SECTION A THE ENGINEER IN BUSINESS

1 Vodafone is a UK mobile network operator which does not act as a provider to virtual mobile operators who retail mobile services using another retailer's mobile network. Three is a UK mobile network operator which does act as a network provider to virtual mobile network operators. If Vodafone acquires Three, which of the following best describes its growth strategy:

(a) Growth by merger.

(b) Growth by backward vertical integration.

(c) Growth by forward vertical integration.

(d) Growth by diversification.

(e) None of the above. [2.5]

Answer: a. The difference in mobile customer types is irrelevant, this is (a), growth by merger.

2 Four equally sized companies make undersea cables for the European electricity industry. They make high rates of return. When one firm puts down its prices, the other three immediately follow. This is likely to be an example of what type of pricing behaviour?

(a) Predatory Pricing.

(b) Collusive Pricing.

(c) Price Discrimination.

(d) Competitive Pricing.

(e) None of the above. [2.5]

Answer: b. price matching in conditions of high profits and low numbers of firms is likely collusive.

3 Which of these statements is consistent with the Marris theory of the firm?

(a) Firms in the financial services sector pay the employees a salary equal to the value of their output.

(b) Firms in the financial services sector have a sector specific experience.

(c) Firms in the financial services sector favour growth of sales over profit maximisation.

(d) Firms in the financial services sector rotate employees between clients to reduce their client specific knowledge.

(e) None of the above. [2.5]

Answer: c. a. is consistent with Neoclassical theory. b. is a reference to Chandler's work on the history of capitalism. c. is an application of the Marris model where managers maximised growth at the expense of profits. d. the deskilling of workers in order to capture surplus value for the firm is the Marxist theory of the firm.

4 Looking across all firms, which of the following situations is most favourable for firm growth?

(a) GDP rises by 1%, technological opportunity increases by 2%, managerial experience increases by 2%.

(b) GDP rises by 1%, technological opportunity increases by 1%, managerial experience increases by 2%.

(c) GDP rises by 1%, technological opportunity increases by 2%, managerial experience decreases by 3%.

(d) GDP rises by 1%, technological opportunity increases by 2%, managerial experience increases by 3%.

(e) None of the above. [2.5]

Answer: d. Technological opportunity and managerial experience both increase by largest amount.

5 Amazon tracks its performance against approximately 500 measurable goals, with nearly 80% focused on customer objectives. For example, Amazon has metrics showing that a 0.1 second delay in page rendering can lead to a 1% drop in customer activity. Which marketing philosophy does this example best describe?

(a) Product-oriented.

(b) Selling-oriented.

(c) Promotion-oriented.

(d) Customer-oriented.

(e) None of the above. [2.5]

Answer: d. Amazon prioritizes customer-related metrics to enhance customer experience. This is an example of customer-oriented marketing philosophy.

6 Coca-Cola's "Share a Coke" campaign replaced its iconic logo on bottles with popular names and phrases, allowing customers to find bottles with their own name or the names of

friends and family. The campaign encouraged people to share these personalized bottles, creating memorable moments and strengthening emotional connections with the brand. Which stage of brand management does this campaign best exemplify?

(a) Brand identity.

(b) Brand meaning.

(c) Brand relationship.

(d) Brand response.

(e) None of the above. [2.5]

Answer: c. By personalizing the product with names and phrases, the campaign encouraged customers to share meaningful moments with others, fostering stronger emotional ties to the brand. This exemplifying the brand relationship stage of brand management, which involves building and nurturing lasting connections with customers through meaningful engagement.

7 Spotify offers various subscription plans tailored to different customer needs, such as a free ad-supported tier, a premium individual plan, and a family plan. Which strategy does this example best describe?

(a) Market segmentation.

(b) Positioning.

(c) Targeting.

(d) Branding.

(e) None of the above. [2.5]

Answer: a. Spotify identifies different groups of users based on their preferences and needs, which is an example of market segmentation.

8 When Deepseek released its chatbot for download in January 2025, this was an example of managers following

(a) Porter's ideas about differentiation.

(b) Barney's ideas about leveraging core resources.

(c) McGrath's ideas about exiting opportunities at the right time.

(d) Prahalad and Hamel's ideas about engaging the workforce in innovation.

(e) Adner's ideas about ecosystem keystones. [2.5]

Answer: e.

9 When managers consider adopting one of Porter's generic strategies, their implicit assumption is

(a) They can identify opportunities to grow.

(b) They can increase willingness to pay among customers.

(c) They can achieve cost leadership.

(d) They can identify core competences.

(e) They must identify ways to differentiate from competitors. [2.5]

Answer: e. The other answers either have no direct relation to the "generic strategies" or are potential consequences of such an analysis, not underlying assumptions.

10 Which of the following is a product of VRIO analysis?

(a) Sources of temporary advantage.

(b) A BHAG.

(c) An ecosystem map.

(d) An analysis of the firm's activity system.

(e) A financial projection of future profits. [2.5]

Answer: a. A VRIO analysis produces an understanding of disadvantage, parity, temporary advantage, and unused advantage. The other answers do not relate to VRIO analysis.

END OF PAPER

3(a)

(i) The UN Bruntland Commission definition of sustainability is: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

Marks given, for contrasting the development needs of today with those for future generations, and for “without compromising” or similar words.

(ii) Stakeholders for this onshore wind decision might include:
→ the UK government, who has an interest achieving climate change targets and the power to regulate
→ the energy companies, who will need to operate the wind turbines, and have a strong voice with government
→ the electricity grid operator, who will need to connect the turbines to the grid and balance the generation loads, and have significant influence in the process
→ local communities, who may have concerns about the visual and noise impact of the turbines, and have some influence in the planning process.
→ turbine manufacturers, who will need to design and build the turbines, and will make money from this, and have some influence over when the turbines will be deployed.
→ environmental NGOs, who want to promote the deployment of renewables, but have less influence over the decision process.
→ future generations, who will be impacted by climate change and the decisions made today to deploy renewables, and have no agency
→ land owners, who might operate farms where the wind turbines will be sited, and have significant influence over the decision process.

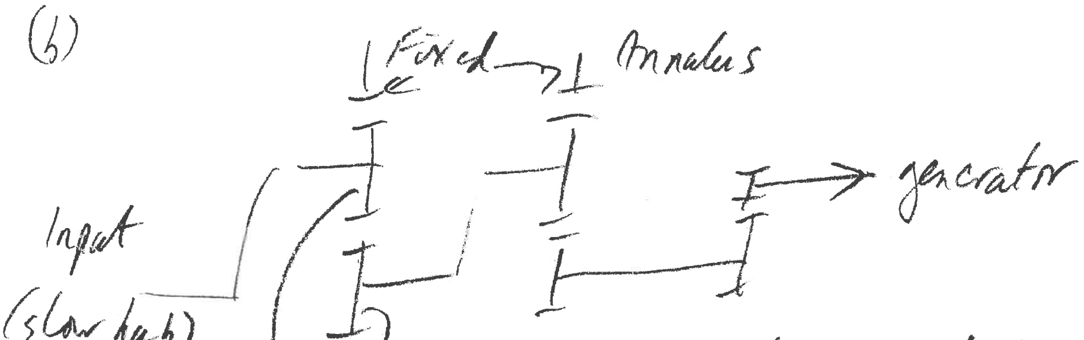
(iii) The synthesis table should take the form of the one below, with the same headings for the rows and columns. The positive and negative impacts can be different from those shown, but should be realistic for onshore wind turbines.

1(a) Tower - slender structure with bending fatigue & vibration critical.

- tubular structure easy to make & cheap
- steel also cheap ↑ eg rolled sheet → welding
- weight not so critical, recycling good for steel but significant embedded energy
- other materials, eg GFRP, seem reasonable to make in tubular sections but may not be stiff enough
- concrete seems plausible but may be harder to construct in remote situation.

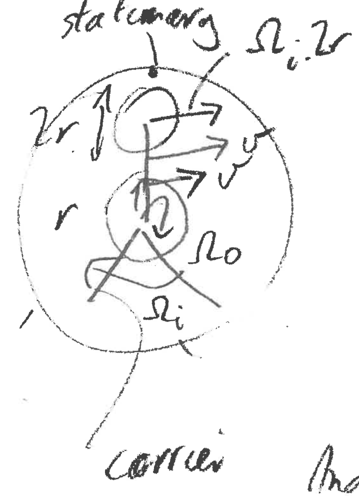
Blade - weight more critical as at top of tower
⇒ CFRP, perhaps GFRP or natural composites
- again fatigue & vibration are key concerns
- worth putting in extra effort to have a more complex structure (eg spar, shell, stiffeners) at the expense of more challenging manufacture & higher cost
- concerns about recyclability of large tonnage of composite
⇒ natural materials?
- large vacuum infusion moulding can give large composite structures but need to consider joining of parts

1 (b)



- multistage to get big step-up in speed
- epicyclic at early high torque stages to keep size, weight & cost down
- final stage is low torque so easier to design ⇒ parallel shafts

(c) (i)



From sun, $v = \Omega_0 r$

From planet $v = 2\,\Omega_i . 2r$

$$\Rightarrow \frac{\Omega_0}{\Omega_i} = 4$$

And with the Ωs going in the same direction

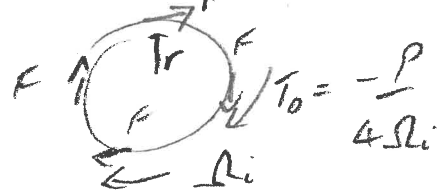
(ii) Input $T_i \Omega_i = P \Rightarrow T_i = \frac{P}{\Omega_i}$

Output $T_0 \Omega_0 = -P$, minus sign as power out of output

$$\Rightarrow T_0 = \frac{-P}{\Omega_0} = \frac{-P}{4\Omega_i}$$

(iii) $4F.r + T_0 = 0$ (# planets)

$$\Rightarrow F = -\frac{T_0}{4r} = \frac{P}{16 r \Omega_i}$$



1 (c) (iii)

$$\sigma_b = \frac{2.5F}{Wm}$$

$$F = \frac{P}{16 r \Omega_i} \Rightarrow 300 \times \cancel{10^6} = \frac{2.5 \cdot 2 \times \cancel{10^6}}{16 \cdot r \cdot 20 \times 2\pi/60} \cdot \frac{1}{0.1 \cdot 2r/60}$$

$\uparrow w$ $\uparrow m$

$$\Rightarrow r^2 = \frac{3600 \times 5}{16 \times 40\pi \times 0.2} \cdot \frac{1}{300} \Rightarrow r = 0.39\,m$$

2P8 - Wind turbines - Crib.

(a). $U = 10$ m/s, $a = 1/3$ $u = (1-a)U = \frac{2}{3} \times 10\frac{m}{s} = \frac{20}{3}$ m/s.

$= 6.67$ m/s.

(b) $C_T = 4\left(\frac{1}{3}\right)\left(1-\frac{1}{3}\right) = \frac{8}{9}$ $\Rightarrow$ $\delta T = \frac{1}{2}\rho U^2 2\pi r \delta r\ C_T$

$$= \frac{1}{2}\left(1\frac{kg}{m^3}\right)\left(10\frac{m}{s}\right)^2 \left(2\pi \times 50m \times 0.5m\right) \times \frac{8}{9}$$

$$= \frac{200}{9} \times 100\pi \text{ N}.$$

$$= 6978 \text{ N}.$$

(c) $C_L = 1.5$, $\delta L = \frac{1}{2}\rho V^2 Bc\delta r\ C_L = \delta T$ $B = 3$, $c = 10m$

$$\Rightarrow V = \left[\frac{\frac{1}{2}\rho U^2\ 2\pi r\ \delta r\ C_T}{\frac{1}{2}\rho\ Bc\delta r\ C_L}\right]^{1/2}$$

$$= U \cdot \left(\frac{2\pi r C_T}{BcC_L}\right)^{1/2} = 10 \text{ m/s} \cdot \left(\frac{2 \times 3.15 \times 50m \times 8/9}{3 \times 10m \times 1.5}\right)^{1/2}$$

$$= 24.9 \text{ m/s}.$$

(d). $\sin\phi = \frac{u}{V} = \frac{6.67 \text{ m/s}}{24.9 \text{ m/s}} = 0.267$

$\Rightarrow \phi = 0.271$ rad $\cong 15°$

$\cos\phi = 0.963 \approx 1.0$ with an error of about 3.7%.

So the small angle assumption is quite good.

