ATAR Notes

VCE CHEMISTRY 3&4
UNIT 3 REVISION LECTURE
APRIL 2019

Presented by:
Jack (:

LECTURE PLAN

BLOCK 1:
REACTION RATES & EQUILIBRIA

10:15 – 11:00

Want to un-bake your cake? Too bad, equilibrium laws say no ¯_(ツ)_/¯

<u>BREAK 1</u>

11:00 – 11:15

Come say hi and ask questions!

BLOCK 2:
ELECTROCHEMISTRY

11:15 – 12:00

Electrolysis? Wtf? halp PLS :o

<u>BREAK 2</u>

12:00 – 12:15

BLOCK 3:
FUELS & THERMOCHEMISTRY

12:15– 1:00

Probably covered extensively in Term 1, ezpz revision

LECTURE PLAN

Notes:

- *Lecture slides will be made available on ATAR Notes website and emailed out at the conclusion of the lecture series (i.e. after next weekend) so don't stress if you miss something!*
- *Feel free to leave at any time, you won't hurt my feelings okay maybe a bit :'(*
- *PLS don't be distracting, I know its easy to get restless but I'll really appreciate it if you can keep chatter until the breaks.*
- *We'll be going pretty fast, there's a lot of content to cover. The aim of today is to revise some stuff you've already done (with focus on the more intricate parts), whilst also providing you with a little bit of a head-start to the Unit 3 topics you'll be studying in term 3!*
- *PLS don't be afraid to come ask me any questions, whether they be about chemistry or VCE in general, I won't bite*

WHO ARE YOU???

- Jack
- Graduated from high school in 2017 (yikes time flies)
- BSc. Advanced Research - Computer Science & Maths @ Monash Uni
- 50 in Chemistry
- Will beat you at mariokart don’t @ me
- ATAR 99.80: 50 Chem, 50 Further, 46 Physics, 45 Bio, 45 English, 43 Methods, 43 Spesh

WHAT DO I NEED TO KNOW?

UNIT 3

FUELS

Fuel choices

- Definition of a fuel
- Comparing different fuels, advantages and disadvantages
- Big focus on comparing

Fuel calculations

- Enthalpy change
- Thermochemical equations
- Universal gas equation
- Stoichiometric calculations

ELECTROCHEMISTRY

Redox basics

- Oxidation and reduction
- Redox half equations and balancing overall equations

Galvanic cells

- Energy transformation
- Common design features (anode, cathode, salt bridge etc.)
- Understanding the EC series

Fuel cells

- Comparing to galvanic cells
- Comparison against combustible fuels
- Design features

Electrolysis

- General principles and structures
- Using EC series to predict reactions
- Stoichiometry and Faradays laws
- Secondary cells

EQUILIBRIA

Reaction rates

- Collision theory
- Maxwell-Boltzmann distributions
- Energy profile diagrams
- Factors affecting reaction rate

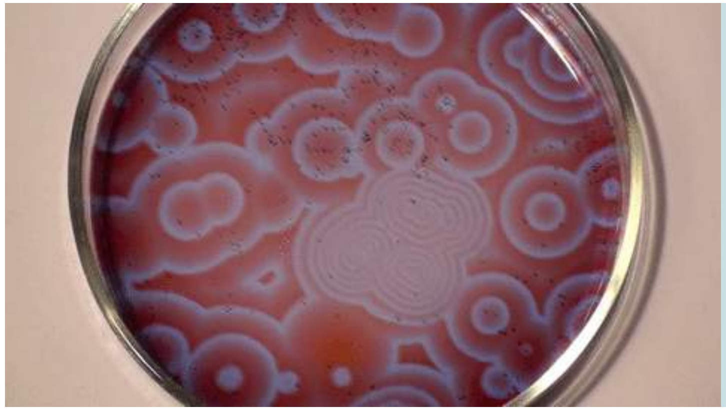
Reaction extents

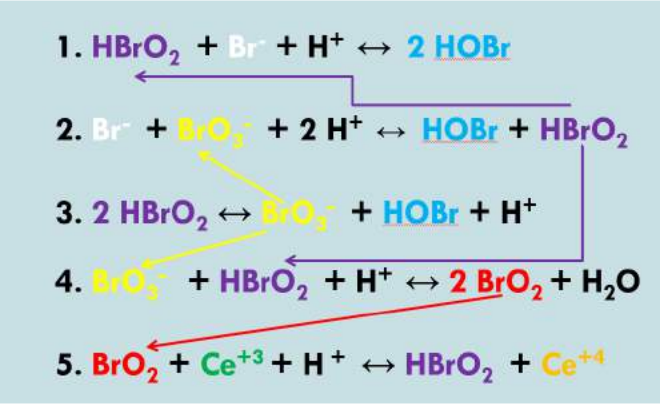
- Understanding equilibrium systems
- Equilibrium constants and reaction quotients
- Le Chatelier’s principle
- Concentration vs. time graphs

$$\begin{array}{rl} & IO_3^{-1}{}_{(aq)} + HSO_3^{-1}{}_{(aq)} \rightarrow I^{-1}{}_{(aq)} + SO_4^{-2}{}_{(aq)} + H^{+1}{}_{(aq)} \\ & 2I^{-1}{}_{(aq)} + 6H^{+1}{}_{(aq)} + IO_3^{-1}{}_{(aq)} \rightarrow I_{2(aq)} + 3H_2O_{(l)} \\ + & I_{2(aq)} + HSO_3^{-1}{}_{(aq)} + H_2O_{(l)} \rightarrow 2I^{-1}{}_{(aq)} + SO_4^{-2}{}_{(aq)} + 2H^{+1}{}_{(aq)} \\ \hline & 2IO_3^{-1}{}_{(aq)} + 2HSO_3^{-1}{}_{(aq)} \rightarrow 2SO_4^{-2}{}_{(aq)} + 2H_2O_{(l)} \end{array}$$

$$Rate = k\left[IO_3^{-1}\right]^m\left[HSO_3^{-1}\right]^n$$

TOPIC 1:
RATES & EQUILIBRIA





1. $HBrO_2 + Br^- + H^+ \leftrightarrow 2\ HOBr$
2. $Br^- + BrO_3^- + 2\ H^+ \leftrightarrow HOBr + HBrO_2$
3. $2\ HBrO_2 \leftrightarrow BrO_3^- + HOBr + H^+$
4. $BrO_3^- + HBrO_2 + H^+ \leftrightarrow 2\ BrO_2 + H_2O$
5. $BrO_2 + Ce^{+3} + H^+ \leftrightarrow HBrO_2 + Ce^{+4}$

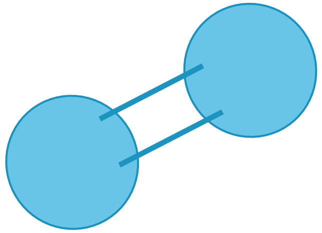
RATES & EQUILIBRIA

REACTION RATES

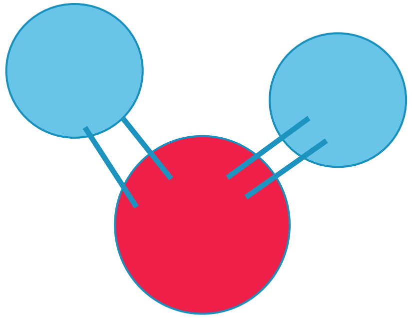
- How and why reactions occur
- Why different reactions occur at different rates
- How we can change the rate of reaction

EQUILIRBIUM

- Irreversible vs. reversible reactions
- Dynamic equilibrium and the extent of a reaction
- Quantifying the extent of a reaction (equilibrium constant)
- Calculations and predicting changes in equilibrium position



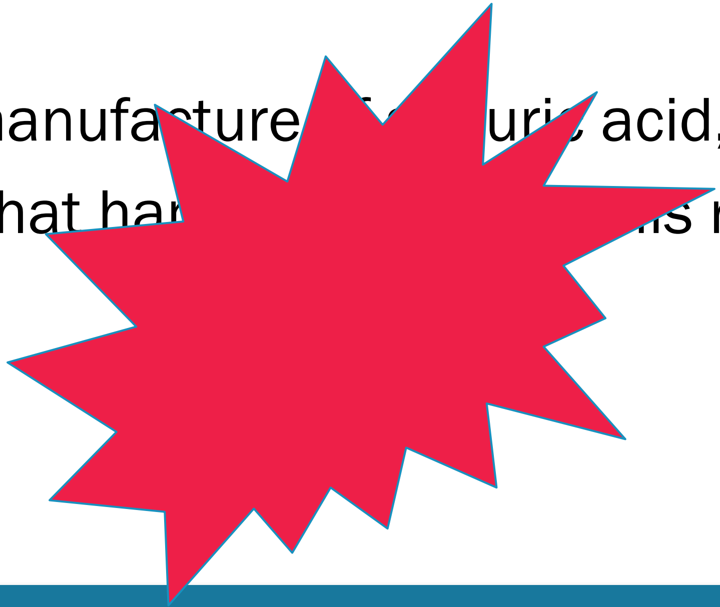
REACTION RATES



We all know that chemical reactions **occur**, but **how do they occur**?

Consider the reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$



- Important step in the manufa ture uri acid, H_2SO_4
- On a molecular level, what ha is reaction?

COLLISION THEORY

- *Chemical reactions are a result of collisions between molecules.*

- However, not all collisions result in a reaction!
- Collisions that result in reaction = *successful* (or ‘fruitful’)

Two main aspects determine whether a collision is successful:

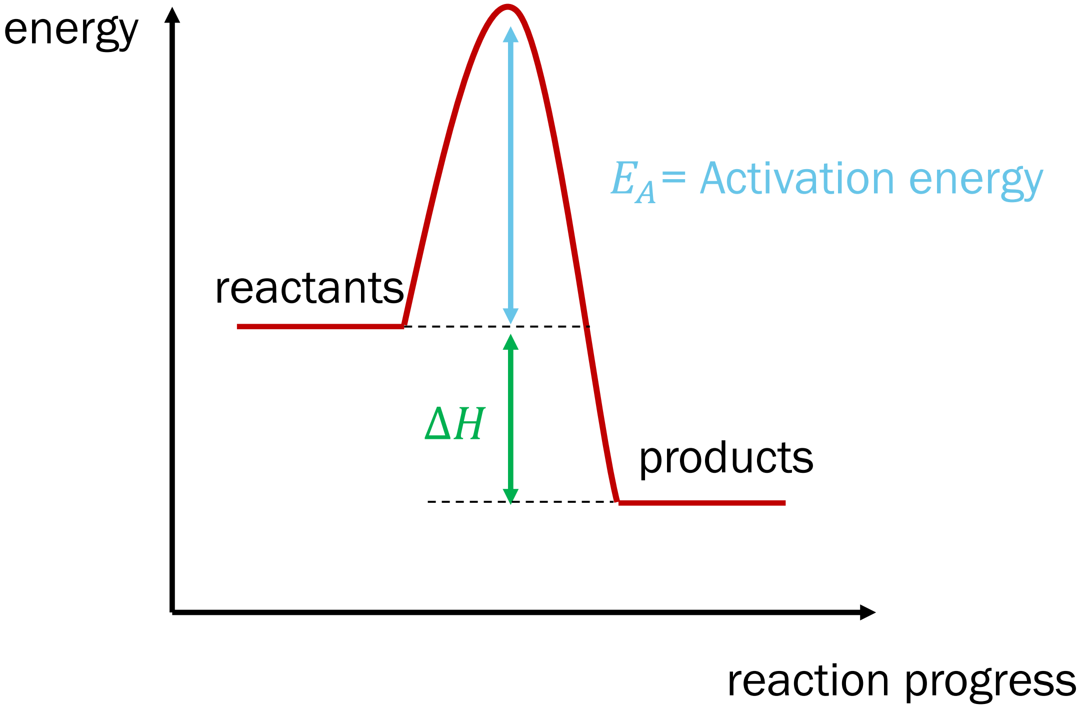
→ 1. Collisions must be *sufficiently energetic*

→ 2. Collisions must occur with *correct orientation*

COLLISION THEORY

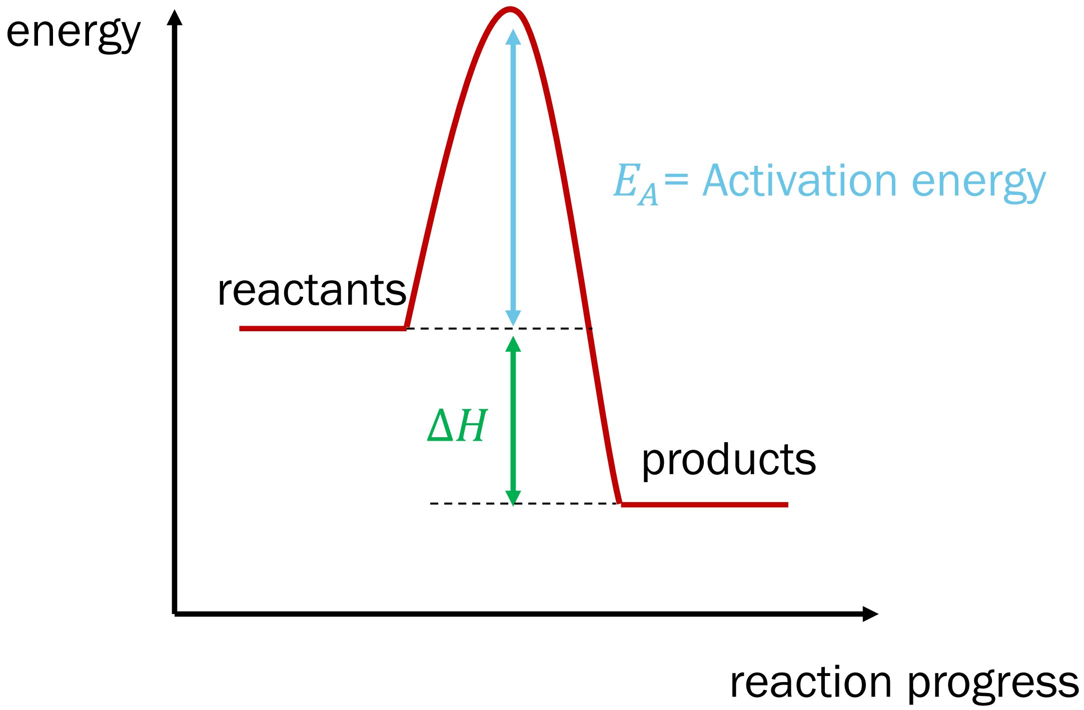
1. Collisions must be *sufficiently energetic:*

→ Particles must collide with sufficient energy to overcome the activation energy (E_A) of the reaction.



