

Don Morris  
1900912  
13/5/22  
ACHA6012  
Page 1 of

Q2)

- a) Bonding variations are determined by the method of electron transfer and/or ion interaction  
Methods:

Ionic Bonding - Transfer of electrons between two atoms to achieve Octet State (Full outer shell). In order to achieve balance, the outer shell is required to accommodate the max number of electrons possible. Thus, the pairing atoms will either donate or receive electrons based on easiest path to gain a full outer shell.

Covalent Bonding - Covalent Bonding works on the same mechanism as Ionic Bonding, as the pairing atoms transfer electrons to form the bond. However, in Covalent Bonding, this sharing of electrons is non-permanent unlike Ionic. Covalent Bonding occurs when the two atoms require the same net number of electrons to achieve Octet state. The key difference is electrons are being shared rather than transferred. Covalent Bonding tends to occur between similar or identical elements, and is rare between metals. Where Ionic Bonding occurs in both metals and non-metals.

Don Morris  
1900912  
13/5/22  
ACHA6012  
Page 2 of

Ionic bonding tends to be stronger than covalent due to the additional Coulombic attractions between the net five or six ions as a result of electron gain or loss.

Metallic bonds - Metallic bonding occurs when two metals shed electrons from their outer shell to form positive metal ions. The shed electrons form a set of free electrons which fill the gap between ions and provide electrostatic attraction between ions and electrons.

I = Ionic, C = covalent  
M = metallic

Comparison:

Formation - See above Paragraphs

Formation for same element - I = no, C = Yes, M = Yes

Isomerism - I = non-directional, C = directional, M = non-directional

Electronegativity - I = high, C = very low, M = no role

Conductivity in Solid State - I = Low, C = low for non-conducting materials, M = high

Valency - Valency is the number of hydrogen atoms a particular atom can bond with, and varies with periodic table group.

Dan Morris  
 1900912  
 13/5/22  
 ACHA6012  
 Page 3 of

b) Copper = FCC

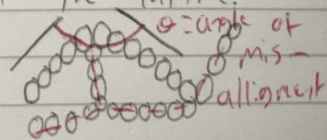
Find  $R$  if  $a = 0.362 \text{ nm}$

let  $a = 2\sqrt{2} R$

$$R = \frac{a}{2\sqrt{2}} \quad R = \frac{0.362}{2\sqrt{2}} = 0.128 \text{ nm to 3 dp}$$

c) Defects:

| point Defect                                                                                                                                                                                                                                                                                                                                                                                                       | Line Defect                                                                                                                                                                                                                                                                                                                                               | Area defect                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>3 main defects:</p> <p>1 - Vacancies: missing atoms in lattice leads to distortion of surrounding atoms</p> <p>2 - Self-interstitial: atom misplaced between standard atomic structure leading to misposition of surrounding atoms</p> <p>*<sub>1</sub> Dislocations: the dislocation of atoms in the lattice leading to slip between layers of atoms. Produces permanent plastic deformation of structure.</p> | <p>* Dislocations: Dislocations create large areas of the lattice where point defects are localized.</p> <p>*<sub>2</sub> 3-Substitutional: occurs when an existing atom in the lattice is replaced by a different type of atom. This does not deform the lattice, but can provide unbalanced properties through the lattice with this discontinuity.</p> | <p>Grain Boundary: occurs between two crystallites of the same crystal structure and properties are kept but the orientation differs. These defects affect the boundaries of interface zones and can lead to the decrease in electrical and thermal conductivity of the lattice.</p> |



\*<sub>2</sub>

Dan Morris  
1900912  
13/5/22  
ACHA 6012  
4 of

Explain of types - See previous table  
Effect on Crystal Structure:  
Point defects:

- Vacancy: localized distortion of atoms in vicinity of defect
- Self interstitial: localized atom misalignment due to misplaced atom. Effects both directions in 2-D structure
- Substitutional: no effect on atomic crystal structure visibly, only properties

Line defect:

- Dislocation: effects large areas of lattice dependent of size of slip crystal structure. Still organized unlike point defect 1 and 2, but is shifted.

Area defect:

- Grain ~~from~~ Grain Boundary: Effects alignment of crystal structure not core atomic location. Seen over a large area of lattice, where the dislocation is only seen along a 1-D plane and grain boundaries are visible in 2-D.