The corresponding Ω is such that

$\Omega r = V\cos\phi$. $\Rightarrow$ $\Omega = \frac{24.9 \times 0.963 \text{ m/s}}{50m} = 0.480$ rad/s

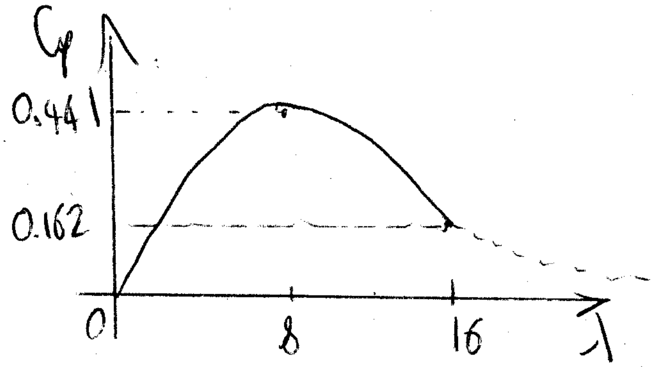
	Human and social capital (People)	Natural capital (Planet)	Manufactured capital (Prosperity)
Materials		(–) Large demand for critical materials (rare earths)	(–) Dependence on few rare-earth producing nations (–) Infrastructure needed for integration of mixed energy sources on grid
Energy	(+) Greater energy security, reduced dependence on fossil fuel imports	(+) Favourable energy payback time	(+) Local autonomy and stronger national energy industry
Environment	(–) Visual and acoustic intrusion	(+) Reduced carbon emissions of national electricity supply (–) Occupy large land area	
Legislation	(+) Contributes to national and international commitments to reduce carbon emissions		
Economics	(+) Can contribute to lower energy bills, given escalating fossil fuel prices		(+) Becoming competitive with fossil fuels
Society	(+) Renewable energy supported by some members of the public (–) Wind farms strongly opposed by some members of the public		(+) Creates jobs, replacing declining industries

P8 crib

b) A synchronous generator produces 3φ output voltage with frequency ∝ to angular speed ($\omega_s = 2\pi f/p$). So in the variable speed case, the frequency of the output voltage would vary, which is incompatible with a fixed frequency grid. Thus the power is rectified to DC, then inverted to 50Hz to match the grid. Permanent magnet generators have no brushes or slip-rings and so need less maintenance, which is an important factor in offshore wind. [3]

c) $C_p = 0.15\lambda e^{-\lambda/8}$ $\frac{dC_p}{d\lambda} = 0.15\left(e^{-\lambda/8} - \frac{\lambda}{8}e^{-\lambda/8}\right) = 0$

$\therefore$ $\lambda_{opt} = 8$ and $C_{p,max} = 0.15 \times 8 e^{-1} = 0.441$



At $\lambda = 16$, $C_p = 0.15 \times 16\, e^{-2} = 0.162$

At $\lambda = 0$, $C_p = 0$

[4]

d) i) $P = 1\,MW$ with $v = 8\,ms^{-1}$ $\Rightarrow$ $10^6 = \frac{1}{2} \times 0.441 \times 1.23\, A \times 8^3$

giving $A = 7201\,m^2$ and $R = 47.9\,m$

$\lambda = \frac{\omega R}{v} \Rightarrow 8 = \frac{\omega \times 47.9}{8}$ so $\omega = 1.34\ rad\,s^{-1}$ (12.8 rpm)

[2]

ii) Cage rotor induction generator so assume $\omega_r \approx \omega_s = \frac{2\pi \times 50}{10} = 31.4 \text{ rads}^{-1}$

$\therefore$ Gearbox ratio is $\frac{31.4}{1.34} = \underline{23.4:1}$

At $v = 12\text{ms}^{-1}$, because speed is virtually fixed (it will speed up a very small amount c.f. $v = 8\text{ms}^{-1}$ as the slip goes slightly more negative)

$\lambda = \frac{1.34 \times 47.9}{12} = 5.35$ so $C_p = 0.15 \times 5.35\, e^{-5.35/8}$

$= 0.411$

$P = \frac{1}{2} \times 0.411 \times 1.23 \times 7201 \times 12^3 = 3.1 \text{ MW}$ [2]

iii) $I_2' = \frac{6600/\sqrt{3}}{0.2 + 0.15/(-0.01) + j1.6} = \frac{3811}{-14.8 + j1.6}$ so $I_2' = 256 \text{ A} \angle -174^\circ$

$P_{in} = \sqrt{3} \times 6600 \times 256 \cos(+174^\circ) = -2.9 \text{ MW}$ so $\underline{P_{out} = 2.9 \text{MW}}$

$Q_{in} = \sqrt{3} \times 6600 \times 256 \sin(+174^\circ) = 306 \text{ kVAr}$ so $Q_{out} = \underline{-306 \text{ kVAr}}$

[2]

(a) (i) $\frac{dw}{dt} = -\dot{m}_f g$ $\quad \dot{m}_f$ = fuel flow rate 1

$sfc = \frac{\dot{m}_f}{F_N} \Rightarrow \frac{dw}{dt} = -sfc\ g\ F_N$ 1

But $F_N = D = \frac{D}{L} L$ and $\frac{d}{dt} = \frac{ds}{dt}\frac{d}{ds}$ 1

$= V\frac{d}{ds}$

$\Rightarrow V\frac{dw}{ds} = -\frac{sfc\ g}{L/D} w \Rightarrow \ln\frac{w_{end}}{w_{start}} = \frac{-g\,sfc}{VL/D} s$ 1 (4)

assuming sfc, VL/D constant.

Hence $s = -\frac{V}{g}\frac{L/D}{sfc}\ln\frac{w_{end}}{w_{start}}$

(ii) $\eta_o = \frac{\text{work to aircraft}}{\text{energy from fuel}}$ 1

$= \frac{F_N V}{\dot{m}_f LCV} = \frac{1}{sfc}\frac{V}{LCV}$

$\Rightarrow \frac{V}{sfc} = \eta_o LCV$

$\Rightarrow s = -\frac{L/D}{g}\eta_o LCV \ln\left(\frac{w_{end}}{w_{start}}\right)$

Since $\eta_o = \eta_p \eta_{th}$ 1

$\Rightarrow s \propto \eta_p$ [redacted] (2)

(b) $\eta_p = \frac{\text{power to aircraft}}{\ldots}$ 1

(b) $\eta_p = \frac{\text{power to aircraft}}{\text{power to flow}}$ 1

$$= \frac{TV}{\Delta \dot{KE}} = \frac{\dot{m}(V_j - V)V}{\frac{1}{2}\dot{m}(V_j^2 - V^2)}$$ 1

$$= \frac{2(V_j - V)V}{(V_j - V)(V_j + V)} = \frac{2V}{V_j + V}$$ 1 (3)

(c) (i) $F_G = \dot{m}_c V_{jc} + \dot{m}_b V_{jb}$ 1

$$\overline{V_j}(\dot{m}_c + \dot{m}_b) = \dot{m}_c V_{jc} + \dot{m}_b V_{jb}$$

$$\frac{\dot{m}_b}{\dot{m}_c} = 1 \Rightarrow \dot{m}_b = \dot{m}_c = \dot{m}/2$$ 1

or $\dot{m} = \dot{m}_c + \dot{m}_b$

$$\Rightarrow \overline{V_j} = \frac{V_{jc} + V_{jb}}{2}$$

$$\Rightarrow F_G = \frac{\dot{m}}{2}(V_{jc} + V_{jb})$$

$$F_G = \dot{m}\overline{V_j}$$ 1

$$\dot{KE} = \frac{1}{2}\dot{m}_c V_{jc}^2 + \frac{1}{2}\dot{m}_b V_{jb}^2$$ 1

$$= \frac{1}{2}\frac{\dot{m}}{2}(V_{jc}^2 + V_{jb}^2)$$

$$V_{jc} = \alpha V_{jb}$$

$$\Rightarrow \dot{KE} = \frac{\dot{m}}{4} V_{jb}^2 (1 + \alpha^2)$$ 1

$$\overline{V_j} = \frac{V_{jc} + V_{jb}}{2} = \frac{V_{jb}(\alpha + 1)}{2}$$

$$V_j = \frac{V_{jc} + V_{jb}}{2} = \frac{V_{jb}(\alpha + 1)}{2}$$

$$\Rightarrow V_{jb} = \frac{2\bar{V}_j}{\alpha + 1}$$

$$\Rightarrow \dot{KE} = \frac{\dot{m}}{4} \frac{4\bar{V}_j^2}{(\alpha+1)^2}(1+\alpha^2)$$

$$= \frac{\dot{m}\bar{V}_j^2}{(\alpha+1)^2}(1+\alpha^2)$$

$$\Rightarrow \Delta\dot{KE} = \dot{m}\left[\bar{V}_j^2 \frac{1+\alpha^2}{(1+\alpha)^2} - \frac{V^2}{2}\right]$$

$$\eta_p = \frac{\text{power to a/c}}{\text{power to flow}} = \frac{V F_N}{\Delta\dot{KE}}$$

$$= \frac{V \dot{m}(\bar{V}_j - V)}{\dot{m}\left[\bar{V}_j^2 \frac{1+\alpha^2}{(1+\alpha)^2} - \frac{V^2}{2}\right]}$$

$(\div V^2)$

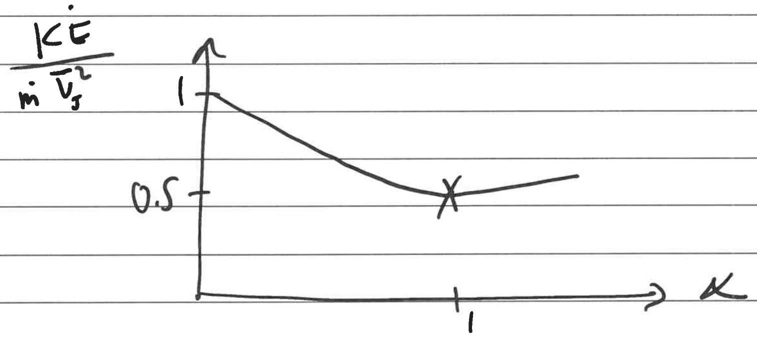
$$= \frac{\bar{V}_j/V - 1}{(\bar{V}_j/V)^2 \frac{1+\alpha^2}{(1+\alpha)^2} - \frac{1}{2}}$$

$$\Rightarrow \eta_p = \frac{\phi - 1}{\phi^2\left(\frac{1+\alpha^2}{(1+\alpha)^2}\right) - \frac{1}{2}}$$

(9)

(ii) $\alpha = 1$ is the optimum, as this

(ii) $\alpha = 1$ is the optimum, as this minimises the KE flux in the exhaust stream (which is waste). (or η_p explanation). 2

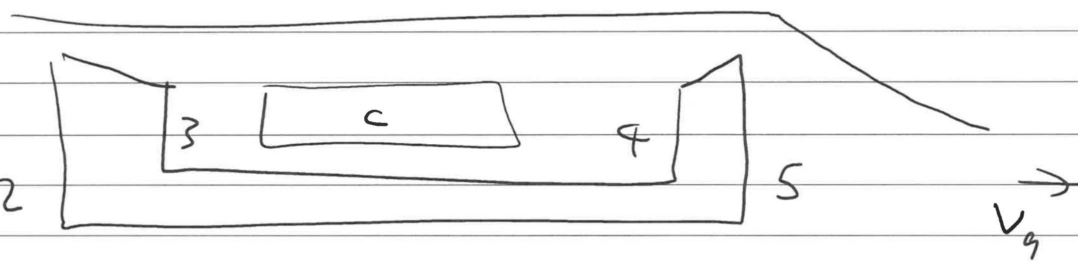


2 (4)

(iii) The inefficiency comes from the turbine and fan predominantly. So taking power out of the core flow and delivering it to the bypass means going through two main losses. 1
The larger those losses are, the less desirable it is to take power from the core flow and deliver it to the bypass stream. 1

$\Rightarrow$ As η decreases, the optimal α increases. 1 (3)

(a)



(2)

(b) $P_{02} = p_a \left(1 + \frac{\gamma-1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}}$ $\quad M = \frac{400}{\sqrt{\gamma R T_a}} = 1.33$

$T_{02} = T_a \left(1 + \frac{\gamma-1}{2} M^2\right)$

$P_{02} = 76.5\ kPa$

$T_{02} = 305\ K$

$$\eta_c = \frac{T_{03}^{is} - T_{02}}{T_{03} - T_{02}} = \frac{\left(\frac{P_{03}}{P_{02}}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\frac{T_{03}}{T_{02}} - 1}$$

$$\Rightarrow \frac{T_{03}}{T_{02}} = 1 + \frac{1}{0.85}\left[10^{\frac{\gamma-1}{\gamma}} - 1\right] = 2.095$$