COLLISION THEORY

1. Collisions must be *sufficiently energetic*:



Reaction energy profile

- Either sides ⇒ reactants/products in **ground state**
- Top of hill ⇒ transition state (highest energy, therefore unstable)

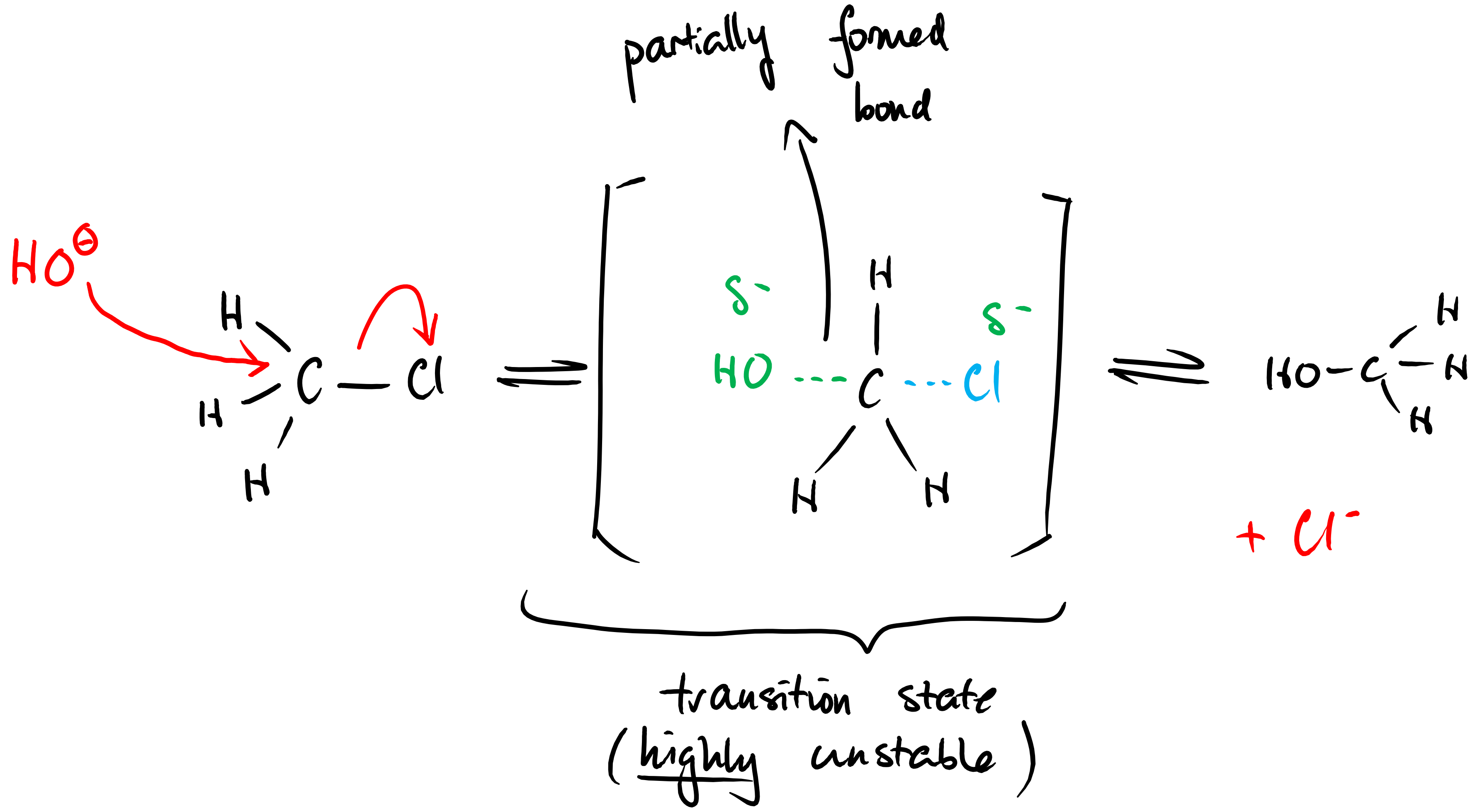
Activation energy, E_A

- Can be described as *activation barrier*
- E_A = energy needed to go from *ground state* to *transition state*
- Collisions must be sufficiently energetic to be successful

Energy of collision ≥ Activation energy

COLLISION THEORY

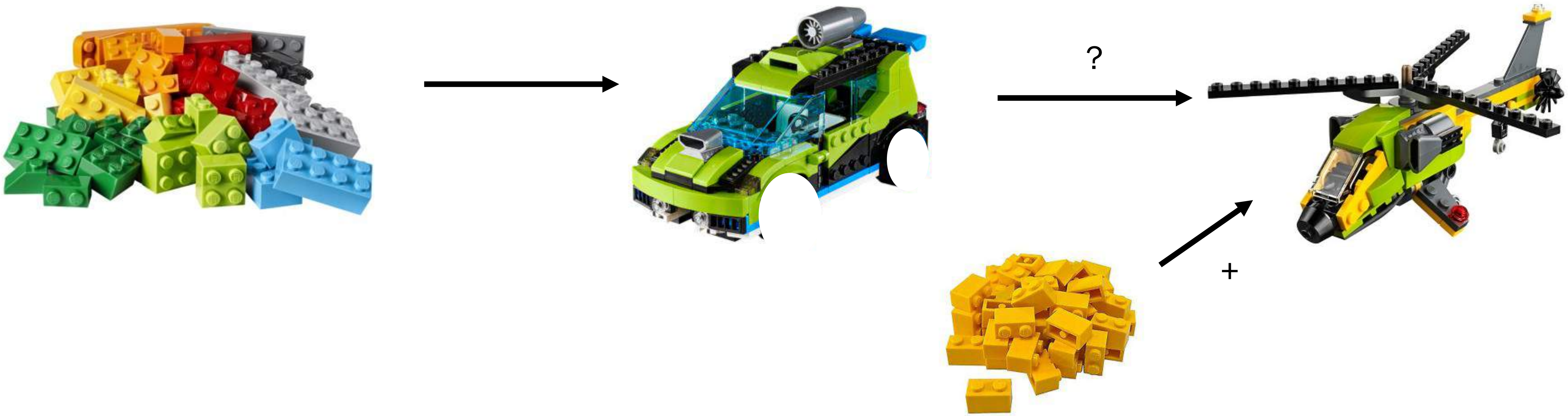
1. Collisions must be *sufficiently energetic:*



COLLISION THEORY

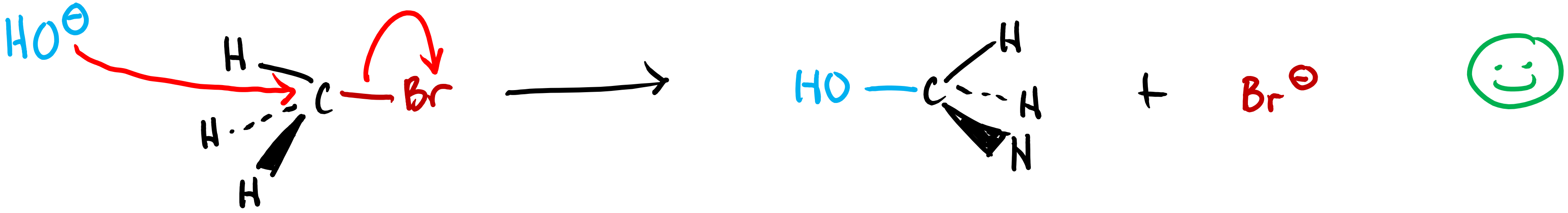
1. Collisions must be *sufficiently energetic:*

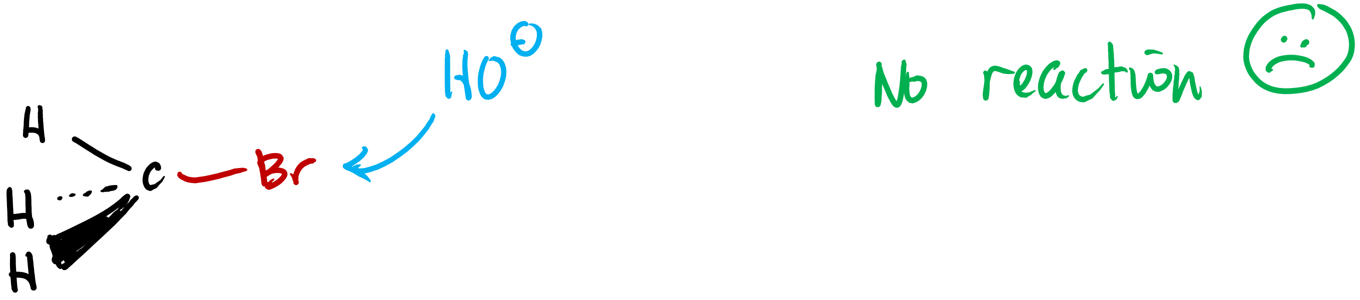
→ Still not making sense? Let's think about lego! Imagine lego bricks are like atoms making up molecules…



COLLISION THEORY

→ 2. Collisions must occur with *correct orientation:*





No reaction

COLLISION THEORY

To reiterate, the main aspects determine whether a collision is successful:

→ 1. Collisions must be *sufficiently energetic*

→ 2. Collisions must occur with *correct orientation*

RATES OF REACTION

Being able to alter reaction rates is extremely important in every aspect of life!!

- → Energy in our body needs to be released quick enough to sustain our energy requirements.
- → Batteries need to create electrical energy fast enough to power electronic devices .
- → Food needs to preserved as long as possible, we want the reactions involved in rotting to proceed as slowly as possible.
- → Industry want reactions to occur as quickly as possible, so they can make more chemicals and thus more money!
- → etc. etc. etc.

→ Key point: Most of the time, we want to increase the rate of reaction!
How do we do this?

RATES OF REACTION

We are concerned with making reactions **go faster**. What can we do?

There are **two** fundamental ways to increase reaction rate:

Method 1: Increase *collision frequency*

- Higher temperature
- Higher pressure and concentration
- Higher surface area

Method 2: Increase the *proportion of successful collisions*

- Higher temperature
- Catalysis

As we will see, we can utilise both methods to increase reaction rate :)

RATES OF REACTION

Method 1: Increase collision frequency:

Increase temperature

- → Higher temp ⇒ faster movement of particles ⇒ higher collision frequency ⇒ higher frequency of successful/fruitful collisions ⇒ higher reaction rate

Increase concentration (solutes), pressure (gases)

- → More particles ⇒ more collisions ⇒ more successful/fruitful collisions ⇒ higher reaction rate

Increase surface area (solids or surfaces)

- → Higher surface area ⇒ more 'stuff' to bump into ⇒ more collisions ⇒ more successful/fruitful collisions ⇒ higher reaction rate

RATES OF REACTION

Method 2: **Increase proportion of successful collisions:**

Increase temperature

→ Higher temp ⇒ particles move faster ⇒ have more energy ⇒ more collisions overcome E_A

→ Key point: Increasing temperature affects reaction rate in both ways!

- Higher temp ⇒ higher collision freq.
- Higher temp ⇒ higher success rate (**)

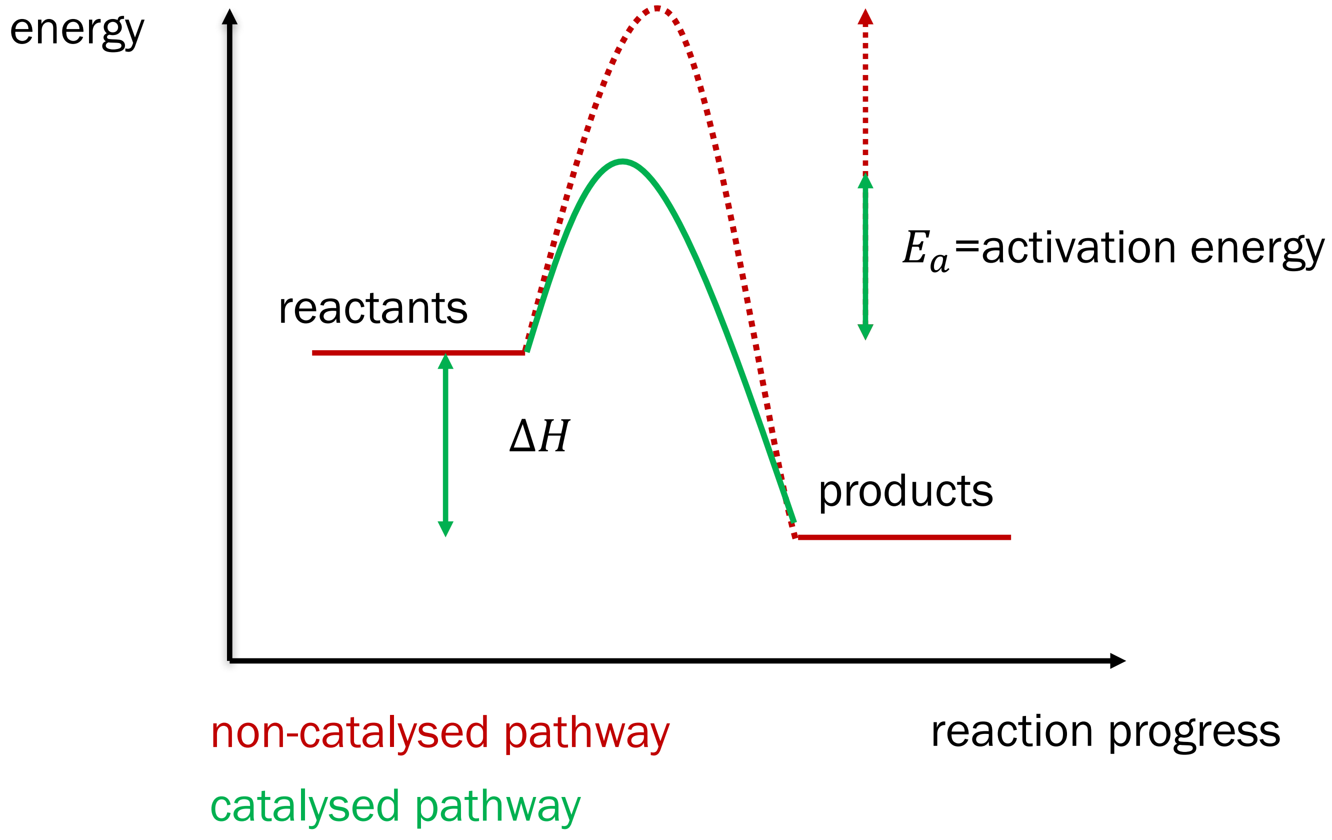
RATES OF REACTION

Method 2: **Increase proportion of successful collisions:**

Use a catalyst

- Catalysts provide an *alternative reaction pathway* with lower activation energy (E_A) that allows more collisions to succeed
- **Important:** *alternative* reaction pathway – catalysts change the reaction mechanism!

RATES OF REACTION



When you successfully catalyse your reaction and its now 10^{17} times faster

RATES OF REACTION

Question 17

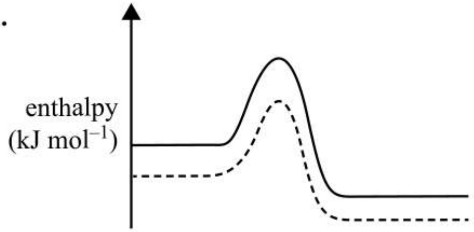
The oxidation of sulfur dioxide is an exothermic reaction. The reaction is catalysed by vanadium(V) oxide.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

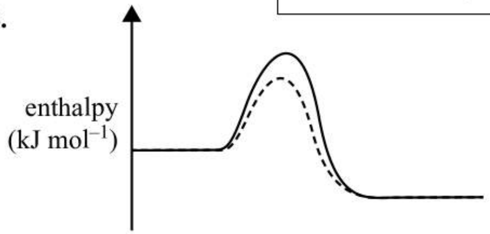
Which one of the following energy profile diagrams correctly represents both the catalysed and the uncatalysed reaction?

------- catalysed reaction
——— uncatalysed reaction

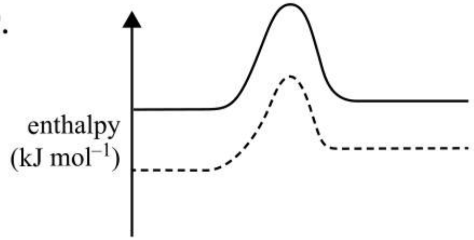
A.



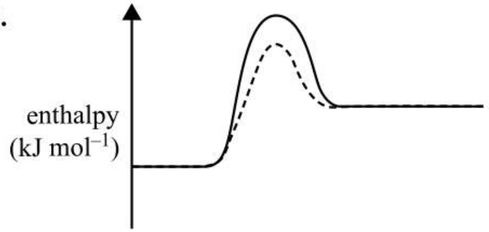
B.



C.



D.