Dan Morris

1900912

13/05/22

ACHA 6012

5 of

- d) Dislocation Movement relates Secondary Creep.
- Defects move closer to grain boundaries under load
  - ~~forms triple points at grain boundaries~~  
Defects move to the weakest points in the structure (grain boundaries triple points)
  - relatively predictable, speeds up creep failure by ~~the~~ transferring defects to weaker areas to increase probability of failure.

Q3)

a) Casting

- Used primarily for large metal components such as engine blocks.
  - Most metals can be used, mainly being steel and aluminium.
  - Moulds can be re-used
  - Suitable for even high melting point metals.
- Limitations:
- Poor dimensional control
  - Poor surface finish
  - labour intensive
  - large material loss.

Dan Morris  
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13/02/22

ACHA 6012

6 of

### Forging:

- Combination of heat and pressure leads to higher end strength
- high production rate

- ~~Not~~ All metals can technically be forged however some are harder to work with.

Example, brass fractures easily under heat.

This can be solved by cold forging which can also be used for metals like aluminium.

- Similar materials can be used as casting however forging gives less shape forming control

### Limitations:

- high cost
- high energy use
- limited size and shape forming
- multiple secondary phases required - more cost + labor

### 3D printing:

- Materials: currently limited to plastics and metal
  - metal is very new and expensive, ~~can~~ SpaceX pioneered this for rocket production
  - More materials likely available in the future, currently highly limited

Dan Morris  
1900912  
13/05/22  
ACT1A 6012  
Page 7 of

### Limitations:

- ~~Time~~ takes long time periods
- can fail during printing resulting in wasted material and time
- high initial cost
- not applicable for mass production (currently)
- requires enhanced safety measures due to harmful gas production in some cases
- part size limitation

### 6) RPN

D - Detection: likelihood of detection before large failure

S - severity: severity of failure consequences

P - Probability: How likely is this failure or issue?

These 3 stages are ranked from 1-10

10 being more severe, undetectable and high probability.

RPN - D.S.P is used to find a metric of where resource should be applied to solve the issue.

### C) U notch

$$d = 10 \times 10^{-3} \text{ m}$$

$$h = 1.9 \times 10^{-3} \text{ m}$$

$$r = 0.5 \times 10^{-3} \text{ m}$$

$$F = 55 \text{ N}$$

Q = student number 'E'

Dan Morris  
1900912

13/05/22

ACHA6012

8 of

i) Bend. is

Find  $K$

$$\frac{b}{r} = \frac{1.9}{0.5} = 3.8 \quad \text{Use Second Set}$$

$$C_1 = 0.935 + 1.922\sqrt{3.8} + 0.004(3.8) = 4.6969$$

$$C_2 = -0.552 - 5.327\sqrt{3.8} + 0.086(3.8) = -10.6094$$

$$C_3 = 0.754 + 6.281\sqrt{3.8} - 0.121(3.8) = 13.5908$$

$$C_4 = -0.138 - 2.876\sqrt{3.8} + 0.031(3.8) = -5.6266$$

$$K_E = C_1 + C_2\left(\frac{2h}{D}\right) + C_3\left(\frac{2h}{D}\right)^2 + C_4\left(\frac{2h}{D}\right)^3$$

$$K_E = 4.6969 - 10.6094\left(\frac{2 \times 1.9 \times 10^{-3}}{1 \times 10^{-2}}\right) + 13.5908\left(\frac{2 \times 1.9 \times 10^{-3}}{1 \times 10^{-2}}\right)^2$$

$$- 5.6266\left(\frac{2 \times 1.9 \times 10^{-3}}{1 \times 10^{-2}}\right)^3 = \underline{6.3910}$$

$$\text{ii) } \sigma_{\max} = K_E \left( \frac{32M}{\pi(D-2h)^3} \right) = 6.391 \left( \frac{32.55}{\pi(1 \times 10^{-2} - 1.9 \times 10^{-3} \cdot 2)^3} \right)$$

$$\sigma_{\max} = \underline{1.5023 \times 10^{10} \text{ Pa}}$$

$$\sigma_{\max} = 15.02 \text{ GPa}$$

Dan Morris

10/00/12

15/05/22

ACHA 0012

Page 9

a) Central Crack:  $3.9\text{mm}$ ,  $3.9 \times 10^{-3}\text{m}$   
 $\sigma = 625 \times 10^6 \text{Pa}$