$\Rightarrow T_{03} = \underline{\underline{639\ K}}$ (4)

(c) $\frac{\Delta h_0}{U^2} < 0.4$ per stage, n stages

$$\Rightarrow \frac{n \Delta h_0}{U^2} = \frac{h_{03} - h_{02}}{U^2} < 0.4n$$

(Take equality)

$$0.4n = 1005 \frac{639 - 305}{280^2} \approx 4.28$$

$\Rightarrow n = 10.7 \rightarrow$ $\underline{\underline{11 \text{ stages min}}}$ (2)

$\Rightarrow n = 10.7 \rightarrow$ <u>11 stages min</u> (2)

(d) $T_{04} = 1300\,K \qquad \eta_t^{is} = 0.9$

Comp work = turb work $\Rightarrow T_{04} - T_{05} = T_{03} - T_{02}$

$\Rightarrow T_{05} = 1300 - (639 - 305) = \underline{966\,K}$ 1

$$\eta_t = \frac{T_{04} - T_{05}}{T_{04} - T_{05}^{is}} = \frac{1 - T_{05}/T_{04}}{1 - \left(P_{05}/P_{04}\right)^{\frac{\gamma-1}{\gamma}}}$$ 1

$$\Rightarrow \frac{P_{04}}{P_{05}} = \left[1 - \frac{1}{\eta_t}\left(1 - \frac{T_{05}}{T_{04}}\right)\right]^{-\frac{\gamma}{\gamma-1}} = 3.24$$ 1

$P_{04} = 10\,P_{02} = 765\,kPa$ [no p loss in combustor] 1

$\Rightarrow P_{05} = \frac{765}{3.24} = \underline{\underline{236.1\,kPa}}$ (4)

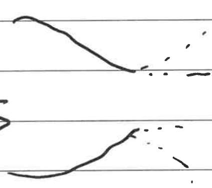
(e) $\frac{n\,\Delta h_0}{U^2} = \frac{1005(1300 - 966)}{300^2} < 2.0\,n$

(equality $\Rightarrow n = 1.86$) 1

$\Rightarrow n = 2$ (2)

Favorable pressure gradient $\Rightarrow$ fewer stages 1

(f)



5   9 $P_{09} = P_{05}$ (isentropic)

$P_9 = P_a$ (static)

$T_{09} = T_{05}$ (no heat/work)

$$T_9 = T_{09}\left(\frac{p_9}{p_{09}}\right)^{\frac{\gamma-1}{\gamma}} = T_{05}\left(\frac{p_a}{p_{05}}\right)^{\frac{\gamma-1}{\gamma}}$$ 1

$$= 966\left(\frac{26.5}{236.1}\right)^{\frac{\gamma-1}{\gamma}} = 517 \text{ K}$$ 1

$$c_p T_{09} = c_p T_9 + \frac{V_9^2}{2}$$ 1

$$\Rightarrow V_9 = \sqrt{2 \times 1005 \times (966 - 517)}$$

$$= \underline{\underline{950 \text{ m/s}}}$$ 1

Speed of sound $c = \sqrt{\gamma R T_9} = 456$ m/s 1

$\Rightarrow$ converging-diverging nozzle needed. (5)

(g) (i) Call position after reheat 6

$$T_{06} = T_{05} + 500 = 966 + 500 = 1466 \text{ K}$$ 1

$$T_9 = 1466\left(\frac{26.5}{236.1}\right)^{\frac{\gamma-1}{\gamma}} = 785 \text{ K}$$

$$V_9 = \sqrt{2 c_p (T_{09} - T_9)}$$

$$= \sqrt{2 \times 1005 \times (1467 - 785)}$$ 1

$$= \underline{\underline{1171 \text{ m/s}}}$$

$\Rightarrow$ + 23% thrust 1 (3)

(ii) Old fuel $\propto T_{04} - T_{03}$

$= 1300 - 639$

$= 661 \text{ K}$

New fuel $\propto (T_{04} - T_{03}) + (T_{06} - T_{05})$ 1

$\propto 661 + 500$

$\Rightarrow \dfrac{\text{new fuel}}{\text{old fuel}} \propto \dfrac{661 + 500}{661} = 1.76$ 1

76% increase in fuel used. 1 (3)

(iii) Combat aircraft or other where short dashes are needed. (1)

(a) Isentropic and $P_e = P_a$ (1)

$\Rightarrow T_e = T_a$

(b) $F_N = \dot{m}(V_J - V)$ 1

$P = \frac{1}{2}\dot{m}(V_J^2 - V^2)$ 1

$= \frac{1}{2}\dot{m}(V_J - V)(V_J + V)$ 1

$= \frac{1}{2}F_N(V_J + V)$

$\Rightarrow \frac{F_N}{P} = \frac{2}{V + V_J}$ 1 (4)

(c) $c = \sqrt{\gamma R T} = \sqrt{1.4 \times 287 \times 288}$

$= 340$ m/s 1

$\frac{F_N}{P} = \frac{2}{340 \text{ m/s}} = 5.88 \frac{\text{N}}{\text{kW}}$ 1

($\times 1000$ to ~~get~~ to N/kW)

[This works out as ~1 lbf/hp]

$F_N = \dot{m} V_J = \rho A_N V_J^2$ 1

$\Rightarrow A_N = \frac{F_N}{\rho V_J^2} = \frac{445 \times 10^3}{1.225 \times 340^2}$ (for ρ)

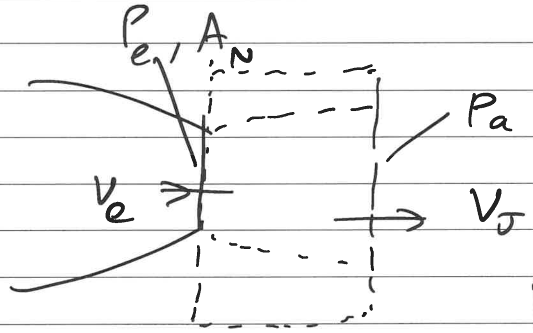
$= 3.142$ m^2 1

$\dot{m} = \rho_J A_J V_J$

$= 1.225 \times 3.142 \times 340$

$= \underline{\underline{1309\ kg/s}}$ 1 (5)

(d) (i)



2

$F_G = \dot{m} V_J$

$$F_N = \dot{m}(V_J - V) = F_G - \dot{m} V$$ 1

Momentum:

$$\dot{m} V_J - \dot{m} V_e = p_e A_N - p_a A_N$$ 1

$$\Rightarrow \frac{F_G + p_a A_N}{A_N p_{02}} = \frac{p_e A_N + \dot{m} V_e}{A_N p_{02}}$$ 1

Take $\dfrac{F_G + p_a A_N}{A_N p_{02}} = k$ (const) (5)

(ii) $$k = \frac{445 \times 10^3 + 101.3 \times 10^3 \times 3.142}{101.3 \times 10^3 \times 3.142}$$

$$= 2.398$$ 1

$$p_{02} = p_a \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$ 1

$$= 26.5 \times \left(1 + 0.2 \times 0.7^2\right)^{1.4/0.4}$$

$= 36.76 \text{ kPa}$ |

$F_G|_{cruise} = k P_{02} A_N - P_a A_N$ |

$= 3.142(2.398 \times 36.76 - 26.5)$

$= \underline{\underline{193.7 \text{ kN}}}$ | (5)

(iii) $\dfrac{\dot{m}\sqrt{C_p T_{02}}}{A_N P_{02}} = \dfrac{1309\sqrt{1005 \times 288}}{3.142 \times 101.3 \times 10^3}$ |

$= 2.213 \leftarrow$ same at cruise

$T_{02}|_{cruise} = T_a\left(1 + \dfrac{\gamma - 1}{2} M^2\right)$ |

$= 223(1 + 0.2 \times 0.7^2) = 244.9 \text{K}$

$\Rightarrow \dot{m}|_{cruise} = \left.\dfrac{2.213 A_N P_{02}}{\sqrt{C_p T_{02}}}\right|_{cruise}$

$= \dfrac{2.213 \times 3.142 \times 36.76 \times 10^3}{\sqrt{1005 \times 244.9}}$

$= \underline{515.2 \text{ kg/s}}$ |

$F_N = \dot{m}(V_J - V)$

$= F_G - \dot{m}V$ |

$= 193.7 \times 10^3$
$- 515.2 \times 0.7 \times \sqrt{1.4 \times 287 \times 223}$

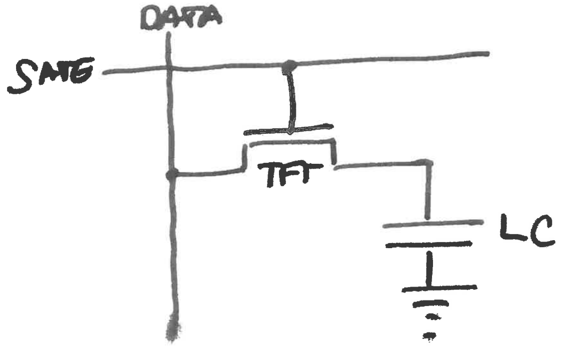
$= 145.[illegible] \times 10$

$\quad - 515.2 \times 0.7 \times \sqrt{1.4 \times 287 \times 223}$

$= \underline{85.75\ kN}$ 1 (5)

#

1 (a)



The TFT is there to allow a voltage to be set across the LC so that it switches. The TFT is then turned off so the voltage is retained while the other rows are programmed.

(b) If $V_{DS} << V_G - V_t$ then

$$I_{ds} \approx \mu \frac{W}{L} C_{ox} [V_{gs} - V_t] V_{ds}$$

$$R_{TFT} = \frac{\partial V_{ds}}{\partial I_{ds}}$$

$$R_{TFT} = \frac{1}{\mu \frac{W}{L} C_{ox} (V_{gs} - V_t)}$$

(c)(i) Charging follows an exponential, so we need

$$e^{-t/\tau} = 0.05$$

$$-\frac{t}{\tau} = \ln(0.05)$$

$$\tau = \frac{-t}{\ln(0.05)}$$

$$= \frac{-3\times10^{-6}}{\ln(0.05)}$$

$$\tau = 1\mu s = R_{TFT} C$$

No. of sub-pixels $p = 2560 \times 1600 \times 3 = 12\,288\,000$

Area of one sub-pixel LC $= A = \frac{0.9 . 0.288 . 0.18}{12\,288\,000}$

$$A = 3.80 \times 10^{-9} m^2$$

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

$$= \frac{8.854\times10^{-12} . 8 . 3.8\times10^{-9}}{10\times10^{-6}}$$

$$C = 2.70\times10^{-14} F$$

$$R_{TFT} = \frac{\tau}{C} = \frac{1\times10^{-6}}{2.7\times10^{-14}} = \underline{37.2 M\Omega}$$

(c)(ii)

$$\frac{W}{L} = \frac{1}{\mu R_{OFF} . C_{ox} . (V_{GS} - V_t)}$$

$$= \frac{1}{1\times10^{-4} . 37.2\times10^{6} . 6.64\times10^{-4} . (3-0.5)}$$

$$C_{ox} = \frac{\varepsilon_0 \varepsilon_r}{d}$$

$$= \frac{8.854\times10^{-12} . 7.5}{100\times10^{-9}}$$

$$C_{ox} = 6.64\times10^{-4}\ Fm^{-2}$$

$$\therefore \frac{W}{L} = 0.162$$

(c)(iii)

$$t_{max} = \frac{1}{60.1600} = 10.4\mu s$$

$$\frac{t_{max}}{t} = \frac{10.4}{3} = 3.47$$

$$\therefore \frac{(V_{GS} - V_{tnew})}{(V_{GS} - V_t)} = \frac{1}{3.47}$$

$$\& \ V_{GS} - V_{tnew} = \frac{2.5}{3.47} = 0.72$$

$$\therefore V_t = V_{GS} - 0.72$$

$$= 3 - 0.72$$

$$V_t = 2.28V$$

2 (a) The wavefunction encodes all that can be known about a particle. $\psi\psi^*$ is the probability of finding the particle at a particular point in space.

(b) $\hbar$ - Plank constant / 2π (ie: a fundamental constant)

m - particle rest mass.

V - potential at point in space.

E - total energy of the particle.

The SE is a statement of conservation of energy.

KE + PE = Total Energy.

(c)(i) Both ψ and $\partial\psi/\partial x$ are conserved at boundaries.