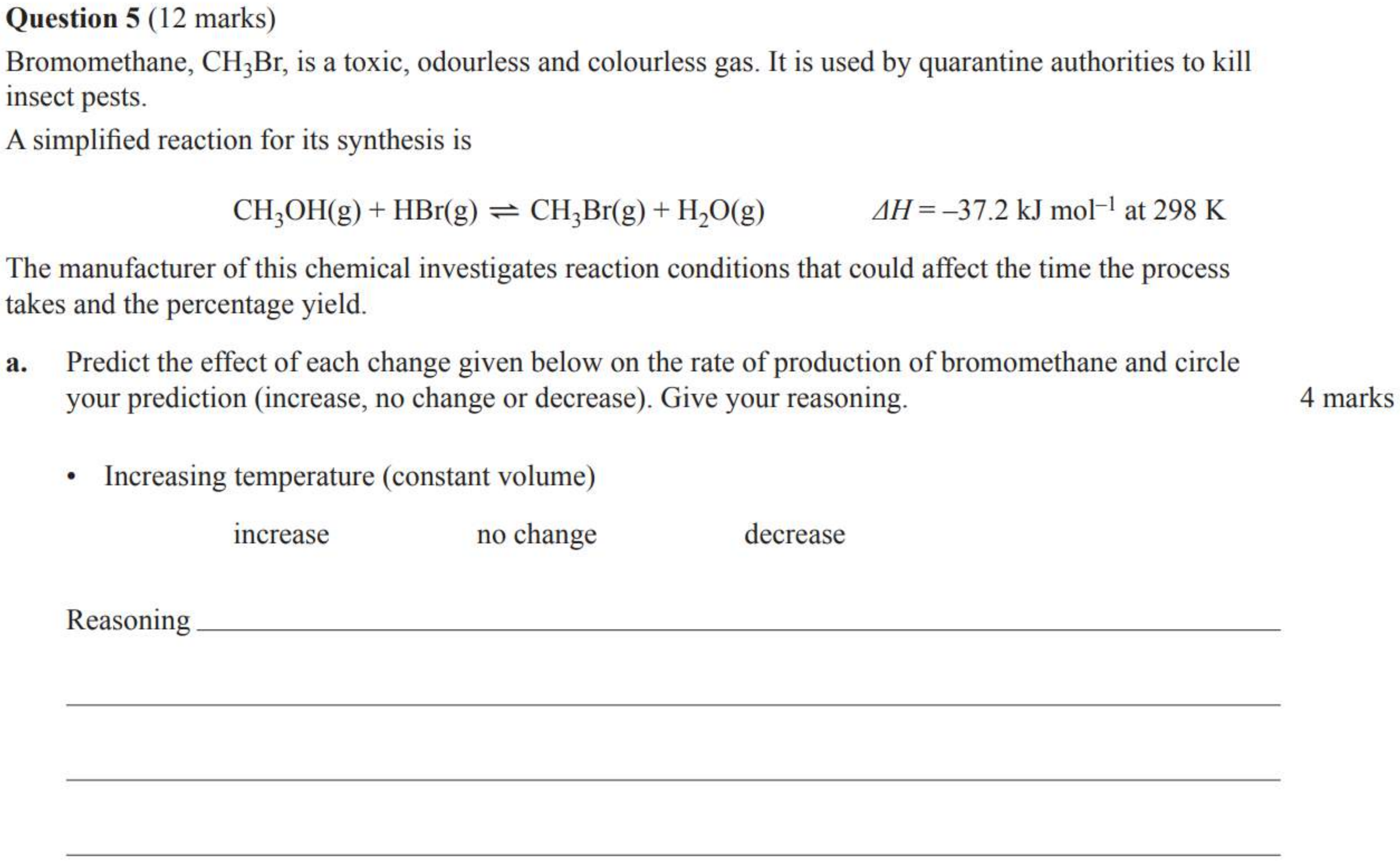
RATES OF REACTION

To summarise, 5 major factors:

- Surface area of solid reactants
- Concentration of reactants in solution
- Gas pressure
- Temperature
- Presence of catalysts

Be careful with these!

PRACTICE QUESTION



Question 5 (12 marks)

Bromomethane, CH_3Br, is a toxic, odourless and colourless gas. It is used by quarantine authorities to kill insect pests.

A simplified reaction for its synthesis is

$$CH_3OH(g) + HBr(g) \rightleftharpoons CH_3Br(g) + H_2O(g) \qquad \Delta H = -37.2 \text{ kJ mol}^{-1} \text{ at } 298 \text{ K}$$

The manufacturer of this chemical investigates reaction conditions that could affect the time the process takes and the percentage yield.

a. Predict the effect of each change given below on the rate of production of bromomethane and circle your prediction (increase, no change or decrease). Give your reasoning. 4 marks

- Increasing temperature (constant volume)

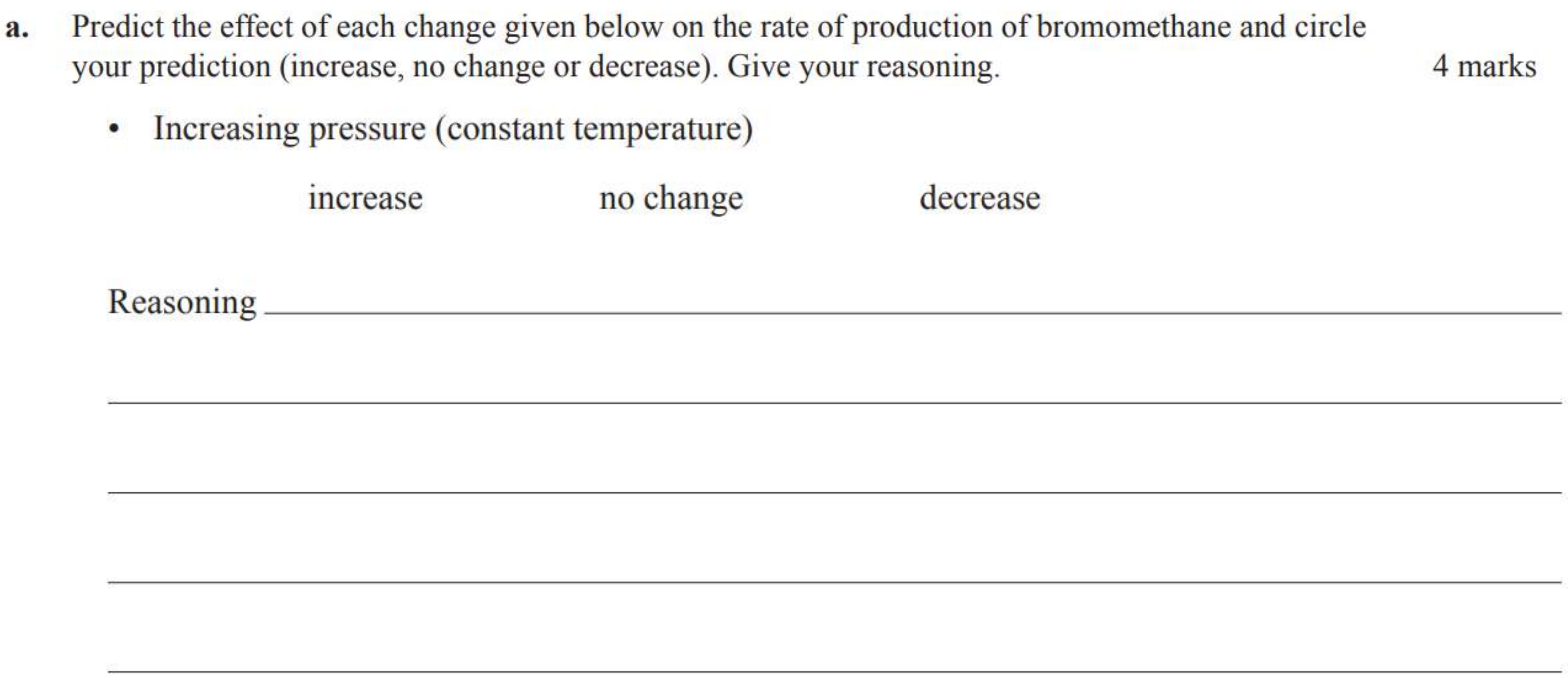
increase no change decrease

Reasoning

VCAA 2016 Q3

PRACTICE QUESTION

$$CH_3OH(g) + HBr(g) \rightleftharpoons CH_3Br(g) + H_2O(g) \qquad \Delta H = -32.7\ \text{kJ mol}^{-1}$$ at 298K



a. Predict the effect of each change given below on the rate of production of bromomethane and circle your prediction (increase, no change or decrease). Give your reasoning. 4 marks

- Increasing pressure (constant temperature)

increase no change decrease

Reasoning ______________________________

____

____

____

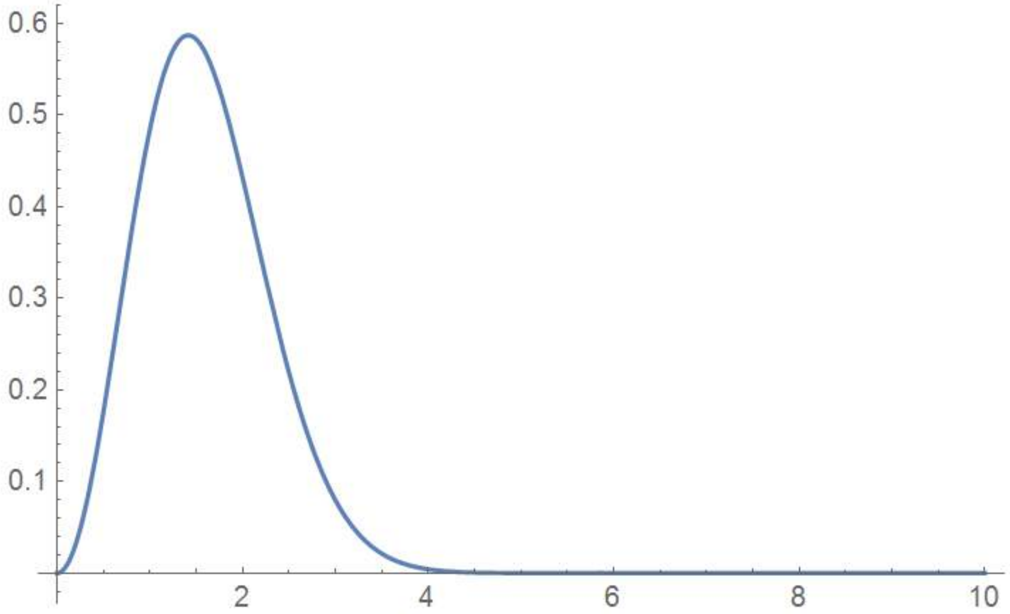
____

VCAA 2016 Q3

MAXWELL-BOLTZMANN DISTRIBUTION

A mathematical model for the distribution of particle speeds that varies with temperature.

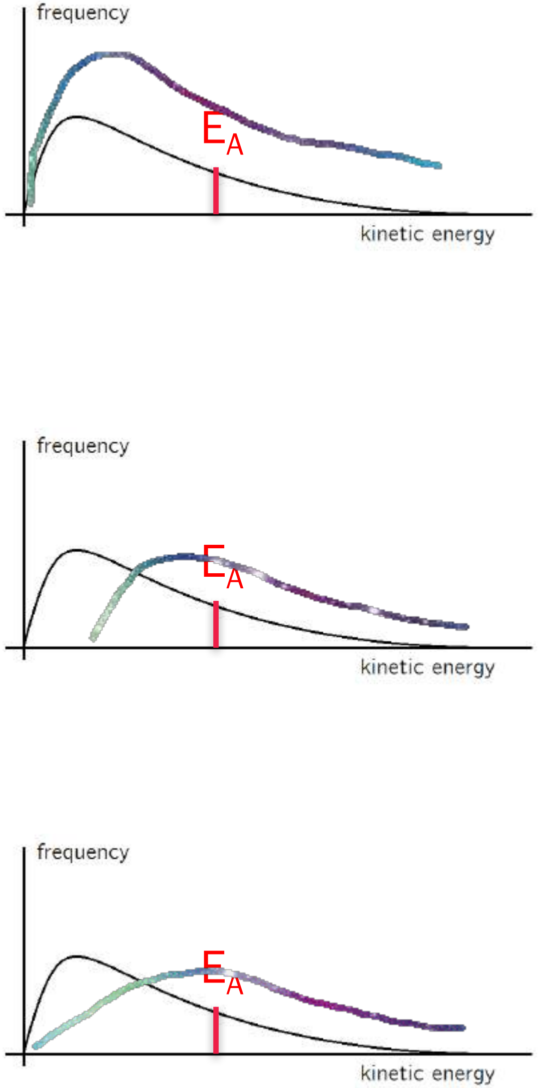
- Shaded area represents number of particles with $E \geq E_A$
- Only collisions with energy above E_A will be successful



https://www.desmos.com/calculator/s2x18iawnh

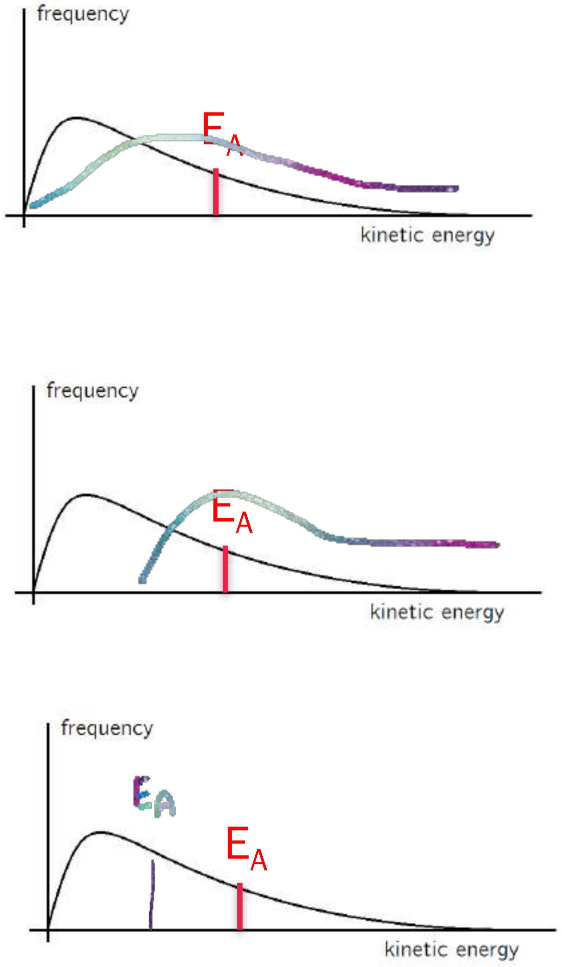
MAXWELL-BOLTZMANN DISTRIBUTION

Increase in temp:



MAXWELL-BOLTZMANN DISTRIBUTION

Use of catalyst:



RATE OF REACTION VS. EXTENT OF REACTION

- Rate of reaction:
  - How FAST the reaction occurs - how fast reactants are converted to products
  - In terms of equilibrium? How fast does it reach equilibrium

- Extent of reaction:
  - How FAR has the reaction gone – how much reactant has been converted to product
  - This is where equilibrium comes in!

Don’t mix these up!

IRREVERSIBLE & REVERSIBLE REACTIONS

$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

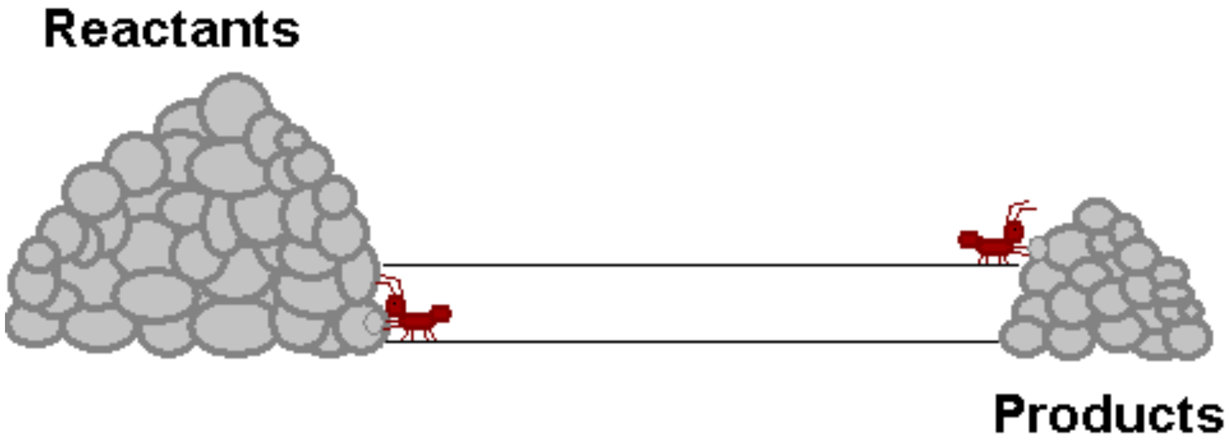
- Some reactions are irreversible, products can't be converted back into reactants.
- For example, you can't un-bake a cake!

$I_3^-(aq) \rightleftharpoons I_2(l) + I^-(aq)$

- However, some reactions are reversible!
- In these reactions, products can also be converted back into reactants.
- An equilibrium arrow ($\rightleftharpoons$) is used to indicate a reaction is reversible!

EQUILIBRIUM

- At ***equilibrium***, the forward and reverse reactions exactly cancel each other out!!



- Chemical equilibrium is sometimes described as dynamic; even though it doesn’t look like any reaction is occurring, there is!
- No reaction appears to occur because the forwards and reverse reaction occur exactly at the same rate, meaning the amount of each doesn’t change.

