (To avoid collisions with the air molecules present in the atmosphere)

(iv) True (Similar to laser beam, the theoretical limit of the focal spot diameter is λ) (Actual focal spot size is influenced by various other factors)

(v) False ($\delta \propto V^2$, so it increases to 4 times)

(vi) False (it depends on voltage applied and density of the material)

(vii) False (Electron beam is generated by thermionic emission)

(viii) Electron beam removes material by heating, melting and vapourizing whereas an ion beam removes material atom by atom from workpiece using kinetic energy and momentum of the ions.

(ix) An ion beam is produced by ionizing, i.e. removing an electron from an atom by electron bombardment. For this, electrons are produced by thermionic emmission from a hot filament, then these electrons are passed through the sample atoms to generate ions. These ions are then accelerated across a high voltage supply and allowed to hit the target.

(x.) An Ion-beam can produce smaller features because it removes material atom by atom knocking them off (sputtering process) whereas an electron-beam which works by heating, melting and vapourizing the work material has a larger reach and operates on atoms in bulk.

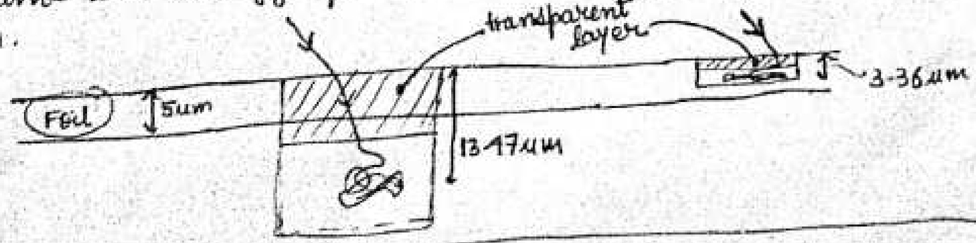
Q2 For an electron beam at 100 kV

$\delta = 13.47\ \mu m$

For an electron beam at 50 kV

$\delta = 3.36\ \mu m$

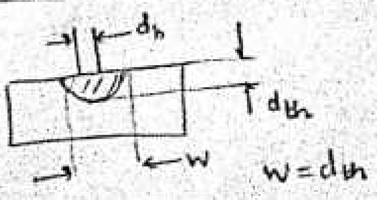
So, for the electron beam at 100kV, the 5um tungsten foil just acts as the transparent layer and it lacks the region beneath that, that will actually get heated up, melt and vaporize. This isn't the case with 50kV beam and the energy gets absorbed completely and the hole can be made.



Q3 kerf-width, $w = 2\sqrt{\frac{K' d_b}{v}}$

$= 2\sqrt{6\times10^{-5} \times \frac{0.1\times10^{-3} \times 60}{12}}$ m

$= \underline{0.346\ mm}$



Now, let for a small time Δt,

Volume of material removed $= (v\Delta t)\,W d$

$$= \frac{12\,m}{60\,s} \times \Delta t\,s \times 0.346\times10^{-3}\,m \times 0.5\times10^{-3}\,m$$

$$\therefore MRR = 3.46\times10^{-8}\,\frac{m^3}{s} = 3.46\times10^{-8}\times10^{9}\times60\,\frac{mm^3}{min}$$

$$\Rightarrow MRR = 2076\,\frac{mm^3}{min}$$

$\therefore$ Power Required $= 12\times2076\,W$

$= 24.912\,KW$

Q4

$$d_{th} = 2\sqrt{\frac{164}{19300\times140}\times\frac{0.0001}{V}}$$

$$MRR = \frac{10,000}{12}\,\frac{mm^3}{min}$$

$$= 833.33\,\frac{mm^3}{min}$$

(5) $w = 50\,\mu m$

$\Rightarrow 50\times10^{-6} = 2\sqrt{\dfrac{19}{4510\times519}\dfrac{d_b}{v}}$

$\Rightarrow \boxed{\dfrac{d_b}{v} = 7.699\times10^{-5}}$

$\Delta T^* = \Delta T_b + \dfrac{(L_f + mL_v)}{C_p}$

$= 3260 + \dfrac{(437 + 0.65\times9000)}{0.519}$

$\boxed{\Delta T^* = 15373.68°C}$

$\eta P = wtv\rho C_p \Delta T^*$

$\Rightarrow 0.1\times5000 = 50\times10^{-6}\times1\times10^{-3}\times v\times4510\times519\times15373.68$