So at $x = 0$

$$\psi_I(0) = \psi_{II}(0)$$

$$A_1 + B_1 = A_2 + B_2 \qquad (1)$$

$$\frac{\partial\psi_I}{\partial x}(0) = \frac{\partial\psi_{II}}{\partial x}(0)$$

$$jk_1A_1 - jk_1B_1 = k_2A_2 - k_2B_2 \qquad (2)$$

At $x = a$

$$\psi_{II}(a) = \psi_{III}(a)$$

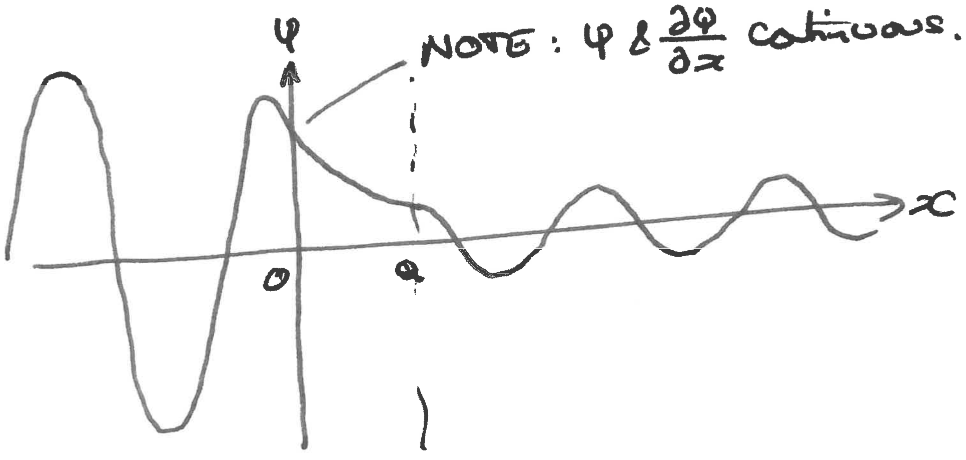
~~$A_1e^{jk_1a} + B_1e^{-jk_1a}$~~

$$A_2e^{k_2a} + B_2e^{-k_2a} = A_3e^{jk_1a} \qquad (3)$$

$$\frac{\partial\psi_{II}}{\partial x}(a) = \frac{\partial\psi_{III}}{\partial x}(a)$$

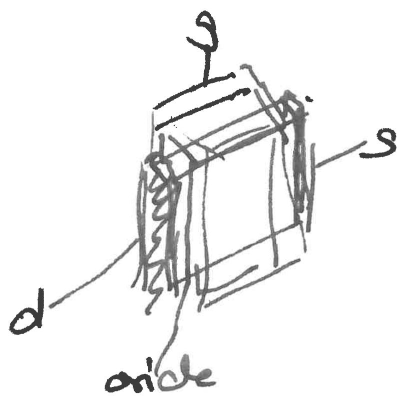
$$k_2A_2e^{k_2a} - k_2B_2e^{-k_2a} = jk_1A_3e^{jk_1a} \qquad (4)$$

(c)(ii)



(c) (iii) Tunnelling becomes exponentially more significant with downscaling of device sizes. A good example is dielectric thinning in MOSFETs leading to the use of high-k dielectrics to allow thicker dielectrics with the same C.

3 (a)



In the FINFET the channel is a vertical fin with the gate dielectric and gate wrapping around 3 sides. Inversion occurs in a greater volume of the channel and so better use is made of the Si. It is also a more compact structure

(b)(i) Low pressure CVD would be best (LPCVD) as this produces high quality coatings with low residual H content at moderate temperatures. Low stress is important so a Si-rich deposition is probably best. Key process conditions are SiH_2Cl_2 and NH_3 flow rate, pressure and temperature.

(b)(ii) 1. ~~LPCVD of~~ rf-PECVD of a-Si:H.
2. Annealing of a-Si:H in a vacuum oven to give poly-Si
3. Deposit Ti top contact by sputtering.
4. Photolithography
   a. Spin on resist
   b. Dry bake.
   c. Exposure.
   d. Development.
   e. Post-bake.
5. Etch the Ti with a proprietary wet Ti etchant.
6. Etch the Si with a high pressure SF_6 isotropic etch to undercut the Si.

(c) Bottom-up processes use nature to form patterned structures without the need for an etch. Top-down processes deposit material generally and then use lithography to remove unwanted material. Bottom-up is particularly suited to nanoscale devices as nanomaterials tend to grow bottom-up. Bottom up is more efficient in material use and so more environmentally ~~[illegible]~~ friendly.

1

Paper 8 - section A (Computer Vision)

Q1(a)(i) Smoothing - reduce high frequency noise which is amplified by differentiation

- scale selection

(ii) $$S(x,y) = \sum_{-n}^{n}\sum_{-n}^{n} I(x-u, y-v)\, g_\sigma(u)\, g_\sigma(v)$$

where $g_\sigma(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}$

and sampled $(2n+1)$ times

(iii) Scale-space logarithmically sampled

$$S(x,y,\sigma_i) = I(x,y) * G_{\sigma_i}(x,y)$$

- do smoothing as 2 x 1D convolutions
- $\sigma_i = 2^{i/s}\sigma_0$ discrete samples for $i = 1, \dots N$

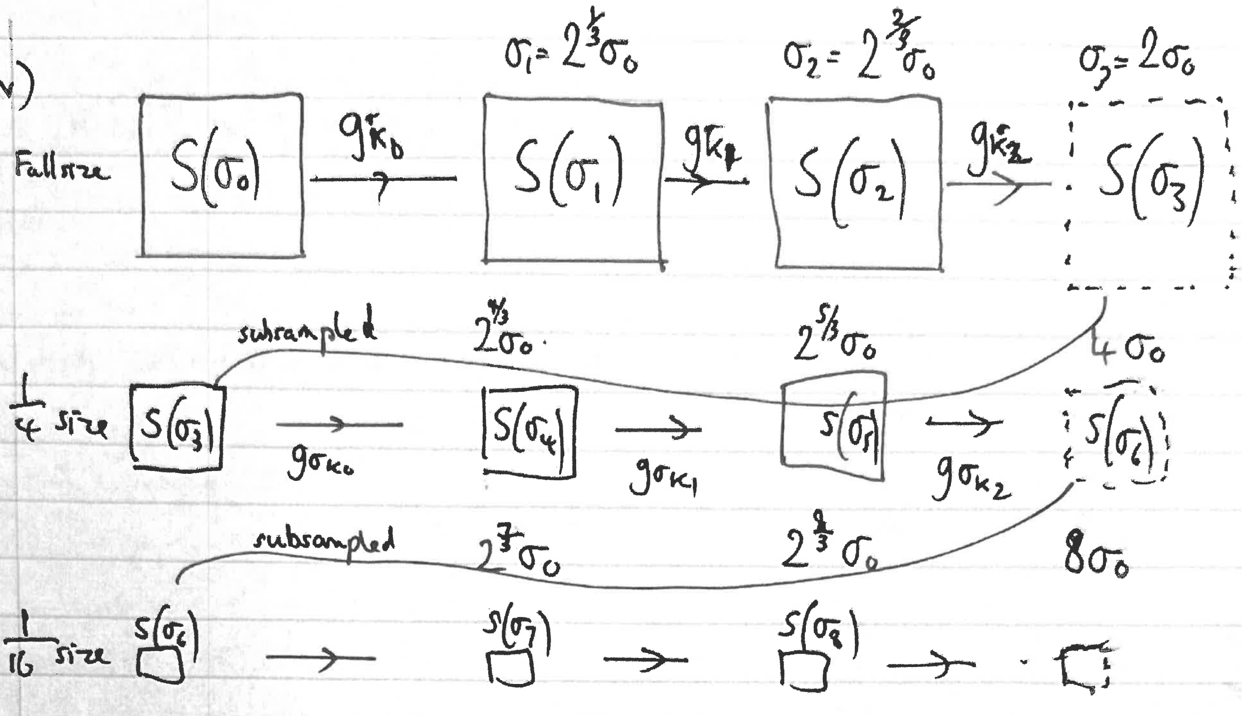
- apply incremental blurs to get larger σ

$$g(\sigma_{i+1}) = g(\sigma_i) * g(\sigma_{ki})$$

- after s incremental blurs we can subsample to 1/4 size.

2

1(iv)



Incremental blur size used at each level

$g_{\sigma_{K_0}} = \sigma_0 \sqrt{2^{2/3}-1} = \sigma_0 \sqrt{2^{2/3}-1}$

$g_{\sigma_{K_1}} = \sigma_1 \sqrt{2^{2/3}-1} = 2^{1/3}\sigma_0 \sqrt{2^{2/3}-1}$

$g_{\sigma_{K_2}} = \sigma_2 \sqrt{2^{2/3}-1} = 2^{2/3}\sigma_0 \sqrt{2^{2/3}-1}$

Use same filters at all other levels but on smaller images

1(b).

(i) $G_\sigma(x,y)$ — low pass filter. $g(x)$ In Fourier domain $G(\omega) = e^{-\frac{\omega^2\sigma^2}{2}}$

$G_{k\sigma}(x,y)$ — lower pass filter

In Fourier domain $g_\sigma(x) \overset{FT}{\longleftrightarrow} e^{-\frac{\omega^2\sigma^2}{2}}$

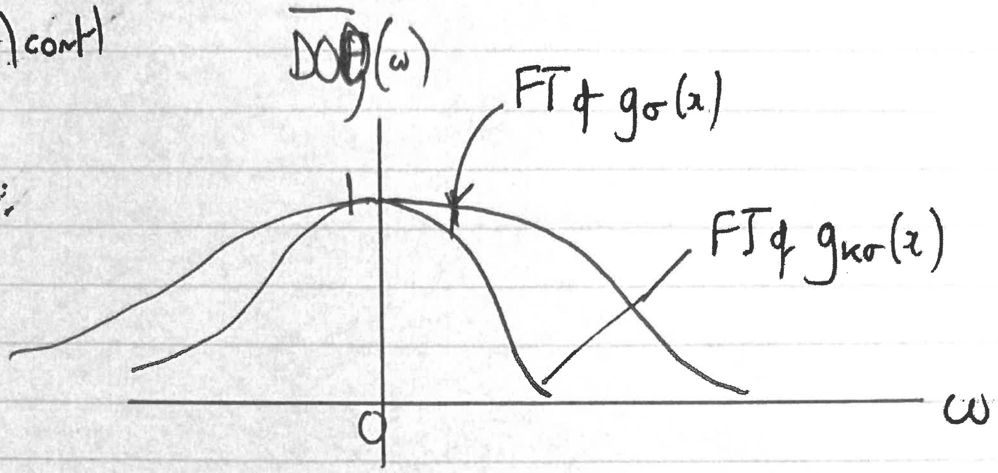
$g_{k\sigma}(x) \overset{FT}{\longleftrightarrow} e^{-\frac{\omega^2 k^2\sigma^2}{2}}$

gaussian shape with $G(0)=1$.

DOG = $g_{k\sigma}(x) - g_\sigma(x)$

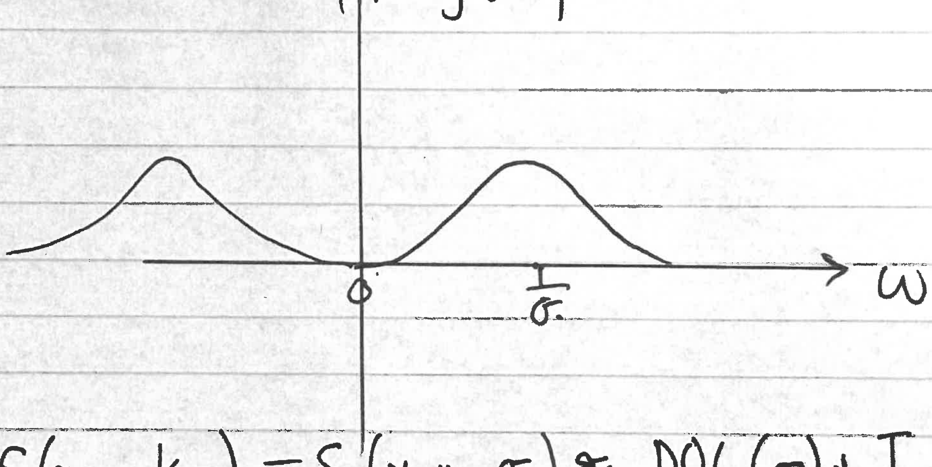
1(b)(i) cont'd

∴



- Difference of 2 low pass filters is a band-pass

$$|\overline{DOG}(\omega)| = e^{-\frac{\omega^2 k^2 \sigma^2}{2}} - e^{-\frac{\omega^2 \sigma^2}{2}}$$



- ∴ $S(x, y, k\sigma_i) - S(x, y, \sigma_i) \approx DOG(\sigma_i) * I(x, y)$

(ii)

The feature being detected is a blob (in 2D) or bar (in 1D) centre.