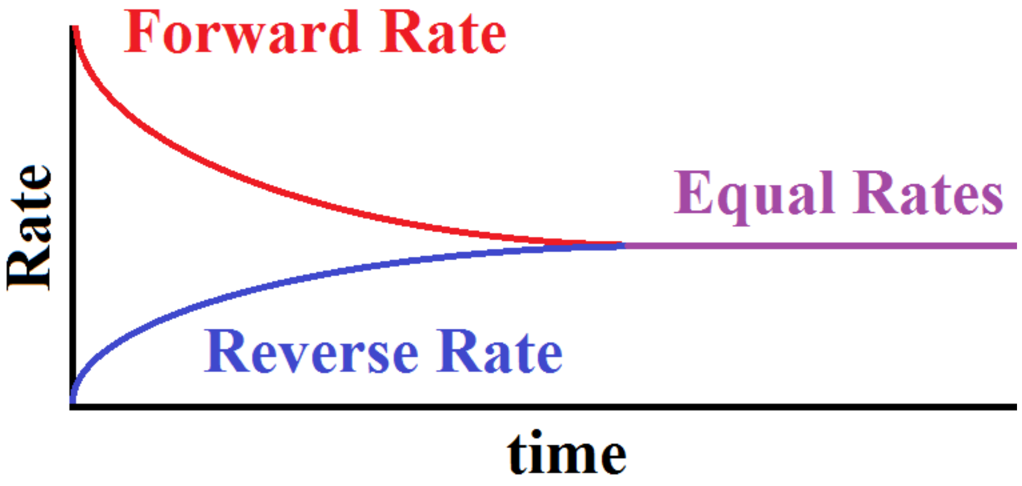
EQUILIBRIUM

- Here’s a little analogy that may be helpful…

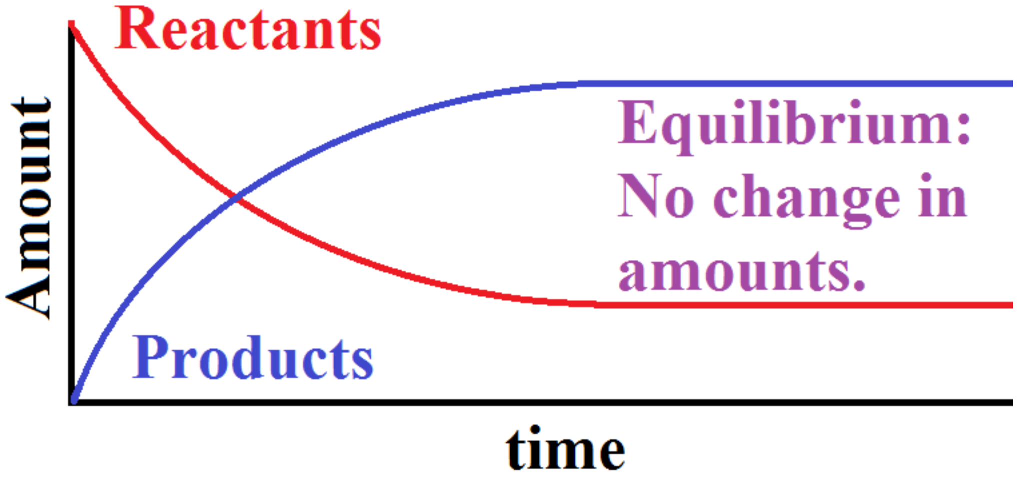
me

my
bank
account

EQUILIBRIUM



→ Rate of forward reaction = rate of reverse reaction



→ Concentrations of chemicals don’t change!

EQUILIBRIUM

- Again, reversible reactions will attain **equilibrium** when forward and reverse rates are **equal.**

- The system will remain at equilibrium, unless it is disturbed!

What happens at equilibrium?

→ Forward reaction rate = Reverse reaction rate

→ Net reaction rate = (Forward rate) – (Reverse rate) = 0

→ Concentrations of chemical species are constant

EQUILIBRIUM

Here's a fun example, do a dare: drinking $0.1\ \mathrm{M}\ \mathrm{CH_3COOH}$ vs. drinking $0.1\ \mathrm{M}\ \mathrm{HNO_3}$?

Which one would you choose???

$\mathrm{HNO_3} \Rightarrow$ very strong acid (~99% ionisation)

$$\mathrm{HNO_{3(aq)}} \rightleftharpoons \mathrm{H^{+}(aq)} + \mathrm{NO_3^{-}(aq)}$$

$\mathrm{CH_3COOH} \Rightarrow$ very weak acid (~1% ionisation)

$$\mathrm{CH_3COOH(aq)} \rightleftharpoons \mathrm{CH_3COO^{-}(aq)} + \mathrm{H^{+}(aq)}$$

EQUILIBRIUM CONSTANT

How do we quantify equilibrium and the extent of a reaction?

The **extent** of a chemical reaction is described by its equilibrium constant *(K)*.

$$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq) \qquad K = 1.7\times 10^{-5} \text{ at } 25\ ^\circ C$$

$$HNO_{3(aq)} \rightleftharpoons H^+(aq) + NO_3^-(aq) \qquad K \approx 22 \text{ at } 25\ ^\circ C$$

EQUILIBRIUM CONSTANT

Say we have some reaction….

$$aA + bB \rightleftharpoons cC + dD$$

We define the **equilibrium constant,** K

$$K = \frac{[C]_{eqm}^{c}[D]_{eqm}^{d}}{[A]_{eqm}^{a}[B]_{eqm}^{b}}$$

$[A]_{eqm}, \ldots =$ concentration of A at equilibrium, so on

Like ΔH and E°, *K* values are associated with chemical equations.

K depends only on temperature!!!

EQUILIBRIUM CONSTANT

What does K tell us?

- K can be used for a lot of calculations (as you'll see next term!!)
- Qualitatively, the value of K gives indication of reaction extent.

$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$ $K = 1.7\times 10^{-5}$ at 25 °C

$HNO_{3(aq)} \rightleftharpoons H^+(aq) + NO_3^-(aq)$ $K \approx 22$ at 25 °C


When your girl sends you "K."

EQUILIBRIUM CONSTANT: EXAMPLE

Sulfur trioxide gas will spontaneously decompose into SO_2 and O_2 in the equilibrium

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g),\ K = ?$$

In a particular sample of gas, equilibrium concentrations were found to be $[SO_3] = 0.100M$, $[SO_2] = 0.250M$ and $[O_2] = 0.037$. Find a value for *K*.

ATTENTION!

Where/when can I get the lecture slides?????????

- Every lecture series I get asked this same one question, so, instead of answering it a bajillion times, let me show you!!

https://atarnotes.com/

Me: flicking through the lecture slides at great speed

Students trying to copy everything down:

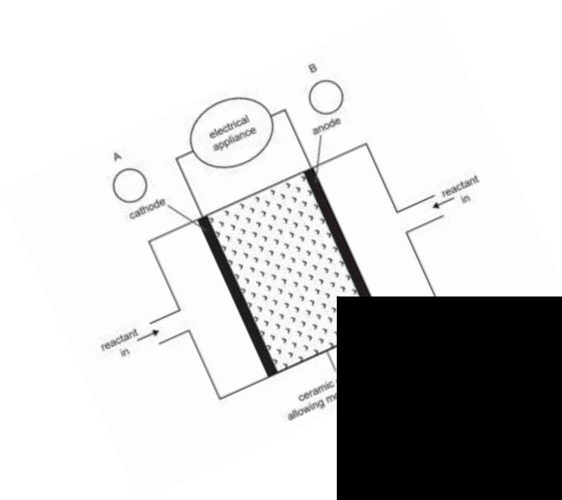
BLOCK 1 SUMMARY

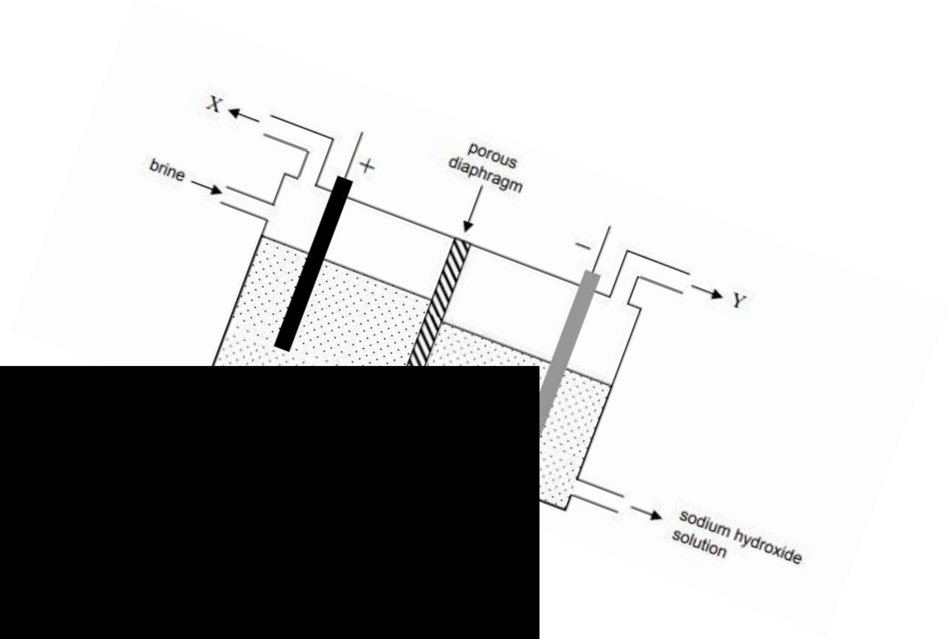
- Reaction rate basics
- Reaction rate vs. extent
- Reversible and irreversible reactions
- Introduction to equilibrium
- Coming up after the break:

  → Electrochemistry!

BREAK 1 – 15 Minutes

QUESTIONS?





TOPIC 2: ELECTROCHEMISTRY

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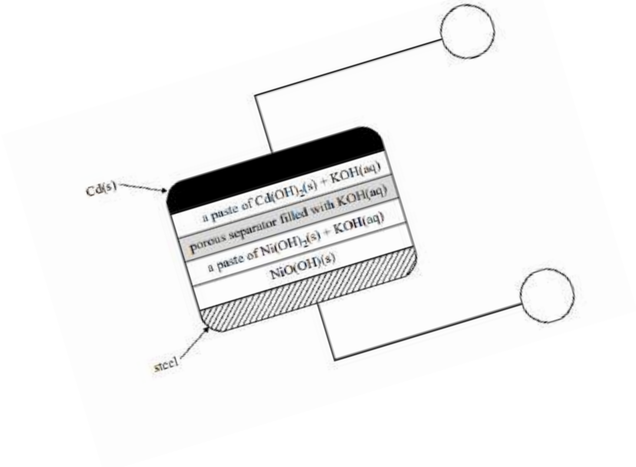
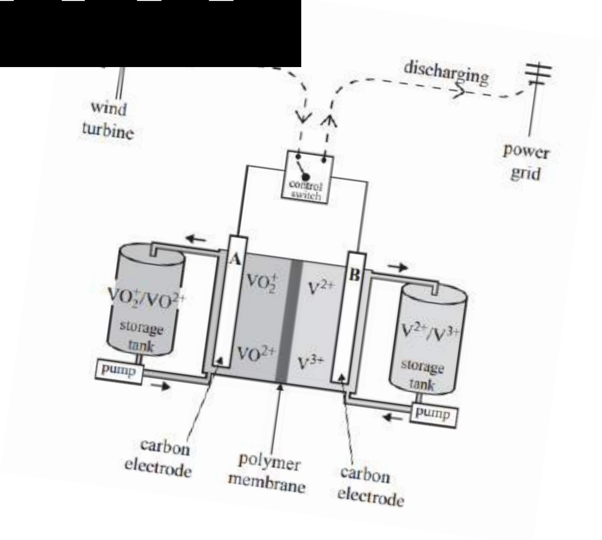




REDOX BASICS

OIL

RIG

OXIDATION

- → is loss of electrons
- → $M \rightleftharpoons M^{+} + e^{-}$

REDUCTION

- → is gain of electrons
- → $M^{+} + e^{-} \rightleftharpoons M$

Image credit: Wikipedia

REDOX BASICS

- In a redox reaction, one species is the oxidant, and the other is the reductant.

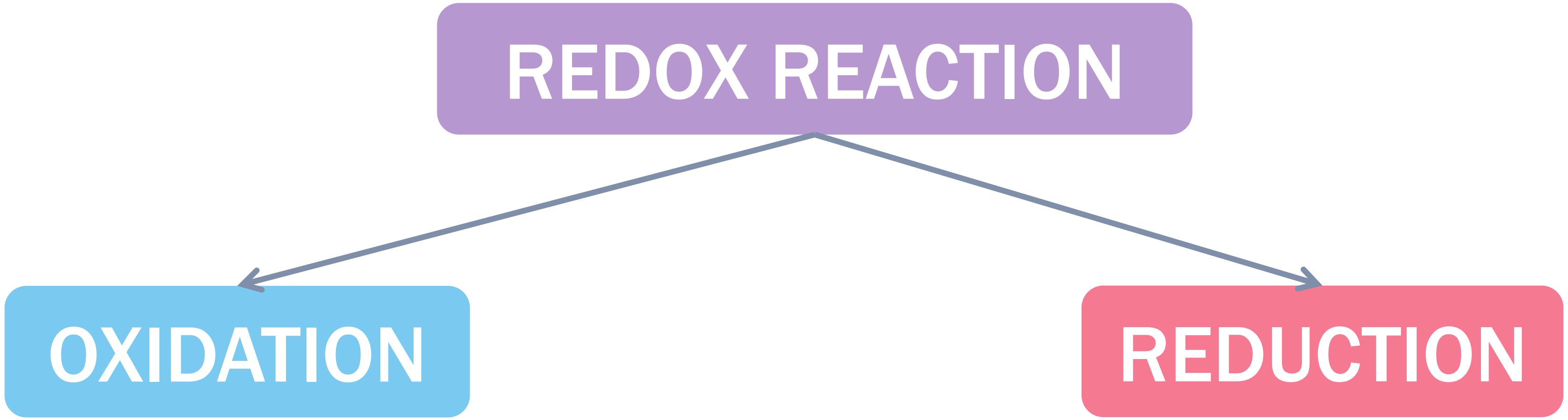
Terminology matters…

→ The oxidant *causes* oxidation (of the reductant) and is itself reduced!

→ The reductant *causes* reduction (of the oxidant) and is itself oxidised!

- Another way you can think about it, a **teacher** does the **teaching**, just like an **oxidant** does the **oxidising.**

REDOX BASICS



REDOX REACTION

OXIDATION

REDUCTION

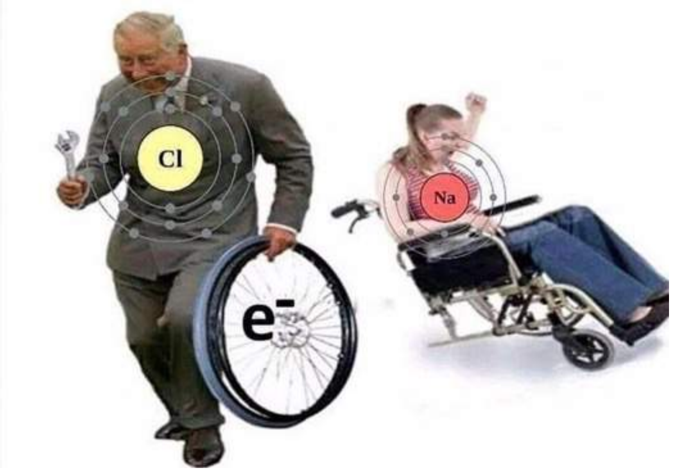
- Oxidation and reduction always occur together. You can’t have one without the other!
- Electrons ‘lost’ by one species have to be ‘gained’ somewhere else, just like how energy is conserved, ‘electrons’ have to be conserved, we can’t just destroy them!

OXIDATION STATES

1) $Pb^{2+}(aq) + 2Cl^{-}(aq) \longrightarrow PbCl_2(s)$

2) $NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$

3) $2Al(s) + 3Cl_2(g) \longrightarrow 2AlCl_3(s)$



- So how can we determine if a reaction is redox?
- We use oxidation numbers, also called *oxidation states*

OXIDATION STATES

- There’s a few rules to remember! Hopefully you’re feeling comfortable with these!

1 → Oxidation states of free elements $(\overset{0}{\mathrm{Fe}}, \overset{0}{\mathrm{Na}}, \overset{0}{\mathrm{Cl}}_2, \overset{0}{\mathrm{He}}\ \mathrm{etc.})$ is 0.

2 → Oxidation states of simple ions $(\overset{+1}{\mathrm{Na}}{}^{+}, \overset{-1}{\mathrm{Cl}}{}^{-}, \overset{+2}{\mathrm{Mg}}{}^{2+}, \overset{-3}{\mathrm{N}}{}^{3-}\ \mathrm{etc.})$ is equal to the charge on that ion.