$E = 200 \text{GPa}$ , find  $G_c$

$$\sigma \sqrt{H_a} = \sqrt{G_c E} \quad \sigma \sqrt{H_a} = K$$

$$a = \frac{3.9 \times 10^{-3}}{2} \quad K = 625 \times 10^6 \sqrt{H_a \times \frac{3.9 \times 10^{-3}}{2}}$$
$$= 48918401.74$$
$$= 48.92 \times 10^6$$

$$K_c = \sqrt{G_c E}$$

$$\frac{K_c^2}{E} = G_c \quad \frac{(48.92 \times 10^6)^2}{200 \times 10^9} = G_c = 11965.1 \text{ Pa}\cdot\text{m}$$
$$= \underline{\underline{11.97 \text{ kPa}\cdot\text{m}}}$$

Dan Morris  
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13/5/22  
ACHA Gold  
Page 10

## Q1) 2 Alt fuel

~~DME~~ - Dimethyl Ether

Hydrogen ~~was~~

Bio-butanol ~~→ Race Tech Mon~~

- a) When applying a new fuel protocol to meet Euro 7 emission standards, there are many different factors to assess. Firstly, reasoning behind the use of these fuels must be given. Hydrogen is a much cleaner fuel than petrol as it isn't a hydrocarbon. Therefore no unburnt HC's, CO, CO<sub>2</sub> are produced. This will ~~mass~~ result in a hydrogen production car meeting these specific targets for these emissions. However, the ~~nox~~ production is still present. Due to hydrogen flammability, hydrogen ICE's can run lower fuel/air ratios, resulting in lower burn temps and less ~~nox~~ than a petrol engine according to Autocar. Butanol is a hydrocarbon compound similar to petrol as a C<sub>4</sub>-hydrocarbon. However, Bio-Butanol can be produced from biomass, compared to fossil fuels in petrobutanol. Butanol is seen to reduce particulate matter compared to petrol, IEA states. IEA also states a reduction in HC, CO and CO<sub>2</sub> was observed, but ~~nox~~ increased due to higher burn temps.

Dan Morris

19/09/12

13/05/22

ACHA 6012

Page 11

EGR was seen to help reduce  $\text{NO}_x$  production at high load, compared to a net slight increase at low load compared to gasoline, reported Cooney (2009) within IEA.

- 6) The ease of Butanol is one which hydrogen does not share, as Butanol can be used in existing ICE motors with little modification. Work done by BP with the Mazda-Lola 2009 Petit Le Mans team showed the energy density of Bio-Butanol was 85-90% of gasoline, compared over the 63% of ethanol. In reality for the same fuel load, a shorter range would be seen for a user as a result.

Race Tech Magazine also stated Bio-Butanol has less reactivity with water, resulting in higher part lifetime such as fuel pumps and fuel lines compared to ethanol and gasoline. The drivability of the Bio-Butanol competitors in the Petit Le Mans teams were said to be good, with smooth power curves and strong at low rpm. This carries over to ~~road use~~ road use, where the drivability of Bio-Butanol vehicles is predicted to be strong.

Compared to hydrogen combustion, the storage system is important to determine

Dan Mann

1900012

13/05/22

ACHA 6012

Page 12

The drivability of hydrogen cars. A method of storage is to store hydrogen gas which is ~~the~~ light. However, the energy density is not good, leading to a large capacity tank required. An alternative is ~~the~~ liquid storage.

This requires high pressure and low temperatures to keep liquid state, which is energy ~~require~~ <sup>intensive</sup> and potentially dangerous. A large tank like this may increase net vehicle mass.

The practicalities of ~~that~~ requiring more modifications for the user to make existing ICE Motors capable of hydrogen combustion will be more expensive in the short term for drivers and manufacturers. People may also be worried of owning a vehicle with a high pressure tank of flammable hydrogen.

C) The cost of hydrogen is still an issue as ~~it~~ electrolysis is expensive. However, water is used to form the hydrogen making this process fully sustainable. ~~The~~ The increase in water collection and storage will be required.

However, the energy required for ~~the~~ electrolysis is high, putting more load on the grid and increasing emission indirectly.

Bio-butanol is environmentally sustainable, however expensive infrastructure is required. BP invested over \$500 million over 10-years to understand this technology. There are currently no commercial facilities producing bio-butanol.

Dan Morris

1/10/09/12

13/05/22

ACHA 6012

Page 13

~~THE~~ Hydrogen is more likely to be a viable fuel for the future due to the existing ~~infrastructure~~ infrastructure compared to Bio-Gutanol. However, it still has major issues to solve, mainly energy density to be a viable replacement to petrol.