The max\min response is the blob (bar) centre and the σ_i of max/min gives the scale.

radius of blob = $\sqrt{2}\,\sigma_i$

Find max/min of DOG image over position (x, y) and scale σ_i by looking at response of 26 neighbours

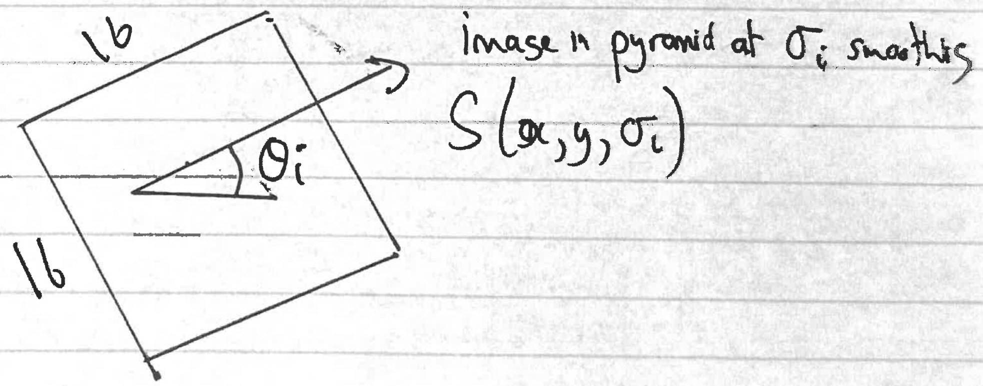
Q1(c)(i).

Find scale of blob σ_i (search 26 neighbours for local max)

Sample 16x16 pixels at (x_i, y_i, σ_i) around blob centre in $S(x, y, \sigma_i)$ image

Produce a histogram of gradients $\nabla S_{\sigma_i}(x, y)$ in 10° bins, smooth and find max/mode gradient. This is reference or dominant orientation θ_i.

Sample 16x16 at $S(x, y, \sigma_i)$ and aligned with dominant orientation.



(ii) Invariance to scale — blob centre and scale normalisation by sampling $S(x, y, \sigma_i)$

orientation — dominant orientation to sample 16x16

lighting — gradients and normalisation to unit vector

perspective — HOGs and 16 cells

non-linear lighting such as specularities — truncate values to < 0.2

occlusion — local descriptor

Q1 (c) (iii) <u>Limitations</u>

- strong perspective
- must be on foreground and not boundary

(iv) For each descriptor in viewpoint 1, $\underline{x}$,
find the best match and second best match in viewpoint 2 based on nearest-neighbour criteria as a distance or dot product, $D(\underline{x}_p, \underline{x}_q)$

Accept match if $\dfrac{D(\underline{x}, \underline{x}_1)}{D(\underline{x}, \underline{x}_2)} < 0.7$

Use k-d tree to find NN more efficiently.

2 (a) (i) Proof by contradiction. Suppose $P = (v_s, ..., v_e)$ is the shortest path between v_s and v_e but we can find a sub-path $(v_i, ...v_j)$ that is not the shortest path between v_i and v_j. This implies there is a shorter path $v_i \to v_j$. Replace the subpath $v_i \to v_j$ in P, with this shorter subpath and we have a shorter overall path $v_s \to v_e$, contradicting the minimality of P. [4]

(ii) Bellman-Ford algorithm for graph $G = \{V, E\}$ with edges, E, and N nodes, $v \in V$, and destination node v_*.

- set $\text{dist}_k(v_*, v_*) = 0$ for all k and $\text{dist}_k(v, v_*) = \infty$ for $v \neq v_*$
- for $k = 1$ to $N - 1$ {
  for each $v \neq v_*$ {
  $\text{dist}_k(v, v_*) = \min_{v \to u \in E} \text{dist}_k(v, u) + \text{dist}_{k-1}(u, v_*)$ } }

The final line relies on the proposition proved in part (i) to iteratively solve the minimisation problem by breaking it into sub-problems. [6]

(b) (i) $w \geq -6$ for Bellman-Ford (to avoid negative cycle BCD) and $w \geq 0$ for Dijkstra. [4]

(ii) Initialize all tentative distances $A - E$ to ∞ and F to 0. Then current node and tentative distance updates proceed as follows:

curr. node	distance updates
F	$D \to 8, E \to 1$
E	$D \to 7, B \to 2$
B	$D \to 5, C \to 6, A \to 8$
D	no updates
C	no updates
A	STOP

Shortest path is (A, B, E, F) with length 8. [6]

(c) (i) Use A* algorithm: replace initial distances in non-destination nodes with euclidean distances computed from physical coordinates, then proceed with remaining steps in Dijkstra's algorithm. This may reduce the number of nodes considered at each step of the algorithm. [2]

(ii) Claim is false: regardless of the value of w, the loop DEF violates the triangle inequality. [3]

3 (a) (i) If the input to the MLP are the raw pixel values, then an MLP with sufficient representation power to carry out the task will be too large and will have too many parameters to be practically deployed and used. If the MLP was made computationally tractable e.g. by projecting down to a small feature space or using summary features of input, then this would not be sufficiently flexible to solve the classification task.

(ii) CNNs build in the following useful inductive biases: shift invariance / equivariance (which reduces the number of required parameters through parameter sharing), local filters (further reducing the number of parameters), a hierarchy of features which become coarser (the reduced resolution further reduces the memory footprint of the model).

(b) (i) The fact that the training loss is small and the test loss is large is likely due to overfitting. This is common when the training dataset does not contain many images and the network is trained from scratch (as opposed to finetuning a pre-trained network).

(ii) 1. data augmentation (crops, rotations, scalings), 2. train a smaller model or a pre-trained model, 3. early stopping the training or reducing the learning rate.

(c) (i) Let the output of the original CNN before the last linear layer be denoted network $\mathbf{h}$. Now introduced weights for each of the K classes $\{\mathbf{w}_k\}_{k=1}^K$. The output of the network can be interpreted as the probability of each class via $x_k = p(y_k = 1|\{\mathbf{w}_j\}_{j=1}^K, \mathbf{h}) = \frac{\exp(\mathbf{w}_k^\top \mathbf{h})}{\sum_j \exp(\mathbf{w}_j^\top \mathbf{h})}$. A sensible cost function is given by the log-probability of the class labels given the inputs:

$$G(\mathbf{w}) = -\sum_n \sum_{k=1}^{K} y_k^{(n)} \log x_k(\mathbf{h}^{(n)}; \{\mathbf{w}_k\}_{k=1}^K).$$

(ii) The first method is, when sampling mini-batches, to not sample iid from the training data but rather select the rare classes more often than the common class e.g. inversely proportional to their occurrence probability. Another option is to upweight the loss on the rarer classes. Both of these options will encourage the network to predict the minority classes on the test dataset.

(iii) First, add a new set of weights to predict the new output $\hat{z}^{(n)} = \mathbf{v}^\top \mathbf{h}^{(n)}$. Second add to the loss another term which penalises the squared error in the predictions of the variable z_n

$$(1-\lambda)G(\mathbf{w}) + \lambda H(\mathbf{w}) = (1-\lambda)G(\mathbf{w}) - \frac{\lambda}{2}\sum_n (z^{(n)} - \hat{z}^{(n)})^2. \qquad (1)$$

The hyper-parameter λ will likely be needed to be set to ensure the two losses tradeoff nicely with one another i.e. training does not focus on one of the losses at the exclusion of the other.

END OF PAPER

SECTION G: *Bioengineering*

Answer not more than **two** *questions from this section*

1 (a) Ultrasound imaging systems and optical scanning laser ophthalmoscopy systems are both able to make measurements of tissue at specific depths (z-axis) in the eye as well as different lateral (x-axis) locations. For both of these systems, explain:

(i) how the measurements are restricted to specific depths and what the approximate depth (z) resolution is; [6]

Answer: This process is sometimes referred to as *Depth-sectioning*, in contrast to just returning data from the first visible surface (like a photograph) or summed over a wide focal region (like a conventional microscope).
For the scanning laser ophthalmoscope, depth-sectioning is achieved by confocal optics. The reflected light is focused at a specific depth into the tissue, and this is directed towards a very small aperture (called the confocal aperture). This aperture is positioned so that light reflected from this depth will be precisely focused at the location of the aperture and will hence all pass through to the single detector which is positioned after the aperture. Any light from shallower or deeper regions is not focused at the confocal aperture, hence only a small fraction is detected. Moving the confocal aperture therefore changes the depth at which the detector is most sensitive to reflected light. The depth resolution is primarily controlled by the width of the confocal aperture.
In this case the approximate depth resolution is 100–400 μm.
In ultrasound imaging, a short electrical pulse is created, and this activates the transducer, causing it to mechanically deform. If the transducer is in touch with tissue, this mechanical wave is transmitted into the tissue and reflected back by interfaces and small scatterers. The reflections are received back by the same transducer and turned back into an electrical signal. The depth location is determined by the time the pulse has taken to perform this round trip, and this presumes a constant speed of sound in the medium. The depth resolution is primarily controlled by the width of the acoustic pulse, though electronic focusing also affects it.
In this case the approximate depth resolution is quite similar: about 100–1000 μm.

(ii) what determines the lateral (x) resolution and what is its approximate value; [4]

Answer: For an SLO, the lateral (x) resolution is determined by the spot size of the laser as it hits the back of the eye, which itself is determined by the optics of the

instrument and the lens of the eye being imaged. Typically achievable values are 15 μm for a normal system, 2 μm if adaptive optics are used.
For ultrasound, lateral (x) resolution is dependent on the lateral (electronic) focusing, which is a function of how many elements are used and the width of the transmission and reception aperture. The value will also depend on the acoustic centre frequency. It is very variable with depth, never better than about 0.5 mm, and often much worse than this.

(iii) what is measured, to what extent this represents a physical property of the tissue, and why this is the case. [4]

Answer: For an SLO, the measured value is notionally the optical reflectivity density. Because of the finite resolution of the system, only the average (lumped) value is measured of a small quantity of tissue, the size being determined by the resolution. However, without knowing the transmission coefficients of the material to light, what we actually measure is this attenuated by the light transmission through (or scattering by) the tissue to and from that point.
However, light is also reflected when the refractive index of the material changes, at which point the measured value is related to the reflection at the interface rather than to a material property.
For ultrasound, the measured value is notionally the average amount of scattering for a small quantity of tissue, similar to above. But most of the signal is from interfaces where changes in acoustic impedance cause reflections.
As with optical signals, the attenuation of sound due to transmission or scattering is not measured, so the measured value is also attenuated by an un-known factor.