3 → In compounds:

- → Main group metals have oxidation state equal to charge of their ions $(\overset{+1}{\mathrm{Na}}\mathrm{Cl}, \overset{+2}{\mathrm{Mg}}\mathrm{Br}_2)$
- → Hydrogen is *almost* always +1, and oxygen is *almost* always -2 $(\overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}})$
- → Sum of all oxidation states must equal charge on species

$$\overset{+4}{\mathrm{C}}\overset{-2}{\mathrm{O}}_2 \qquad \overset{+5}{\mathrm{P}}\overset{-2}{\mathrm{O}}_4{}^{3-} \qquad \overset{+1}{\mathrm{H}}_3\overset{-2}{\mathrm{O}}{}^{+}$$

$$+4 + 2(-2) = 0 \qquad +5 + 4(-2) = -3 \qquad 3(+1) + (-2) = +1$$

OXIDATION STATES

1) $\overset{+2}{\mathrm{Pb}}^{2+}(aq) + 2\overset{-1}{\mathrm{Cl}}^{-}(aq) \longrightarrow \overset{+2}{\mathrm{Pb}}\overset{-1}{\mathrm{Cl}}_2(s)$ ✖ Not redox :[

2) $\overset{+1}{\mathrm{Na}}\overset{-2}{\mathrm{O}}\overset{+1}{\mathrm{H}}(aq) + \overset{+1}{\mathrm{H}}\overset{-1}{\mathrm{Cl}}(aq) \longrightarrow \overset{+1}{\mathrm{Na}}\overset{-1}{\mathrm{Cl}}(aq) + \overset{+1}{\mathrm{H}}_2\overset{-2}{\mathrm{O}}(l)$ ✖ Not redox :[

3) $2\overset{0}{\mathrm{Al}}(s) + 3\overset{0}{\mathrm{Cl}}_2(g) \longrightarrow 2\overset{+3}{\mathrm{Al}}\overset{-1}{\mathrm{Cl}}_3(s)$ ✔ Redox :D

⟶ A reaction will only be redox if two or more atoms have a change in oxidation states!

⟶ If the oxidation state *reduces* then that species was reduced! (e.g. Cl goes from 0 to -1)

⟶ If the oxidation state *increases* then that species was oxidised! (e.g. Al goes from 0 to +3)

BALANCING HALF EQUATIONS

- How do we actually figure out the half equations though? D:
- We use the *KOHES* method!

→ **K** Balance the *K*ey atoms – all atoms except H and O.

→ **O** Balance the *O*xygen atoms – by adding $\mathrm{H_2O}$.

→ **H** Balance the *H*ydrogen atoms – by adding H^+ ions.

→ **E** Balance charge – by adding *E*lectrons (e^-).

→ **S** Don’t forget *S*tates!

BALANCING HALF EQUATIONS

- When using the KOHES method, we have been making an assumption; that the reaction medium is *acidic.*
- What happens if instead the reaction medium is ***basic/alkaline?*** We need an ***extra step!***

→ **K** Balance the *K*ey atoms – all atoms except H and O.

→ **O** Balance the *O*xygen atoms – by adding H_2O.

→ **H** Balance the *H*ydrogen atoms – by adding H^+ ions.

→ **H** Cancel out the *H*ydrogen ions – by adding OH^- ions.

→ **E** Balance charge – by adding *E*lectrons (e^-).

→ **S** Don't forget *S*tates!

EXAMPLE QUESTION

Write the half-equation for the oxidation of $\mathrm{MnO_2}$ to $\mathrm{MnO_4}^-$ in an alkaline environment.

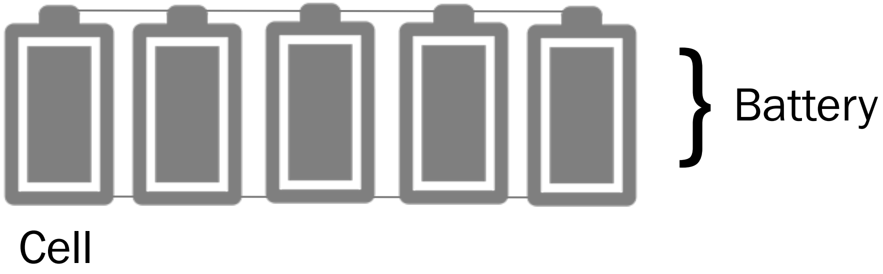
PRACTICE QUESTION

Write the half-equation for the reduction of $\mathrm{O_2}$ to $\mathrm{H_2O}$ in a basic solution.

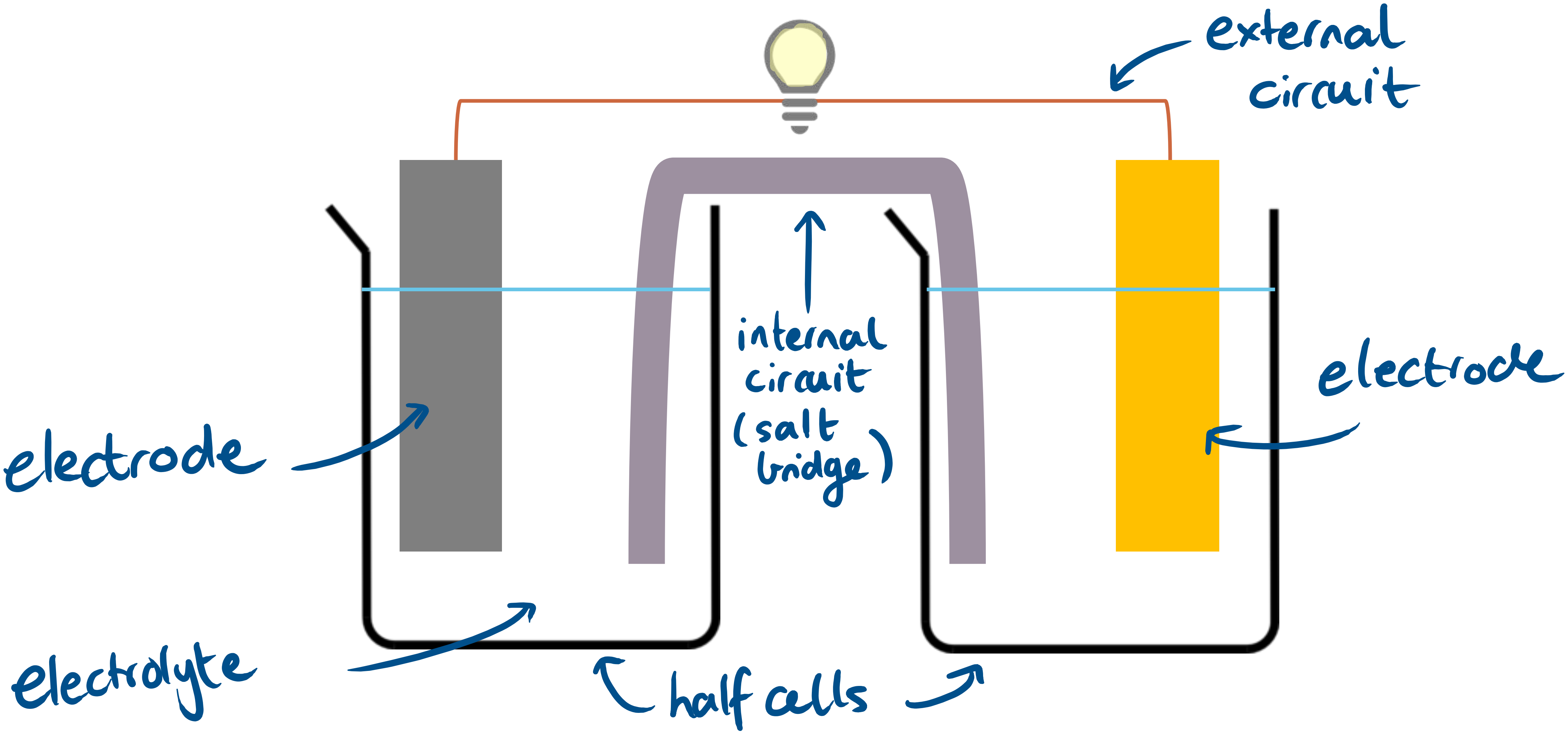
GALVANIC CELLS

- We’ve all used galvanic cells before, they’re an essential part of life as we know it!
- A galvanic cell is simply any device that converts chemical energy into electrical energy.

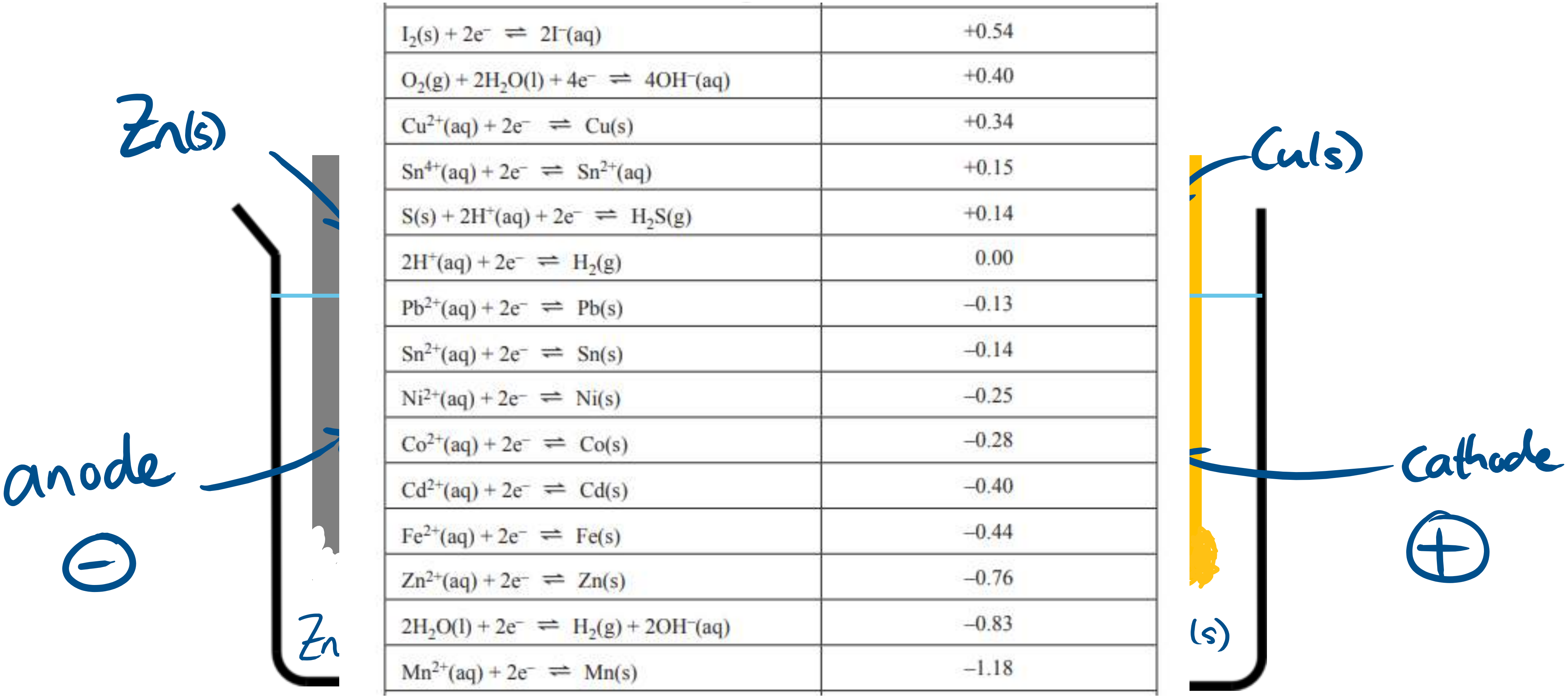
CHEMICAL ENERGY → **ELECTRICAL ENERGY**



GALVANIC CELLS - TERMINOLOGY



GALVANIC CELLS – EXAMPLE



$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	−0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	−0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	−0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	−0.28
$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	−0.40
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	−0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	−1.18

$$\mathrm{Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Cu(s)}$$

REDOX BASICS

AN OIL

RIG CAT

OXIDATION

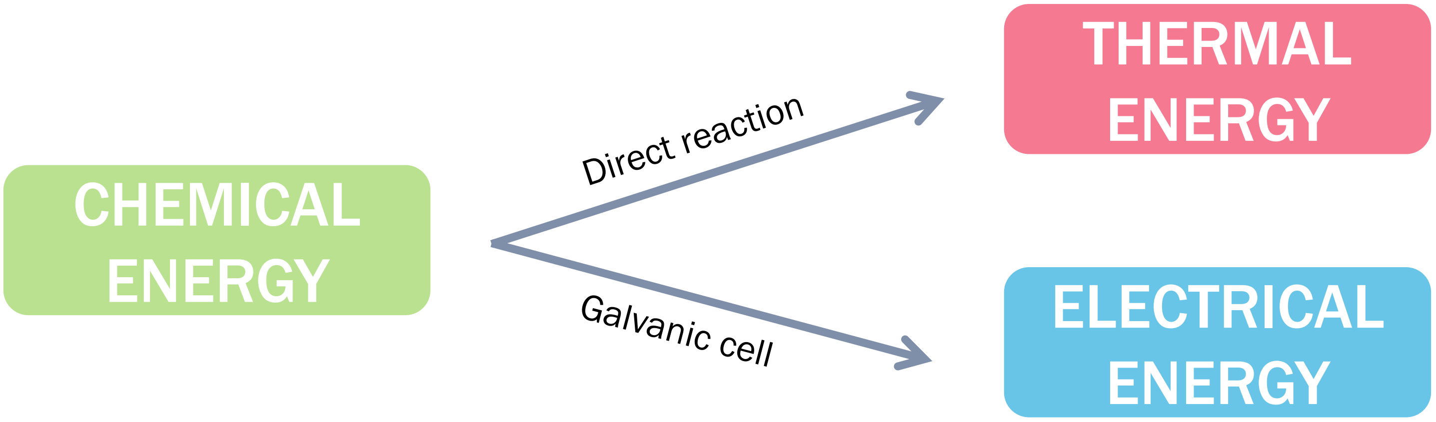
- → loss of electrons
- → occurs at the anode

REDUCTION

- → gain of electrons
- → occurs at the cathode

Image credit: Wikipedia

GALVANIC CELLS



CHEMICAL ENERGY

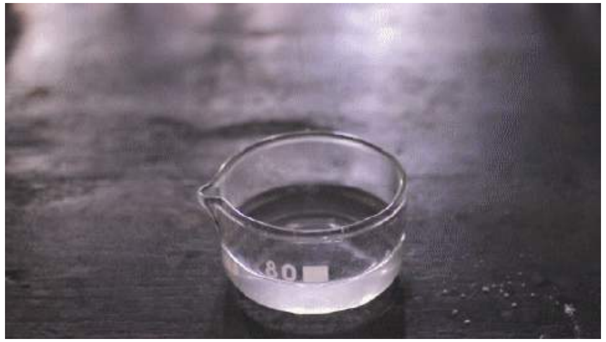
Direct reaction

Galvanic cell

THERMAL ENERGY

ELECTRICAL ENERGY

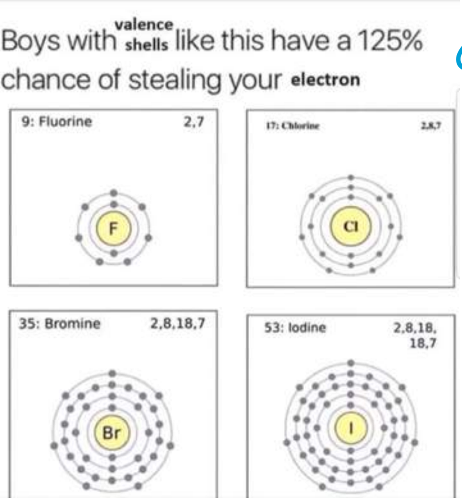
→ Sodium in water



→ Titanium in water

→ Key point: Different metals have *different reactivities*. Galvanic cells can be used to compare reactivities of metals!