$\Rightarrow v = 0.277\ m/s$

$\Rightarrow \boxed{v = 16.673\ \dfrac{m}{min}}$

$\therefore d_b = 7.699\times10^{-5}\times0.277$

$\Rightarrow \boxed{d_b = 21.326\,\mu m}$

---

(6) ~~$d_b = 0.5\,mm$~~

~~$w = 2\sqrt{\dfrac{226\times0.0005}{2700\times900\times v}}$~~

~~$\Rightarrow w\sqrt{v} = 0.006431$ — (i)~~

$\Delta T^* = \Delta T_b + \dfrac{(L_f + mL_v)}{C_p}$

$= 2450 + \dfrac{397 + 0.5\times9492}{0.9}$ (Assuming $m' = 0.5$ (not given))

$= 8164.4°C$

$\eta P = wtv\rho C_p \Delta T^*$

$\Rightarrow 0.1\times50{,}000 = w\ 0.025\ v\ 2700\times900\times8164.4$

$\Rightarrow wv = 1.008\times10^{-5}$

Assuming $w = d_b$, we have,

weld-bead width = 0.5 mm

welding speed = 0.02016 m/s

$= 1.209\ \dfrac{m}{min}$

---

(7) $V = 0.1\,S\,\dfrac{M}{d}\,J\cos\theta$

$0.1\times2\times\dfrac{M}{d}J_1\cos10° = 0.1\times10\times\dfrac{M}{d}J_2\cos85°$

$\Rightarrow \dfrac{J_1}{J_2} = 0.442$

$\Rightarrow \dfrac{J_2}{J_1} = 2.259$

$\Rightarrow \dfrac{I_2}{I_1} = 2.259$ $\therefore$ current should be increased by 125%

Q8 $S \propto \sin^2\theta$

$\Rightarrow \frac{dS}{d\theta} \propto 2\sin\theta\cos\theta$

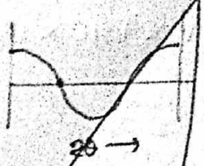
$\Rightarrow \frac{dS}{d\theta} \propto \sin 2\theta$

for $\frac{dS}{d\theta} = 0 \Rightarrow 2\theta = n\pi$, $n = 0, 1, 2 \ldots$

$\Rightarrow \theta = \frac{n\pi}{2}$, $n = 0, 1, 2, \ldots$

$\frac{d^2S}{d\theta^2} \propto 2\cos 2\theta < 0$

$\Rightarrow 2\theta \in \left(\frac{\pi}{2}, \frac{3\pi}{2}\right)$



$\Rightarrow \theta \in \left(\frac{\pi}{4}, \frac{3\pi}{4}\right)$

$\therefore \theta = \frac{\pi}{2}$

$\therefore$ S = maximum for $\theta = \frac{\pi}{2}$

Q8 $V \propto S\cos\theta$

$\Rightarrow V \propto \sin^2\theta\cos\theta$

$\Rightarrow \frac{dV}{d\theta} \propto 2\sin\theta\cos^2\theta + \sin^2\theta(-\sin\theta) = 0$

$\Rightarrow 2\sin\theta\cos^2\theta = \sin^3\theta$

$\Rightarrow 2\cos^2\theta = \sin^2\theta$

$\Rightarrow \tan\theta = \sqrt{2}$

$\Rightarrow \theta = 54.735°$

Q9 $V = 0.15\frac{M}{d} J\cos\theta$

$\Rightarrow 10 = 0.1 \times 0.5 \times \frac{28}{2.33} J\cos 10°$

$\Rightarrow J = 16.899$ mA/cm²

Q10 Power Input = 150 × 50 W

= 7500 W

Power Transferred to W/P = 7500 × 0.9 W

= 6750 W

Power Available for welding = 0.5 × 6750 W

= 3375 W

Let the welding speed be v m/s

So, in 1s, Volume of Material Removed = v × 0.004 × 0.006 m³

$= 2.4 \times 10^{-5}$ v

Mass of material removed in 1s = $\rho \Delta V$

= 0.192 v kg

Energy transferred for welding in 1 s = 3375 J

$\therefore \; mC\Delta T + mL_f = \Delta E$

$0.192v\,(500 \times 1500 + 300{,}000) = 3375$

$\Rightarrow v = 0.016\ m/s$

$\Rightarrow \boxed{v = 1\ \frac{m}{min}}$