(b) The acoustic pulse in an ultrasound imaging system is generated by an electrical pulse with duration $2t_u$ and shape $V(t)$ given by:

$$V(t) = \begin{cases} +1 & -t_u < t < 0 \\ -1 & 0 < t < t_u \\ 0 & \text{otherwise} \end{cases}$$

(i) Calculate and sketch the magnitude of the frequency spectrum of $V(t)$ for

$t_u = 0.04\,\mu$s. [6]

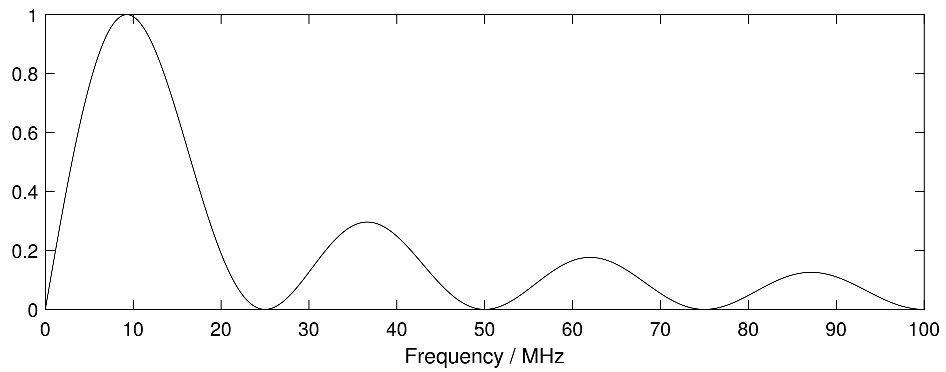
Answer: To calculate the spectrum we need to take the Fourier Transform of V:

$$\begin{aligned}
\mathcal{F}(V) &= \int_{-t_u}^{0} +1e^{-j\omega t}\,\mathrm{d}t + \int_{0}^{t_u} -1e^{-j\omega t}\,\mathrm{d}t \\
&= \left[\frac{1}{-j\omega}e^{-j\omega t}\right]_{-t_u}^{0} + \left[\frac{-1}{-j\omega}e^{-j\omega t}\right]_{0}^{t_u} \\
&= \frac{1}{j\omega}\left(e^{j\omega t_u} - 1\right) + \frac{1}{j\omega}\left(e^{-j\omega t_u} - 1\right) \\
&= \frac{2}{j\omega}\left(\frac{1}{2}\left(e^{j\omega t_u} + e^{-j\omega t_u}\right) - 1\right) \\
&= \frac{2}{j\omega}\left(\cos\omega t_u - 1\right)
\end{aligned}$$

This is always negative imaginary, so the magnitude is hence:

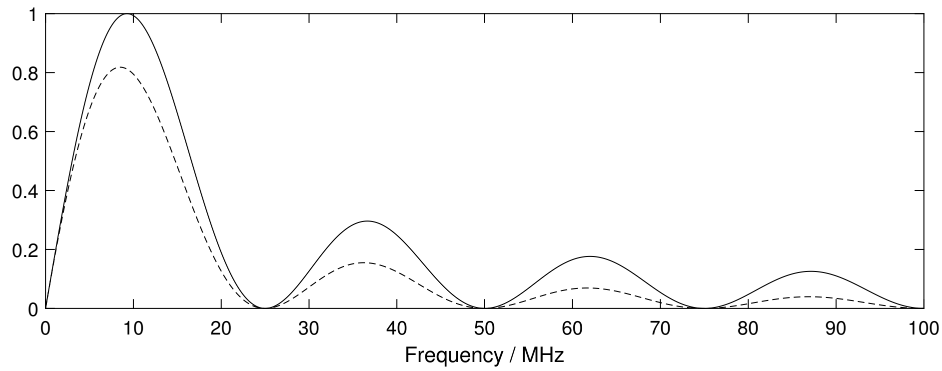
$$|\mathcal{F}(V)| = \frac{2}{\omega}\left(1 - \cos\omega t_u\right) \tag{1}$$

This is plotted below for $t_u = 0.04\,\mu$s:



(ii) How would the frequency spectrum change after passing through tissue at the back of the eye and what effect would this have on the pulse shape? [2]

Answer: The acoustic pulse will be attenuated as it travels through the eye, with the higher frequencies being attenuated more than the lower frequencies. Hence the spectrum will look like the dashed line in the graph below:



This will tend to make the initial pulse more smooth (less high-frequency content), though it shouldn't dramatically affect the width.

(iii) How does this pulse differ from optical pulses used in optical coherence tomography? [3]

Answer: Obviously optical pulses are physically different to acoustic pulses. Optical pulses are also at a much higher frequency, in the THz rather than the MHz range. But they also travel much faster. Hence when expressed in terms of wavelength measured over distance, they are typically $1\mu m$ rather than about $100\mu m$. The shape is also different, since they typically have a much smaller bandwidth of $0.1\mu m$ rather than about $80\mu m$ for acoustic pulses. That means they contain many more cycles (periods) in each pulse, unlike the single period pulse given in this question.

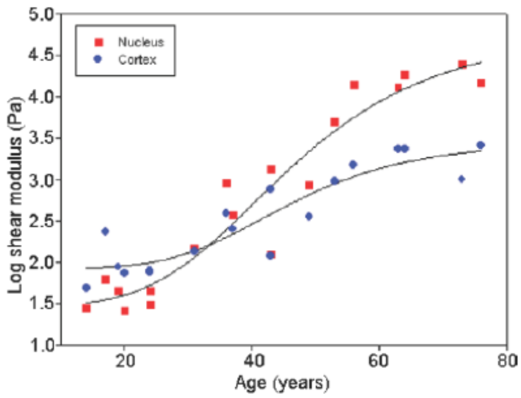
2 (a) What are the main tissue structures forming the outer and the middle layers of the eye? For each layer, describe the tissue structures' main functions, and how these functions are likely to be affected by intraocular pressure. [7]

Answer: The outer layer of the eye consists of the cornea and sclera. The outer layer functions as load-bearing shell of the eye to resist the intraocular pressure. The intraocular pressure in turn maintains the shape of the shell, thus any raised intraocular pressure will lead in elevated stress in the cornea and sclera. However, in normal eyes, due to the autoregulation mechanism of aqueous humour (the clear fluid that fills the space between the cornea and the lens), the intraocular pressure is also auto-regulated, and therefore the tissue functions of cornea and sclera are rarely affected. To note that the structural weak point is at the lamina cribroso (LC), which is a porous structure/disk in the sclera giving rise to stress concentration.

The mid-layer of the eye consists of zonules, ciliary muscle, ciliary body, in continuity with choroid. The zonules, ciliary muscle and ciliary body together controls the shape of the crystal lens, and thus the adjustable focus of the eye. The ciliary boy is also where the aqueous humour is produced, the aqueous humour maintains intraocular pressure and provides nutrients to the eye's tissues. The adjustable focusing functions is negligibly affected by the intraocular pressure; in contrast, the production rate of aqueous humour is autoregulated at the ciliary body and at the Schlemm's canal and the trabecular meshwork. The choroid has three main functions: (1) nourishment: The choroid contains numerous blood vessels that provide oxygen and nutrients to the outer layers of the retina. (2) absorption of Light: It contains pigmented cells that absorb stray light within the eye, helping to reduce internal reflection and improve the clarity of the visual image. (3) temperature Regulation: The blood flow through the choroid helps regulate the temperature of the retina, ensuring that it functions optimally. The intraocular pressure controls the blood flow in the choroid in an analogous to 'starling resistor'. However, there is expected autoregulation mechanism in the choroid which maintains consistent blood flow regardless intraocular pressure.

(b) Describe how aging can change the microstructure of the crystalline lens, and demonstrate its effects on the lens' regional mechanical property by plotting the dependence of log shear modulus versus age. How is the accommodative ability of the eye affected by these changes? [4]

Answer: The lens continually grows throughout life, laying new cells over the old cells. There appears to be no protein turnover in the nucleus throughout lifespan. The lens is thus prone to age related changes, in particular stiffening. Nucleus and cortex of lens becomes stiffer with age, leading to orders of magnitude increase in stiffness. The lens also becomes larger. Lens stiffening over age: harder to deform and focus. this leads to Prespyopia. Presbyopia, or “old man’s eyes,” affects almost all people by the age of 50. Loss of accommodative ability is accompanied with Prespyopia, where near field focusing becomes impossible.



(c) Discuss the function and material selection of an artificial intraocular lens. [3]

Answer: An intraocular lens (IOL) is an artificial lens that is implanted in the eye to replace the eye’s natural lens when it has been removed, usually due to cataracts. Cataracts cause the natural lens to become cloudy, leading to vision impairment. The IOL helps restore clear vision by focusing light properly onto the retina.

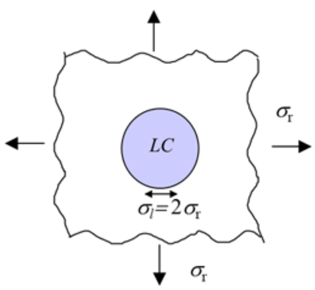
- Early intraocular lenses were PMMA (E   3 GPa).
- Modern acrylate lenses are flexible so as to be folded for surgical insertion; these include both hydrophobic and hydrogel (hydrophilic) polymers.
- In addition to acrylates silicone rubber has been used (E   4 MPa).
- Modern lenses are significantly lighter as well, 20 mg on average compared with 110 mg for early PMMA lenses.
- The reduction in stiffness associated with the modern, flexible lenses allowed for a change in surgical procedure for a minimally-invasive approach requiring no stitches. In which case recovery is much faster and outcomes are significantly approved.
- IOL materials are often doped with UV absorbing additives to protect the retina from radiation damage.

(d) The lamina cribrosa is a porous connective tissue filling the optic nerve head through which the nerve passes. A simplified plane membrane model predicts that the local strain ε_l experienced at the lamina cribrosa is approximately four times that of the remote strain

ε_r experienced at the sclera. Describe, including sketches, such a plane membrane model, stating the assumptions and simplifications made. [7]

Answer: The validity of the model will require that:

- At the level of the whole eye, the eye can be modelled as a pressurised shell with shape maintained by intraocular pressure. The shell property is governed by the sclera and cornea.
- The tissue property is linear elastic and time-independent.
- The lamina cribrosa (LC) is effectively treated as a hole sitting in a plane, which is a simplification when:
  - The LC size is much smaller (e.g. 10 times) than the diameter of the eye globe, thus the global curvature of the eye can be ignored.
  - The modulus of LC is much less than that of the sclera (c.f. foams, relative density $\frac{r^*}{r_s} = 0.1 \Rightarrow \frac{E^*}{E_s} = 10^{-3}$)
- Biaxial remote stresses are those resulted from the intraocular pressure acting on the sclera.
- Assume that the in-plane stretch of LC is determined by stretch of surrounding sclera
- No radial stress at LC interface.



$$\varepsilon_l = \frac{\sigma_l}{E} = \frac{2\sigma_r}{E} = \frac{2\varepsilon_r}{(1-\nu)} \approx 4\varepsilon_r$$

subscripts
r = remote
l = local

(e) Figure G.1 shows the time-dependent uniaxial compressive strain ε applied to a hydrated tissue with linear poroelastic behaviour. Sketch the stress response versus time, briefly explaining the key features of your plot. [4]

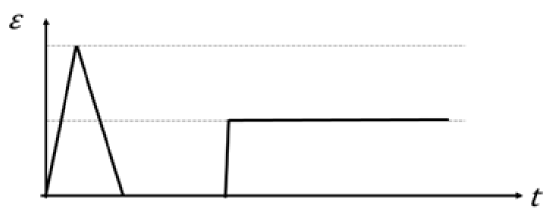
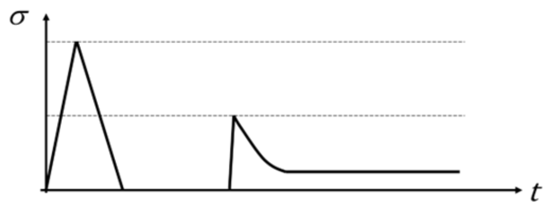


Fig. G.1

Answer:



Linear system, double the compressive strain, double the compressive stress. Fast response at the first compression, thus elastic dominate behaviour.

3 (a) Write short notes on:

(i) what is meant by "the colour" of an object, and two reasons why it is non-trivial for our visual system to perceive it; [3]

Answer: What we normally mean by the "colour" of an object is the reflectance spectrum of its surface, i.e. the propensity the surface has to reflect light of different wavelengths. It is non-trivial for our visual system to perceive colour, for at least two reasons: first, the light that hits our eyes has a spectrum that is the product of the reflectance spectrum and the spectrum of the light source that illuminates the object. The latter must therefore be separately inferred, and 'discounted', to reveal the former. Second, the moment a photon is absorbed by a photoreceptor, much information about its wavelength is lost. Thus, the visual system needs to rely on different types of photoreceptors that have different probabilities of transducing photons of different wavelengths – and even then, we only have three types of photons, which does not permit exact reconstruction of arbitrary spectra (which in principle cannot be summarised by only three numbers).

(ii) the principles according to which accommodation and vergence can be used as physiological cues in the perception of depth. [3]

Answer: Accommodation is the process through which the brain controls the thickness of the eye lens, i.e. control its focal length, in order to maintain a clear image of a given object. Proprioceptive signals from the ciliary muscles (which contract or relax in this process) thus contain information about the depth at which the object is located. These signals are relayed to the brain where they can be contribute to depth perception. Similarly, vergence is the process through which the brain coordinates the rotation of our eyes to ensure that whichever object we look at always remains in the center of both retinas. It is in fact part of the same, coordinated reflex as accommodation. Just how much the eyes have to rotate to preserve binocular vision of an object depends on the depth of this object. The muscle stretch that results from this process is sensed by muscle spindles and relayed to the brain as an additional cue for depth.