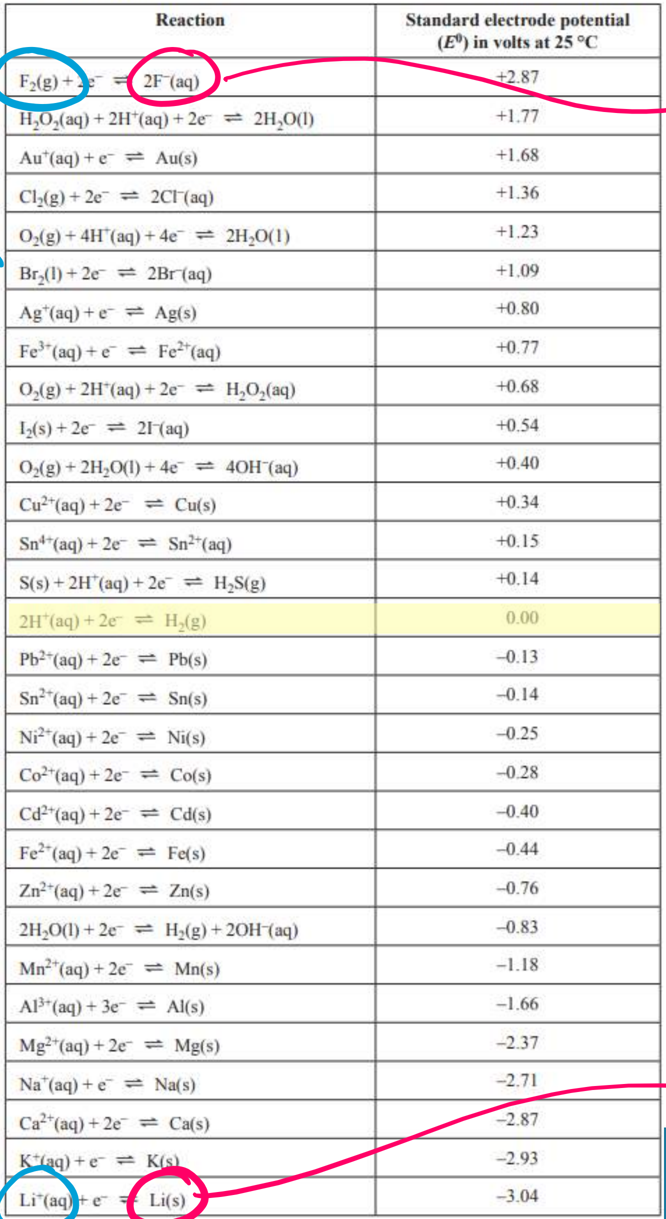
ELECTROCHEMICAL SERIES



Strongest oxidant

Increasing oxidant strength

Weakest oxidant



Reaction	Standard electrode potential (E^0) in volts at 25 °C
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$Au^+(aq) + e^- \rightleftharpoons Au(s)$	+1.68
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	−0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	−0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	−0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	−0.28
$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	−0.40
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	−0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	−1.18
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	−1.66
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	−2.37
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	−2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	−2.87
$K^+(aq) + e^- \rightleftharpoons K(s)$	−2.93
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	−3.04

weakest reductant

Increasing reductant strength

Strongest reductant

Page 4 in your data book!

ELECTROCHEMICAL SERIES

- So we've seen that the following reaction will able to be used in a galvanic cell to generate electrical energy:

$$\mathrm{Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Cu(s)}$$

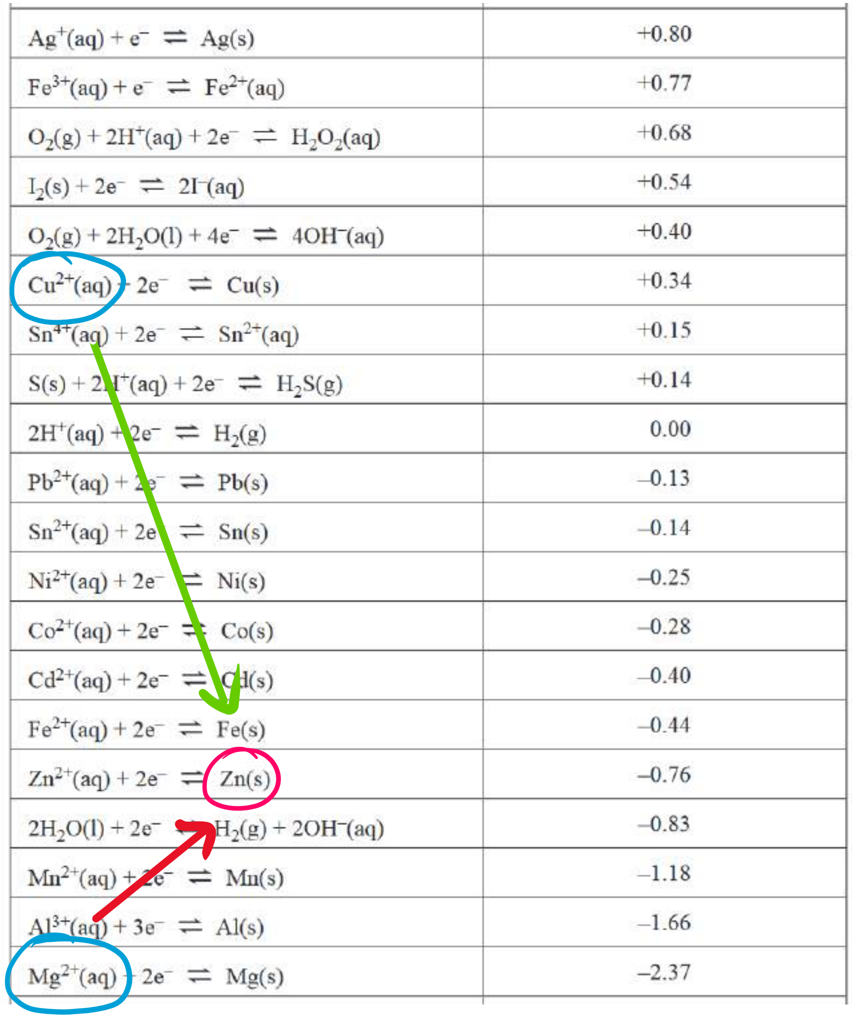
- What if we replaced $\mathrm{Cu^{2+}}$ with $\mathrm{Mg^{2+}}$, would we still be able to generate electrical energy?

??? $$\mathrm{Zn(s) + Mg^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Mg(s)}$$???

→ Answer: No!

→ Key point: The EC series allows us to predict whether a reaction will occur spontaneously or not.

ELECTROCHEMICAL SERIES



$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	–0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	–0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	–0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	–0.28
$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	–0.40
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	–0.44
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$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	–0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	–1.18
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	–1.66
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	–2.37

$$Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Cu(s)$$

✔ spontaneous

$$Zn(s) + Mg^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Mg(s)$$

✖ not spontaneous

⟶ If the oxidant (left hand side) is above the reductant (right hand side), the reaction will spontaneously occur!

ELECTROCHEMICAL SERIES

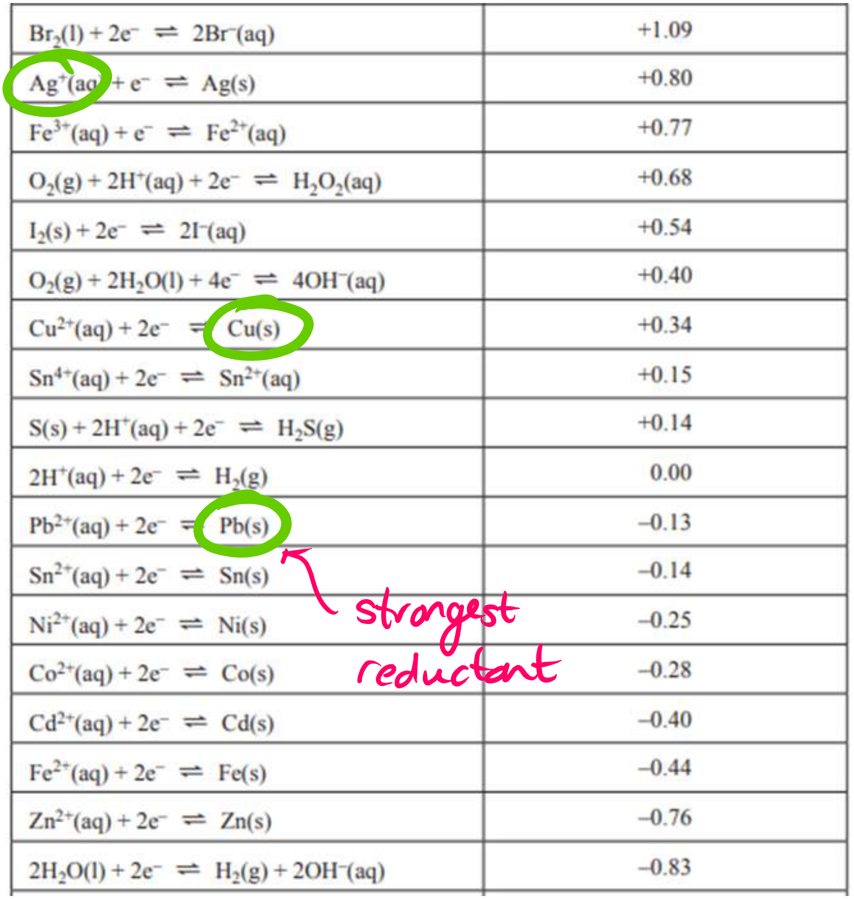
- What if there are multiple reactions possible?

→ Preferential oxidation/reduction!

Example: If we add $\mathrm{Cu}(s)$ and $\mathrm{Pb}(s)$ to a Ag^+ solution…

→ Key point: Strongest oxidant ***ALWAYS*** reacts with the strongest reductant!!!

strongest oxidant



$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
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$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
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$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	−0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	−0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	−0.25
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$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	−0.40
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	−0.83

strongest reductant

ELECTROCHEMICAL SERIES

WHO WOULD WIN?

2019 CHEMISTRY DATA BOOK 4

2. The electrochemical series

Reaction	Standard electrode potential (E^0) in volts at 25 °C
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$Au^+(aq) + e^- \rightleftharpoons Au(s)$	+1.68
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$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
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$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
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$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
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$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	−0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	−1.03
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	−1.67
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	−2.34
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	−2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	−2.87
$K^+(aq) + e^- \rightleftharpoons K(s)$	−2.93
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	−3.02

SLC
@ 1.0 M
concentrations

A series built upon thousands of rigorous scientific experiments

~~25.5 °C~~

~~1.2 M~~

~~1 atm~~

One changey boi

→ **Key point:** The EC series can only be reliably referenced under SLC conditions of 25 °C and 100 kPa.

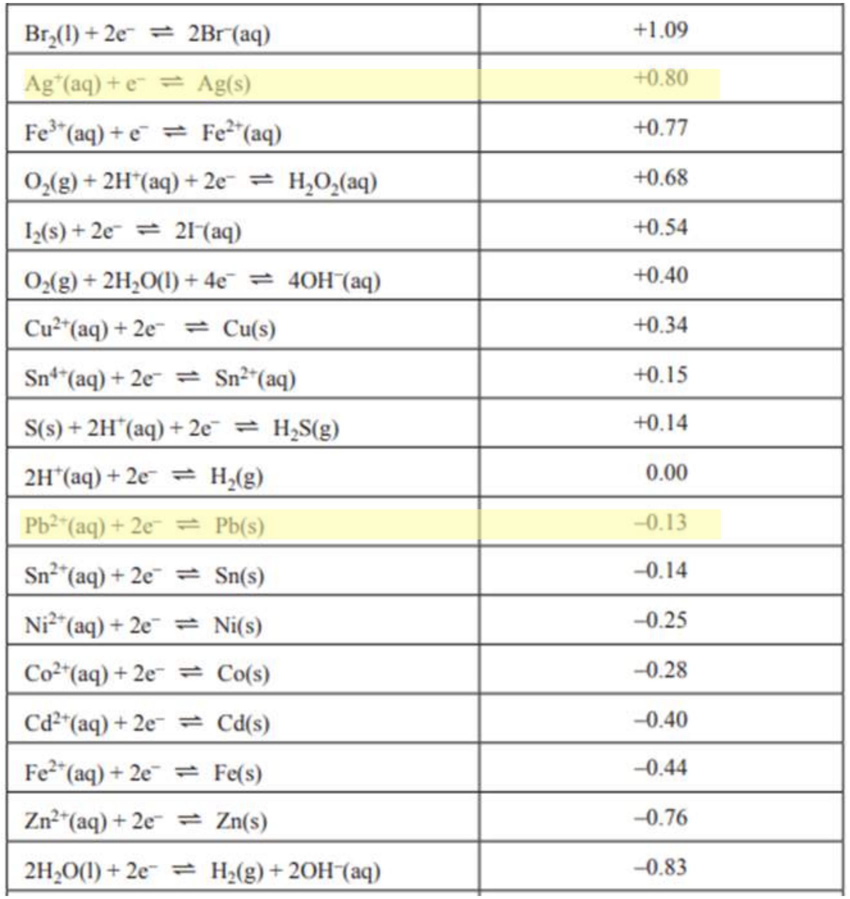
ELECTROCHEMICAL SERIES

ELECTROCHEMISTRY

- Earlier we talked about how a potential difference, also known as a voltage, exists over two half cells in a galvanic cell.

$$E^{\circ}_{\text{cell}} = E^{\circ}_{\text{oxidant}} - E^{\circ}_{\text{reductant}}$$

$$\begin{aligned} E^{\circ}_{\text{cell}} &= +0.80 - (-0.13) \\ &= +0.93\ \text{V} \end{aligned}$$



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$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	–0.83

FUEL CELLS

- Fuel cells are a *specific type of galvanic cell*

- They still have half cells, electrodes, an external circuit, and convert chemical energy into electrical energy.

- However, unlike traditional galvanic cells, they do not ‘run out’ of charge and need recharging.

→ Key point: This is because, unlike primary or secondary cells, fuel cells do not store their reactants. Instead, the are continuously supplied from an external source.

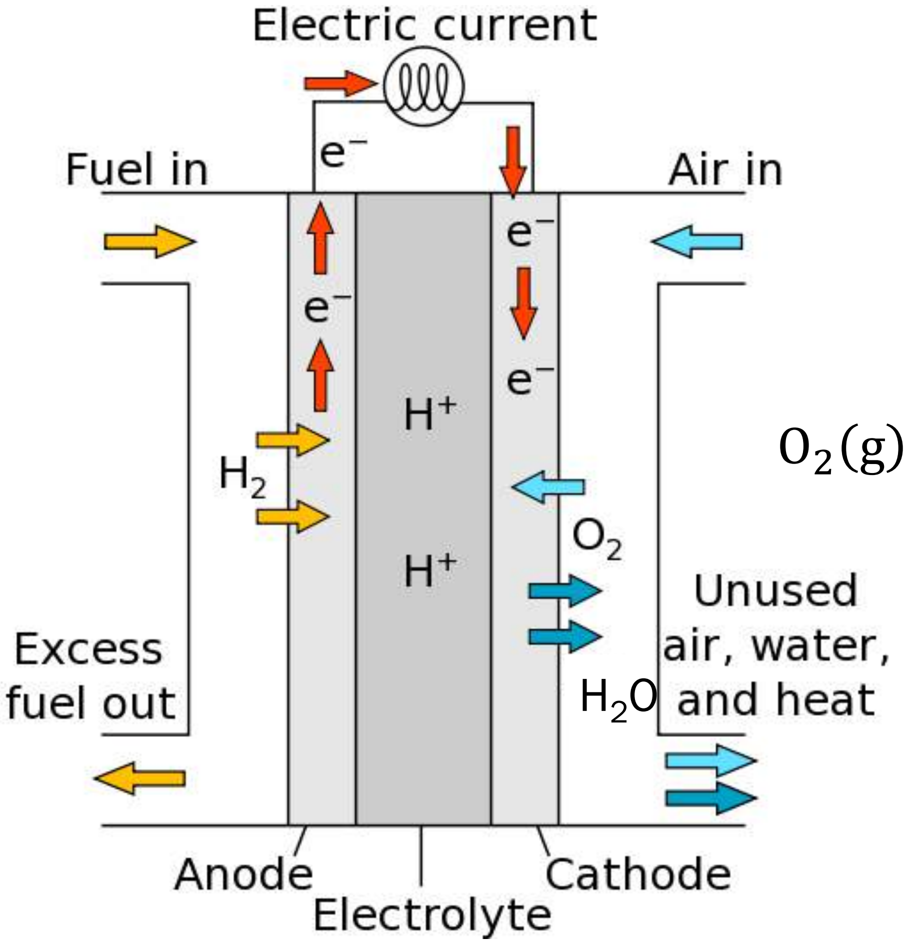
ELECTROCHEMISTRY

Image credit: Wikipedia

HYDROGEN FUEL CELLS

OXIDATION

$H_2(g) \longrightarrow 2H^+(aq) + 2e^-$

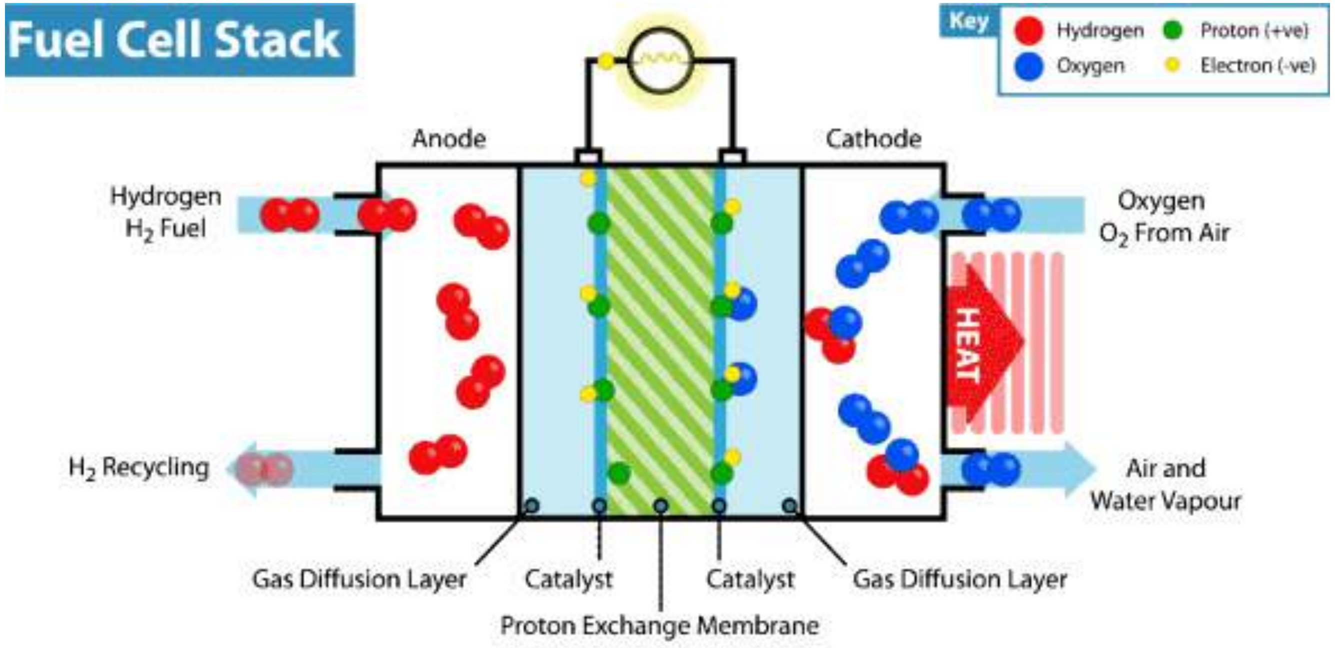


REDUCTION

$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(g)$

Image credit: Stanford University

HYDROGEN FUEL CELLS



→ Key point: Fuel cells don't store reactants or products, they continuously get supplied & exhaust them.

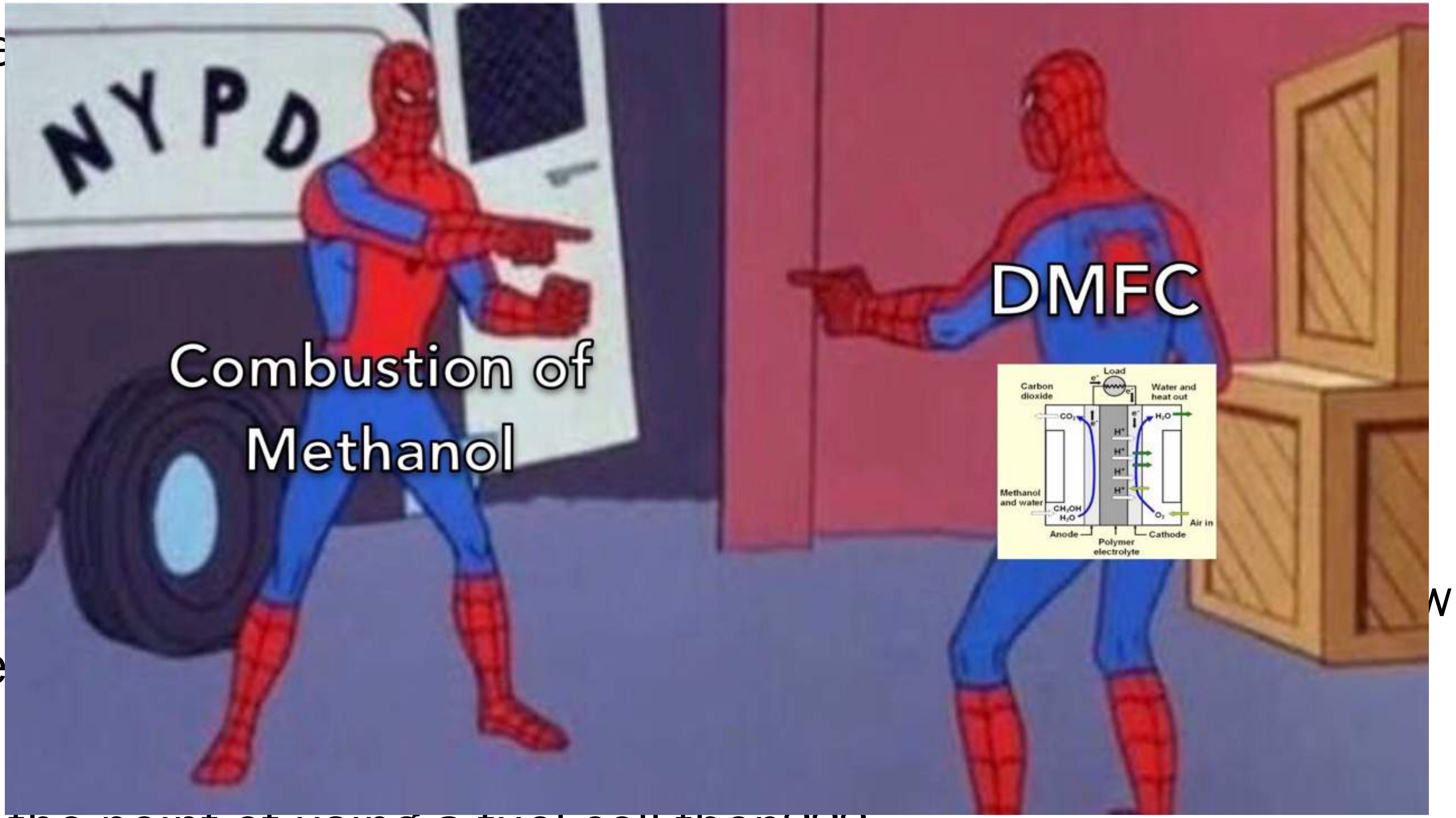
Image credit: geek.com

FUEL CELLS

- As we can see, the fuel cell is pretty much the same as a galvanic cell, except that we've got **continuous supply of reactants.**
- This is the ***main difference*** between other galvanic cells and fuel cells. If on an exam you're asked for a difference, this is the one you should go to first!
- However, there are a few other ***subtle differences***, including:
  - Properties of the electrodes used
  - Operating temperatures
  - The role of the electrolyte
  - What they're used for

- Many different fuels can be used in fuel cells. We've seen hydrogen, another common fuel is methanol.

FUEL CELLS – EFFICIENCY



- The ove
- What's
- Essenti … whether we use fue
- What's the point of using a fuel cell then???

FUEL CELLS – EFFICIENCY

- Let’s look at **energy transformations** involved here…

→ **DMFC – very direct & straightforward**

Chemical energy → *electrical energy*

→ **Combustion to run generator –many steps**

Chemical energy → *heat energy* → *mechanical energy* → *electrical energy*

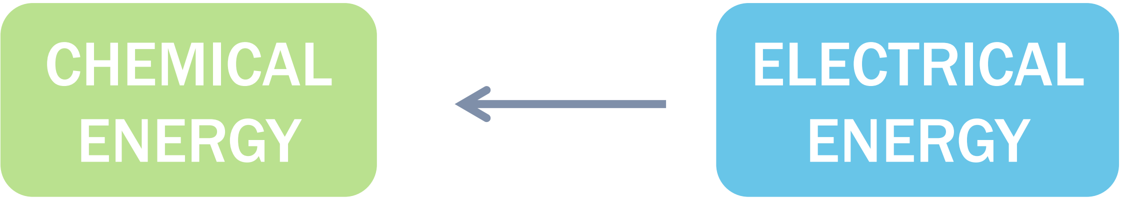
→ Key point: At each step, we will lose some energy as waste heat… :(Thus, fuel cells are ***significantly more efficient***!

FUEL CELLS

- To summarise:
  - → Fuel cells are simply galvanic cells that have continuous supply of their reactants
  - → There are a few other differences, including role of the electrolyte, use of catalytic & porous electrodes, and a higher operating temperature.
  - → Common fuel for fuel cells are: $H_2(g)/O_2(g)$, $CH_3OH(g)/O_2(g)$, but there are many different options!
  - → Fuel cells are superior in comparison to conventional fuels in respect to their **relatively high energy efficiencies.**

ELECTROLYTIC CELLS

- Electrolytic cells are the *reverse* of galvanic cells.
- Non-spontaneous redox reactions are driven **forwards** by input of energy (electrical current)
- Electrodes are inserted directly into electrolyte and current passed through


CHEMICAL ENERGY ← ELECTRICAL ENERGY

$Au^+(aq) + e^- \rightleftharpoons Au(s)$	+1.68
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00

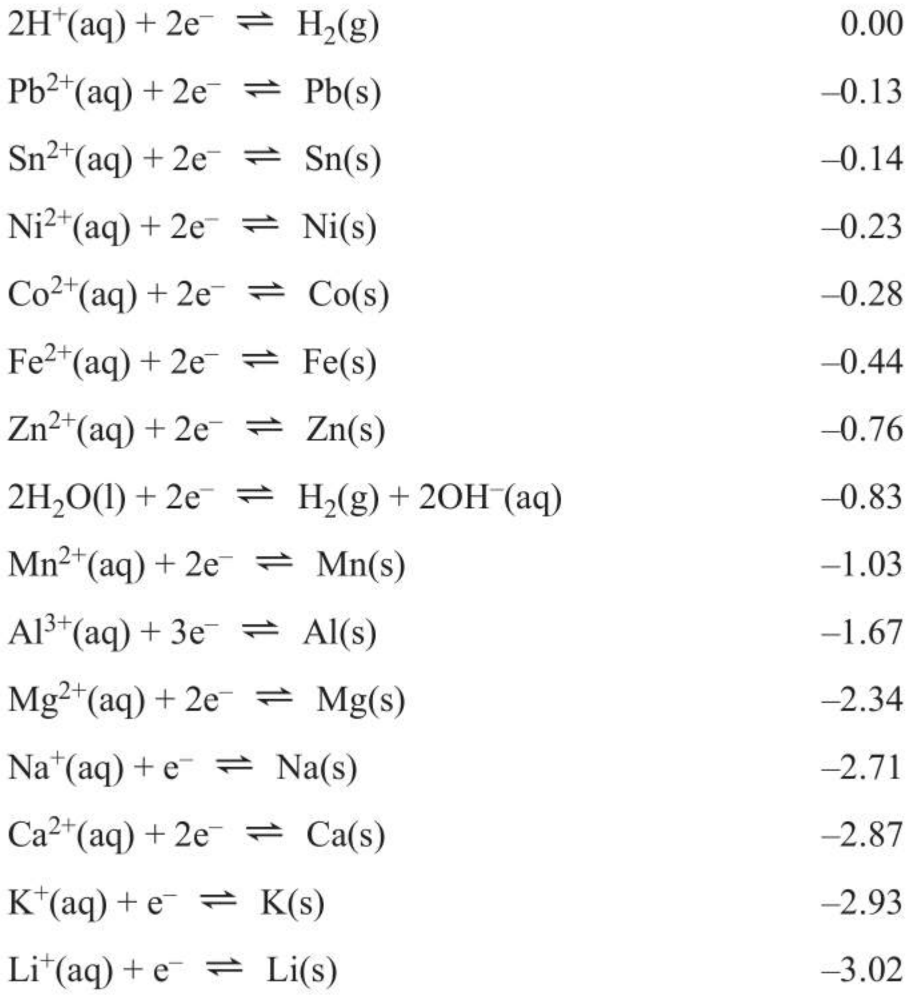
GALVANIC VS ELECTROLYTIC

	GALVANIC	ELECTROLYTIC
Cathode reaction	**Reduction**	**Reduction**
Anode reaction	**Oxidation**	**Oxidation**
Direction of flow	**Anode to cathode**	**Anode to cathode**
Cathode polarity	+	-
Anode polarity	-	+
Negative electrode	Where electrons are lost (anode)	Where electrons are gained (cathode)
Salt bridge	Cations to positive cathode Anions to negative cathode “Maintain electrical neutrality”	None
Separation of reactants	Must be separated	Don’t need to be separated

ELECTROLYTIC CELLS

Electrolyte will contain several redox-active species.

- Strongest oxidant is reduced at the cathode
- Strongest reductant is oxidised at the anode
- Molten electrolytes: quite simple to determine the oxidant/reductant.
- Remember to consider H_2O in the case of an aqueous electrolyte!



$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	–0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	–0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	–0.23
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	–0.28
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	–0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	–0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	–1.03
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	–1.67
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	–2.34
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	–2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	–2.87
$K^+(aq) + e^- \rightleftharpoons K(s)$	–2.93
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	–3.02

ELECTROLYTIC CELLS

- What reacts preferentially? – probably the hardest part of electrochemistry
- Remember: “Electrons go to the highest bidder”

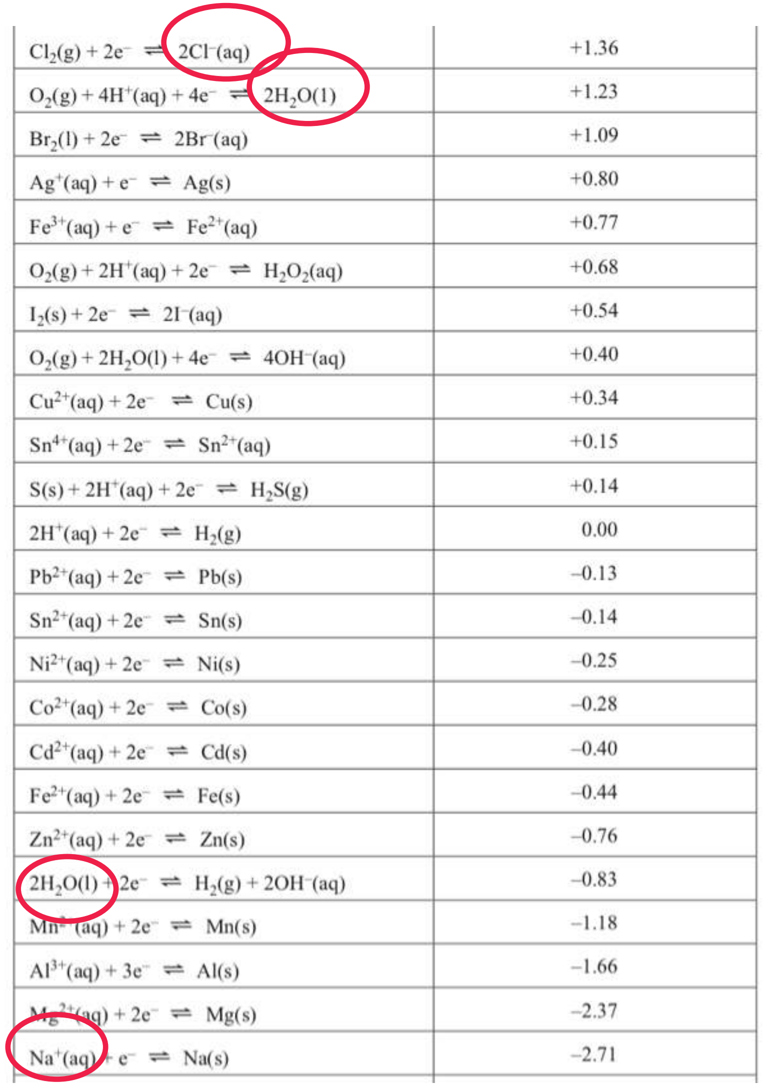
- You might also like to think of it as only the best applicants get the job
  - The best oxidant gets to be the oxidant (i.e. the strongest oxidant)
  - The best reductant gets to be the reductant (i.e. the strongest reductant)

- In a more scientific sense, if you have a stronger oxidant and stronger reductant they’re going to do more work on their own and thus you have to put in less energy– it all just happens more easily!