(b) Consider a terrestrial animal species whose eye, shown in Fig. G.2, has a simple, symmetric (convex) lens at a distance of 1 cm from the back of the eye, where the retina is located. The lens has an effective refractive index $r_{\text{lens}} = 1.6$.

(i) How can such an effective refractive index be achieved? [2]

Answer: As homogeneous biological tissue has a maximal refractive index of about $r_{\text{lens}} = 1.5$, a refractive index of $r_{\text{lens}} = 1.6$ means that the lens must be inhomogeneous.

(ii) What should be the curvature radius of the lens when focussing on objects at a distance of hundreds of meters? [4]

Answer: From the basic laws of optics, we have:

$$\frac{1}{f} = \frac{1}{S_{\text{object}}} + \frac{1}{S_{\text{retina}}} \tag{2}$$

From the lensmaker's formula for thin lens, we have:

$$\frac{1}{f} = \frac{r_{\text{lens}} - r_{\text{medium}}}{r_{\text{medium}}} \frac{2}{R} \tag{3}$$

Putting the two together, we get:

$$\frac{S_{\text{object}} + S_{\text{retina}}}{S_{\text{object}} S_{\text{retina}}} = \frac{r_{\text{lens}} - r_{\text{medium}}}{r_{\text{medium}}} \frac{2}{R} \tag{4}$$

and solving for R, we get:

$$R = 2 \frac{r_{\text{lens}} - r_{\text{medium}}}{r_{\text{medium}}} \frac{S_{\text{object}} S_{\text{retina}}}{S_{\text{object}} + S_{\text{retina}}} \tag{5}$$

$$= 2 \frac{r_{\text{lens}} - r_{\text{medium}}}{r_{\text{medium}}} \frac{S_{\text{retina}}}{1 + \frac{S_{\text{retina}}}{S_{\text{object}}}} \tag{6}$$

Substituting the constants provided, gives us the following:

$$S_{\text{retina}} = 1 \text{ cm} \quad \text{(distance from retina=imaging plane)} \tag{7}$$

$$r_{\text{medium}} = 1.0 \quad \text{(medium is air, because the animal is terrestria} \tag{8}$$

$$S_{\text{object}} \gg 100\,\text{cm} \Rightarrow \frac{S_{\text{retina}}}{S_{\text{object}}} \simeq 0 \quad \text{(distance of object)} \tag{9}$$

$$R = 2 \frac{1.6 - 1.0}{1.0} \frac{1 \text{ cm}}{1} \tag{10}$$

$$= 1.2 \text{ cm} \tag{11}$$

(iii) What should be the curvature radius of the lens when focussing on objects at a distance of 1 cm? [2]

Answer: Using the same equation as derived above, but substituting different S_{object}

gives us:

$$S_{\text{object}} = 1\,\text{cm} \tag{12}$$
$$R = 2\,\frac{1.6 - 1.0}{1.0}\,\frac{1\,\text{cm}}{1 + \frac{1\,\text{cm}}{1\,\text{cm}}} \tag{13}$$
$$= 0.6\,\text{cm} \tag{14}$$

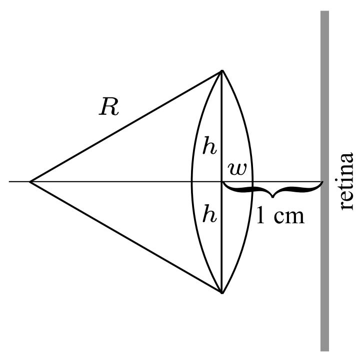
(iv) Explain if there are any constraints on the curvature radius of the lens if its half-height (shown as h in Fig. G.2) is fixed at $h = 1.1$ cm. Support your explanation with calculations. [6]

Answer: Let w be the half-thickness of the lens (see figure below). Simple geometrical considerations give us:

$$R^2 = h^2 + (R - w)^2 \qquad \text{(Pythagorean theorem)} \tag{15}$$

from which we obtain:

$$w = R - \sqrt{R^2 - h^2} \tag{16}$$



The key insight is that w cannot be larger than the distance of the lens from the retina, S_{retina}:

$$w \leq S_{\text{retina}} \tag{17}$$

Substituting Eqs. 16 into 17, we get:

$$S_{\text{retina}} \geq R - \sqrt{R^2 - h^2} \tag{18}$$
$$\sqrt{R^2 - h^2} \geq R - S_{\text{retina}} \tag{19}$$
$$R^2 - h^2 \geq R^2 + S^2_{\text{retina}} - 2\,S_{\text{retina}}\,R \tag{20}$$
$$R \geq \frac{S^2_{\text{retina}} + h^2}{2\,S_{\text{retina}}} \tag{21}$$

Substituting the constants provided gives us the following:

$$R \geq \frac{1\ \text{cm}^2 + 1.1^2\ \text{cm}^2}{2 \cdot 1\ \text{cm}} = 1.105\ \text{cm} \approx 1\ \text{cm} \tag{22}$$

(v) Given the constraint on the curvature radius that you derived in (b)(iv), explain, with reasons, if the animal can focus on objects at each of the distances discussed in (b)(ii) and (b)(iii), respectively. [2]

Answer: For objects at distances of hundreds of meters (question (b)(ii)), the curvature radius needed is 1.2 cm, which is above the minimal curvature radius 1 cm derived above, so the animal can focus on such objects. For objects at a distance of 1 cm (question (b)(iii)), the curvature radius needed is 0.6 cm, which is below the minimal curvature radius 1 cm derived above, so the animal cannot focus on such objects.

(vi) What biological mechanism might allow the animal to focus on objects at different distances, and how does this violate some of the assumptions made about the lens in this question? [3]

Answer: Muscles (so called ciliary muscles) attach to the lens (via suspensory ligaments). When these muscles contract, the lens flattens, making its curvature radius larger. When these muscles relax, the lens contracts, making its curvature radius smaller. These changes in curvature radius allow the animal to focus on objects at different distances. However, this mechanism also means that the (half-)height of the lens is not fixed, contrary to what was assumed in question (b)(iv): it is larger when it becomes flatter, and it is smaller, when it becomes more curved.

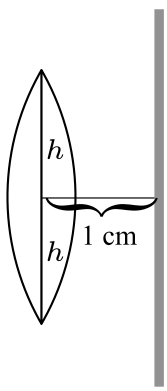


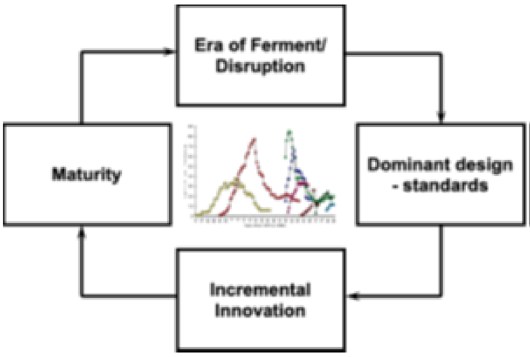
Fig. G.2

END OF SECTION

Question 1

(a) Describe the generic *industry evolution* model. Apply the model to the bicycles industry. [5]

The question refers to the diagram below.



Era of Ferment/Disruption: numerous competing approaches and designs emerging.
In the bicycle industry, this could be seen in the late 19th century, when many different designs were being developed, including the high-wheel bicycle ("penny-farthing").

Dominant Design/Standards: As the market matures, a few standard designs became established. This standardisation leads to increased production and sales, and increased the confidence of customers in the technology.
For bicycles, the ‘safety’ bicycle design (the one we know today: with two wheels of equal size, a chain drive, and a diamond frame), became the dominant design

Incremental Innovation: Companies focus on improvements in cost, reliability, and efficiency. This is an era where incremental innovation and market segmentation emerge.
In bicycles, refinements in materials, manufacturing processes, and components like gears and brakes. The market segments and different types of bikes emerge (mountain/city/race bikes etc)

Maturity: The market slows down as the product reaches the limits of cost-effective improvements.
In the bicycle industry, the size of the market is hard to grow via upgrades of the product.

Best answers will also recognise that the number of players in the sector follows a bell shape, with a decline after the emergence of the standard.

(b) "VitalScan" is a new medical device which can be used to monitor key parameters of patients with chronic conditions both at home and in hospitals.

(i) Describe the role of at least eight key stakeholders in the development of "VitalScan". [8]

There are internal and external stakeholders. Internal stakeholders hold information about how to develop the product, how to manufacture and sell it. External stakeholders are those who have information about what the market needs and help guiding the design process.

The generic external stakeholders' figures include: the initiator, the influencer, the decider, the buyer and the user. Internal stakeholders are for example groups such as product Designers, R&D, Manufacturing, operations, Marketing, Procurement.

Stakeholders can also be classified in terms of level of influence (high/low) and interest (high/low) .

For the VitalScan (for example) :

internal	external
Marketing and sales: they have to form an understanding of how to best sell and market the device i.e. to communicate the unique selling points of the device. Will have knowledge of selling previous devices if the company has been on the market previously with another device in this industry.	Patients = users of the device. There might be people with different types of chronic illness who would be able to help understanding the challenges faced in monitoring their parameters and what might be the best device features.
Manufacturing and Assembly: will have requirements for the manufacturing. They want to make sure the production yields products to specifications and in the quantity needed. Will have an interest in optimising the production.	Hospitals = doctors and nurses are also users, who might adopt the technology to support the monitoring of patients in the wards and might have information on the challenges faced in using the device and interpreting the data acquired.
Designers will need to understand how to balance the requirements and needs of the market (external stakeholders) and optimise the characteristics of the product for internal stakeholders (e.g. manufacturability and post-sale quality)	Medical Approving organisation (e.g. insurances, MHRA in UK) = these are the buyers, who will know what in their eyes 'value for money' for the VitalScan is.

After-sales services will prefer to minimise their efforts (e.g. reduce parts stock, optimise the repair)	Medical devices suppliers and distributors = they understand how the market works and will be the ones who will potentially make or break the success of the device in the market as they are able to advise the users on whether to purchase this rather than another device

The best answers will be the most complete and would recognise the external as well as the internal categories and might refer to the interest vs influence categorisation.

(ii) Discuss why the analysis of the key stakeholders is important for those who are taking "VitalScan" to market. [5]

The key stakeholders have important information which can help the successful design of the device (including its manufacturing) and further its successful adoption by the market. In sum, their analysis is helpful to define the design mix. Good answers will recognise that the analysis of the key external stakeholders will lead to define a good "design mix' (the core benefits of the product, the definition of the core product and its characteristics, the product/service system and the meta product) and will eventually inform the business model development and the ability to attract funding support (e.g. internally or from VCs).

Good answers will recognise that some stakeholders have interest in the outcome of the project, and some have influence in this outcome, and some have both. Understanding these priorities helps to inform the needs that have to be satisfied for the project to succeed, vs needs that are wishes.

It is important not to neglect the internal stakeholders to facilitate the process of taking the design into manufacturing and eventually to sale (e.g. prior knowledge on building/innovating/selling medical devices).

(iii) Describe which techniques the company could use to capture the perspectives of the key stakeholders at the start of the process of bringing "VitalScan" to market. Describe in detail how the company could combine two different techniques to do this, explaining your reasoning. [7]

The company can use a variety of techniques to qualify (i.e. explore) the perspectives of the stakeholders and to quantify or validate the insight about the stakeholders. Compatibly with time available and cost, using combinations of techniques (tailored to the specific stakeholder group and the stage of the product development) would help doing a better evaluation of the stakeholders perspectives,

At the start of the ideation of the product, a good combination could be for example an approach that firstly aims to identify the aspects that users stakeholders perceive as important, followed by a technique to quantify how common those aspects are across a large set of users.

The best answers would bring plausible and concrete example(s) of techniques considering advantages and limitations, or expand, covering different stakeholders mentioned in b(i), and will be structured.

For example, to understand the users (patients, carers, hospital staff) could be done first through an observation of the patients with chronic diseases and their journey to monitor and communicate their vital parameters to their doctors as well as how this is done in hospitals. Using Observations of the users would allow to discover issues and needs of such patients and of the hospital staff including those which the users are not necessarily aware of. Personas could be drawn out of the evidence accrued during observation, to bring to life the requirements of the users. This technique would require time, and it might not be possible to repeat it across many patients/hospitals (too costly). Hence it would not allow to understand whether the challenges and needs observed are generally and universally experienced by patients and hospitals across the market (e.g. something might be important for patients in a certain healthcare system but not in others). Hence, the company could design also a survey to test whether the issues emerged from the observation exercise of few patients/hospitals are shared universally, to identify the most important and unifying benefit that this device could bring as perceived by the market.

Question 2

(a) **Discuss the key strategic issues companies face when they grow. Use real examples to illustrate your answers.** [8]

Issues include:

- Developing a **strategy** that allows the company to grow. Deciding:
  - **How to grow:** choosing between one of the following approaches.
    - A) by innovating in the same field (adding new products or services to their range of products); B) by expanding their market by re-positioning existing products (e.g. by selling their products in different markets (See Lucozade); C) by changing how the company delivers its products/services (e.g. changing business model innovation); D) By changing completely what the company does (Paradigm innovation, for example Virgin changed from being a music label only company to selling many types of travel/entertainment experiences and services).

        - E) How to balance radical and incremental innovation is a key challenge. Incremental is easier and might lead to revenue quicker. Radical is risky but might help avoid being disrupted. Companies start to become more conservative and take risk more seriously as they grow (as they have more to lose – see for example Kodak's story) which causes a challenge.
    - **How to fund the growth**: initially choosing where do the funding come from (e.g. acquiring grants/selling equity (to Angels or VCs) later also launching IPOs)/entering a debt with a bank/ through products/services sales). When they become large, they need to mostly rely on their funds to support R&D for innovation.
    - **How to manage scale**: dealing with the increased complexity of operations across functions. Manage:
        - higher numbers of increasingly specialised people, possibly not co-located. Communication distances increase even if they are all in the same building - (one cannot know everything that goes on, need to find effective ways of knowledge sharing, and ways to delegate tasks).
        - Systems (including manufacturing and supply chain) numbers and complexity increase (and, with it, the level of bureaucracy). Need to increase system efficiency (the quality needs to be more reliable) as the number of interconnected systems increases.

Good answers will recognise most of these aspects. Excellent answers will link content across the lectures.

(b) **Your company is developing a new AI-driven kitchen robot which it wants to market under the name "AI Dente". It plans to present it publicly for the first time at the CES trade exhibition in Las Vegas next January. The advertisement will feature the slogan "Served AI Dente", accompanied by a photograph taken by a professional photographer of you and your friends preparing to taste a sophisticated dish made by "AI Dente". You have been asked to advise on the types of IP which the company should consider in planning this product's development, production and marketing. For each type of IP, outline the steps needed to protect the IP under UK law, and comment on any specific points which the company should consider before the exhibition.**

[9]

The company needs to consider protecting many aspects of the robot (from the design and functionality of the robot to the manufacturing, to the slogan and any other wording/design on the advertisement, and the trade name).

A search will be needed to establish the 'prior art' – i.e. what has been done before – and then to work out what features can be protected, how (which type of IPR is appropriate) and also workout if the company would be able to enforce the IPR.

- it would be important to identify *what features of the design and functionality are novel,* inventive and have industrial application and to seek to patent them (e.g. the software (AI), the functionality of the food processing robot (e.g. the mixing arm, the ingredient dispensing system etc.)). The first step in obtaining a patent is to file a description with the Patent Office – this need not be a full application, but it must include all features which will be included in the subsequent full application. It is essential that the invention is not made public before the application is filed – so that it is very urgent to do this before the exhibition, and to stress the need for confidentiality to all staff. It would also be useful to establish if any information about the design which has leaked into the public domain – if it has, then the patent application may fail, or any patent granted may be invalid. The company should take advice from a patent agent or lawyer immediately.
- The *design of the robot* could in principle be protected by design right or as a registered design, but a competitor might find it easy to make small changes and avoid infringing this IP
- The *manufacturing process* is unlikely to be formerly protectable by patents (it is probably very standard), unless it includes some novel features. Also, even if it is novel, before investing in a costly patent one needs to ascertain if it is possible to easily spot when the manufacturing process has been used by others (i.e. is it possible to detect an infringement?). So, trade secrets might be most appropriate to protect any novel manufacturing method.
- The *slogan and advertisement* will be protected by copyright, and under UK law this does not require registration – the act of publishing is enough to give copyright. The name 'AI Dente' might be acceptable as a trademark in the UK since it is not too descriptive of the product but also this needs to be checked with the help of a lawyer. Trademarks are registered with the Patent Office. TM The name would have benefits in building brand identity and preventing competition.
- the company needs to be sure that it is legally entitled to reproduce *the photograph* – who owns the copyright? Even if the photograph was commissioned by the company, the owner of the copyright could be the photographer, or the company, or some other party. Advice from a lawyer prior to taking it might be helpful.

The best answers will list a good number of possible aspects that need to be protected and will take in consideration the urgency to seek expert advice from legal specialists to address these points, in the light of the imminent disclosure at the exhibition.

(c) **Describe the different perspectives of a large and of a small/new company when they are approaching the setup of a partnership to develop a new technology/product.** [8]

The best answers will present a complete picture of the main perspectives on both sides.

Typically	Large Co Perspective	Start-up perspective
Partnership Aims	Acquire a complementary asset (technology/knowledge) to their own to enter a new market/ improve their products	Share a technology/knowledge to acquire capital or resources to bring their tech to market and grow
Concerns	Wary of IP leeks or weak IP (not being able to protect their innovation)	Wary of their own short-term needs (e.g. lack of financial stability, resources)
Concerns	Wary of their brand being abused or of the consequences on their brand if an innovation in the market fails	Wary of potential abuse of their ideas and innovation (being ripped off)
Clockspeed	Slow: Require due diligence to take all the steps to make sure the innovation is solid (i.e. that it works as it should and there is no failure in the market)	Fast: Impatient in the face of slow decision cycles and slow improvements. Capable of fast pivot on focus.
Limitation in understanding each other	Might not be aware of all startup's needs	Often limited understanding of large company (cannot see all large company's systems, do not know all the people in the company)
Attitude related to the technology/ product	The product/technology is one of many.	The product/technology is the reason why the company exists and where all resources are invested. High stake.
Communication and management of partnership	Complex: distributed (both geographically and in terms of functions); not everyone knows everything about themselves and the partnership. Partnership responsibility over many projects, responsibility might be delegated during the course of the project as people change role	Flat structure; all people likely involved in the partnership/one partnership is typically all they can take on.

Question 3

(a) **Describe the key types of innovation and explain how companies typically balance their efforts across these different types of innovation.** [7]

The main types of innovation are:

- Product/Service Innovation: This involves changes to what is offered to the customer (e.g. a new vacuum cleaner)
- Process Innovation: This relates to how the operations of the business are managed. Tesco's online shopping and delivery was given as an example of a new business process innovation.
- Position/Placement Innovation: This concerns how a product or service is positioned in the market. Lucozade is an example of placement innovation, moving the brand from being sold as a recovery drink to becoming seen as a sports energy drink.
- Paradigm Innovation: This refers to a radical change in what the business does (e.g. Nokia moved from being a rubber products making company to a telecommunication firm).

Each of these types of innovation can be either Incremental (small improvements /changes) or radical (very new and major changes – a lower radical innovation would be some innovation which is new to the company whilst the most radical level is innovation which is new to the world).

Research indicates that most innovations are not radical but rather aim at cost reductions, improvements to existing products, and additions to product lines. This is because doing radically new things is inherently riskier and more prone to failure. However, radical innovation could prevent a company being disrupted and could lead to great returns.

To balance the innovation types companies must (follow the pentathlon framework)

1) consider the role of each key innovation in their strategical plans to decide the best way to grow and be competitive (which product to reposition, which products to launch into the market, whether a process innovation is necessary, whether there is a new line of products that is required). They need to assess market trends and how these drive the need for innovation, and the opportunities provided by each type of innovation;

2) balance the cost and risk of each innovation with the potential reward.(large) Companies manage multiple innovation-related projects simultaneously across all the categories. They use tools such as "bubble charts" to map risk, potential returns, and project costs, to help prioritise innovation budgets.

3) consider what expertise (people) and resources are needed to follow the ideation/selection/implementation plans.

You are the developer of a new AI-driven kitchen robot, called "Al Dente", designed to aid in the preparation of sophisticated dishes (described also in question 2(b)). You are applying for backing from a Venture Capital (VC) fund.

(i) Explain what you would include in the business plan for the VC fund, providing examples of details specific to "Al Dente". [10]

This answer should include at a minimum the headings of the business plan and a generic description following this slide:

The quality of the answer would be also judged by the effort (creativity and logic) in the examples given in each part of the business plan.

1) Description of the market for "Al Dente". (i.e. differentiation from other products (3stars Michelin dishes with no skills!) and who might be interested to buy this robot and why? – e.g. individuals in the high-end kitchen appliance who do not have time to cook but like to entertain at home, or owners of catering services who need to deliver high quality and visually pleasing dishes with limited personnel)
2) The description of the solution – building a pitch FOR/WHO-NEEDS/THEPRODUCT OFFERS A SOLUTION/UNLIKE OTHERS e.g. "Short of time but needing to impress? this AI-driven robot produces highly sophisticated dishes worthy of a 3 Micheline stars restaurant without effort. It shops and cooks! It can deliver infinite original nutritiously rich and personalised recipes for up to 10 people with minimal human assistance! The alternative robots in the market are limited in their capabilities (they do not shop or advise on your meals choice and the range of dishes)"
3) Description of the Management team: (e.g. "we have a strong, knowledgeable and complementary team of 4 people.
   A. with expertise in embedded AI – previously worked in large company AI projects,
   B. a chef who has been recognised for originality of recipes and knowledge in nutrition,
   C. a mechanical engineer whose PhD project led to a patentable innovation;
   D. a designer who worked in the fashion industry")
4) Description of the Operations - (e.g. "we have intention to partner with Bosch to provide the strong engine at the core of the robot, and to consider growing towards the first prototype by licensing our AI for other applications/sectors. We will start with a small-batch production and we plan to scale it up in a second round of investment")
5) Financial projections –Business model (product, service and consumables) + financial returns from the commercialisation of the AI in other sectors will start flowing in from year 1 (we have a potential licensor already), we aim to launch the full product in 3 years after presenting it to the CES exhibition in Las Vegas. After that, we expect a financial return of XXX millions in the first 3 years from sales in US and Europe and to be able to double it in the following 3 years by selling also in China").

6) Marketing strategy – (e.g., for AI licensing we have plans to hire a specialist to take care of the identification of licensors. For the robot, the CES event will be the main opportunity to get the product known and attract articles in high-end fashion magazines + Instagram influencers.")
7) Resources required – (here we specified the financial requirements (how much and when), the missing expertise (IPR manager, licensing manager, collaboration development skills, manufacturing engineer) and the physical resources we have and are planning to acquire (external manufacturing supplier, testing facilities)
8) Exit opportunities – (e.g. "in 5 years we expect to be able to sell the product to a large appliance company (e.g. Bosch who are already our partners or Kitchen aid)")

(ii) Which information in the business plan do you think will have the greatest impact on the VC's decision to back your venture? Justify your answer. [5]

The answer should follow the outline of this slide:

The key factors in the VCs decision are dictated by the desire for VCs to back successful teams with great technologies/products and ultimately to anticipate that they have the chances to grow sufficiently their investment in a short time (for example):

- *The quality of our management team: the fact we worked together for a couple of years and compensated each other providing quality skills for the project gave guarantees that we will be able to withstand the crises due to the inevitable issues emerging when taking a technology to market. This is important as VCs want to understand we have a reliable and competent team, which can work together reducing the chance of any setback*
- *Technology: the innovative step in the AI- technology applied to food preparation. Having licensors in the pipeline showed that the technology is robust and interesting to big companies and that there are other sources of revenue.*
- *Our access to market - the fact we have already identified a licensor for the AI and the prospect of us being able to get to a known worldwide exhibition. This indicates that we will have sales early on and provide confidence in our plan.*
- *Exit opportunities: having known reliable partners (such as Bosch) who may become the acquirers of the product and would hence provide exit for them will be important.*

At a minimum, the answer will list the generic important factors from the VCs perspective. This list needs to be explained also in the context of why VCs care about each of these aspects more than others contained in the business case. Best answers will contextualise each item with the specific examples of the AI Dente demonstrating application capability.

(b) What is the difference between invention and innovation? Give an example from your personal studies of an invention that led to innovation. [3]

Whilst invention relates to creating something new, innovation relates to the diffusion of that invention into the market. Innovations emerge from tech stimuli (tech push) or from needs in the market (market pull). Innovation is created when a tech push meets a market pull and a market emerges (i.e. a group of people who wants to pay for it) .

Many examples have been given during the lectures. If students can think of other examples this will be taken positively. Best answers are those most complete and that do not just rely on material from the lectures for the examples.
(e.g. mNRA technology (invention) has been used to produce COVID-19 Vaccines (innovation))