ELECTROLYTIC CELLS

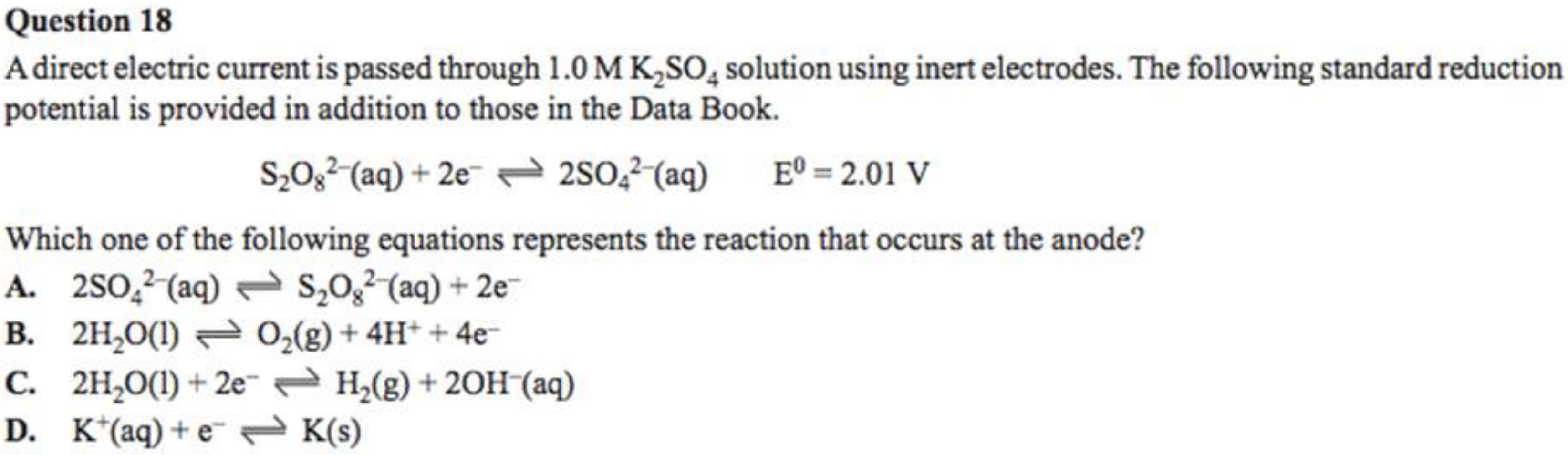
- NaCl (l)
  - Species present? Na^+, Cl^-
  - Strongest oxidant? Na^+
  - Strongest reductant? Cl^-

- NaCl (aq)
  - Species present? Na^+, Cl^-, H_2O
  - Strongest oxidant? H_2O
  - Strongest reductant? H_2O
  - Water is "preferentially reduced and oxidized"



$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	–0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	–0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	–0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	–0.28
$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	–0.40
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	–0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	–0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	–1.18
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	–1.66
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	–2.37
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	–2.71

PRACTICE QUESTION



Question 18

A direct electric current is passed through 1.0 M K_2SO_4 solution using inert electrodes. The following standard reduction potential is provided in addition to those in the Data Book.

$$S_2O_8^{2-}(aq) + 2e^- \rightleftharpoons 2SO_4^{2-}(aq) \qquad E^0 = 2.01\ V$$

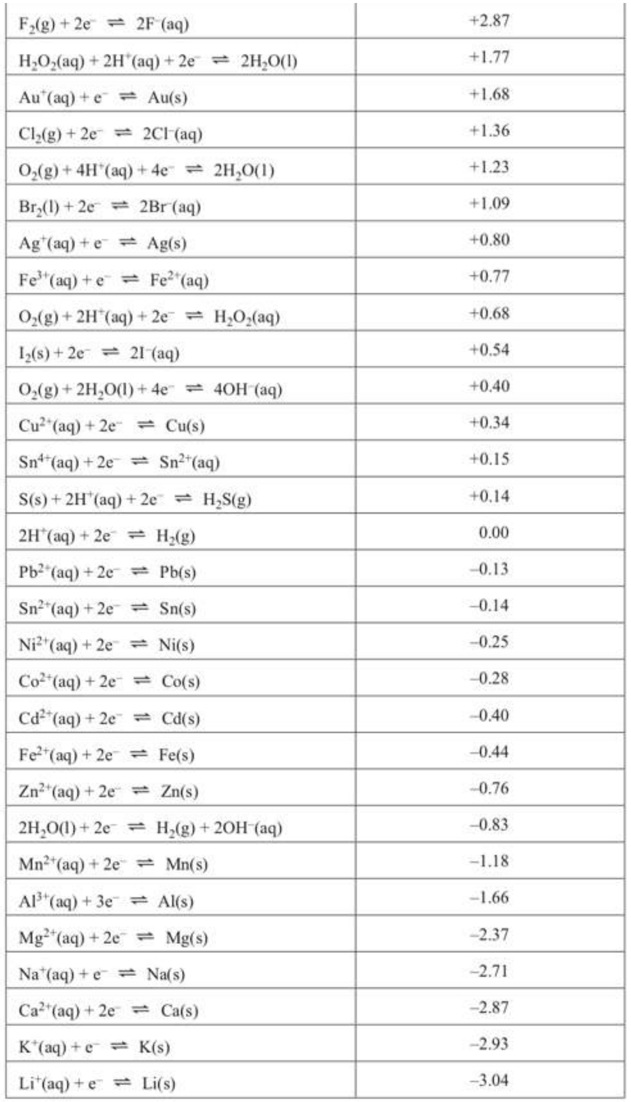
Which one of the following equations represents the reaction that occurs at the anode?

A. $2SO_4^{2-}(aq) \rightleftharpoons S_2O_8^{2-}(aq) + 2e^-$

B. $2H_2O(l) \rightleftharpoons O_2(g) + 4H^+ + 4e^-$

C. $2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$

D. $K^+(aq) + e^- \rightleftharpoons K(s)$



$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$Au^+(aq) + e^- \rightleftharpoons Au(s)$	+1.68
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	–0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	–0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	–0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	–0.28
$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	–0.40
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	–0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	–0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	–1.18
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	–1.66
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	–2.37
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	–2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	–2.87
$K^+(aq) + e^- \rightleftharpoons K(s)$	–2.93
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	–3.04

Question source: VCAA 2010

SECONDARY CELLS

- There are two basic types of cells/batteries:

PRIMARY CELLS

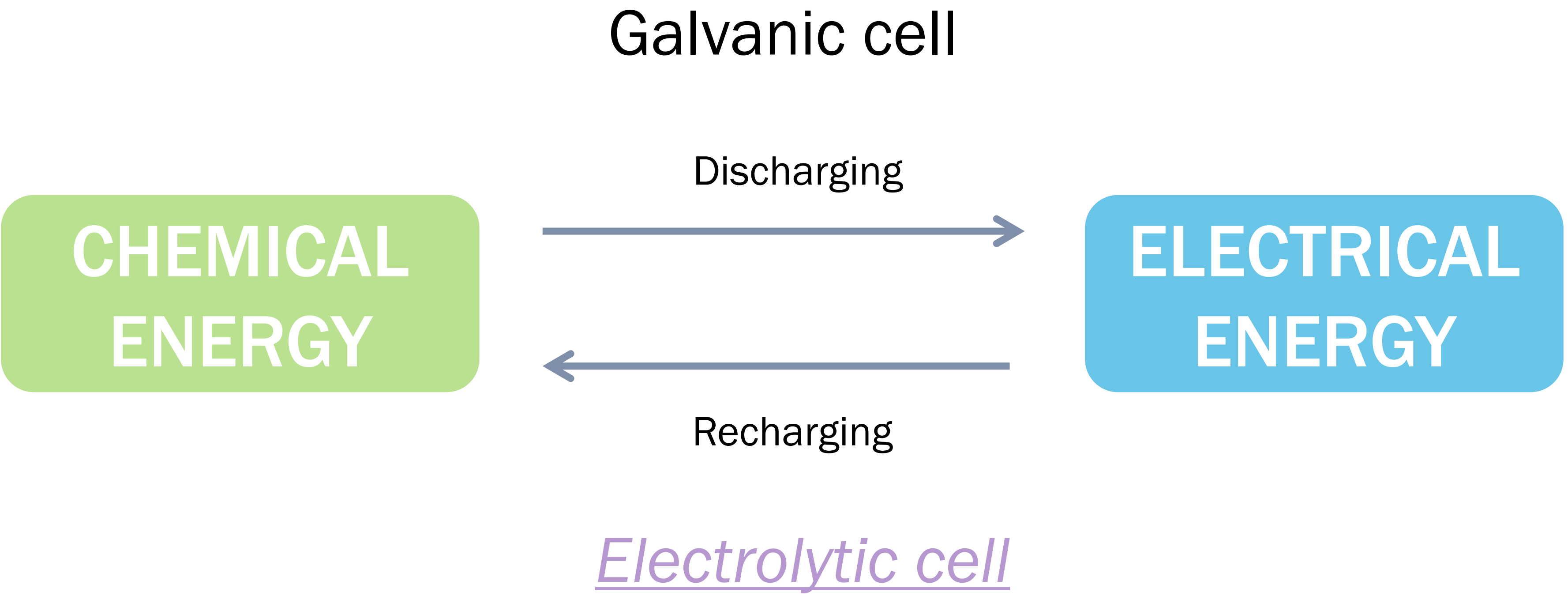
→ Non – rechargeable
→ Disposable

SECONDARY CELLS

→ Rechargeable
→ Re-usable

Image credit: Wikipedia

SECONDARY CELLS



Galvanic cell

Discharging

CHEMICAL ENERGY

ELECTRICAL ENERGY

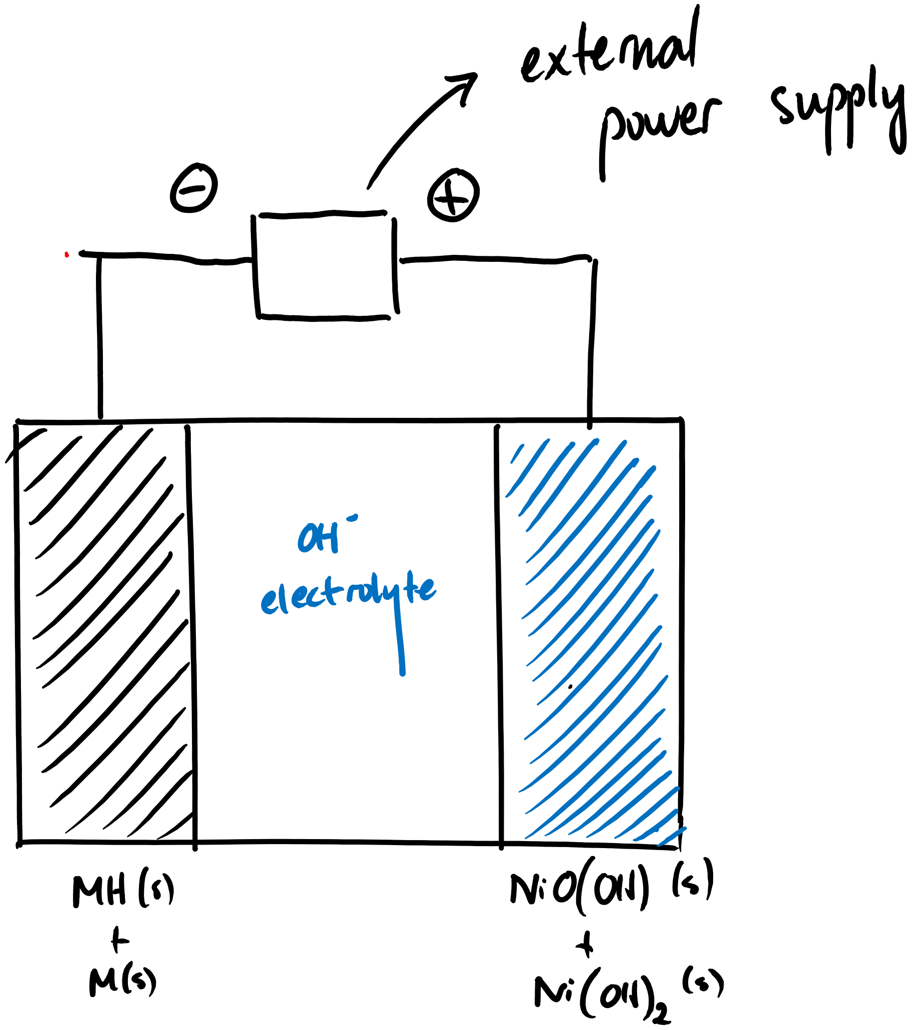
Recharging

Electrolytic cell

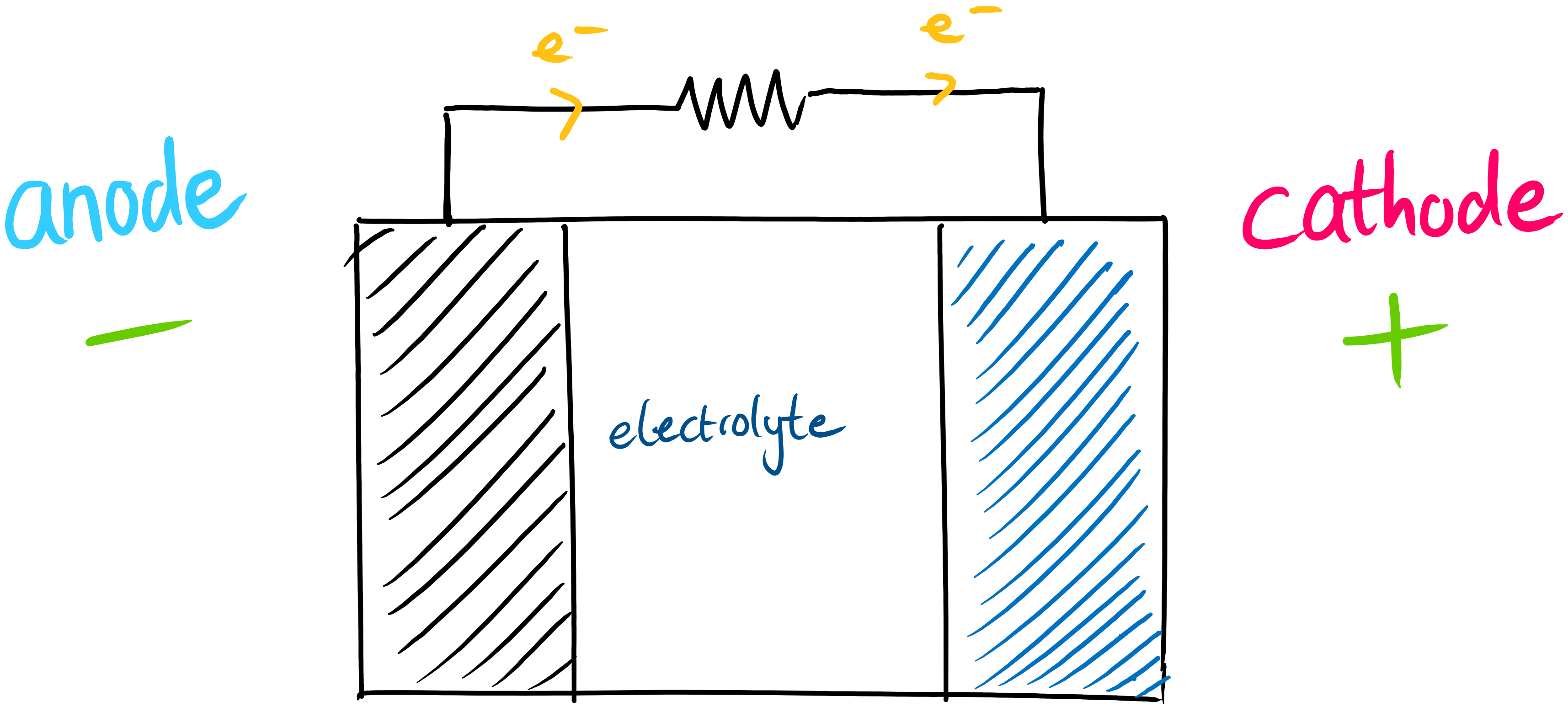
Image credit: Wikipedia

SECONDARY CELLS

- Secondary cells are *rechargeable* – can be driven forwards (like galvanic cells) but also backwards (like electrolytic cells)
- Requirements for being a *secondary cell:*
  - Discharge reaction must be **reversible**
  - Products of discharge must remain in contact with electrodes
- Polarity of electrodes will never change (+ or -)
- Anode and cathode will swap between recharge and discharge.



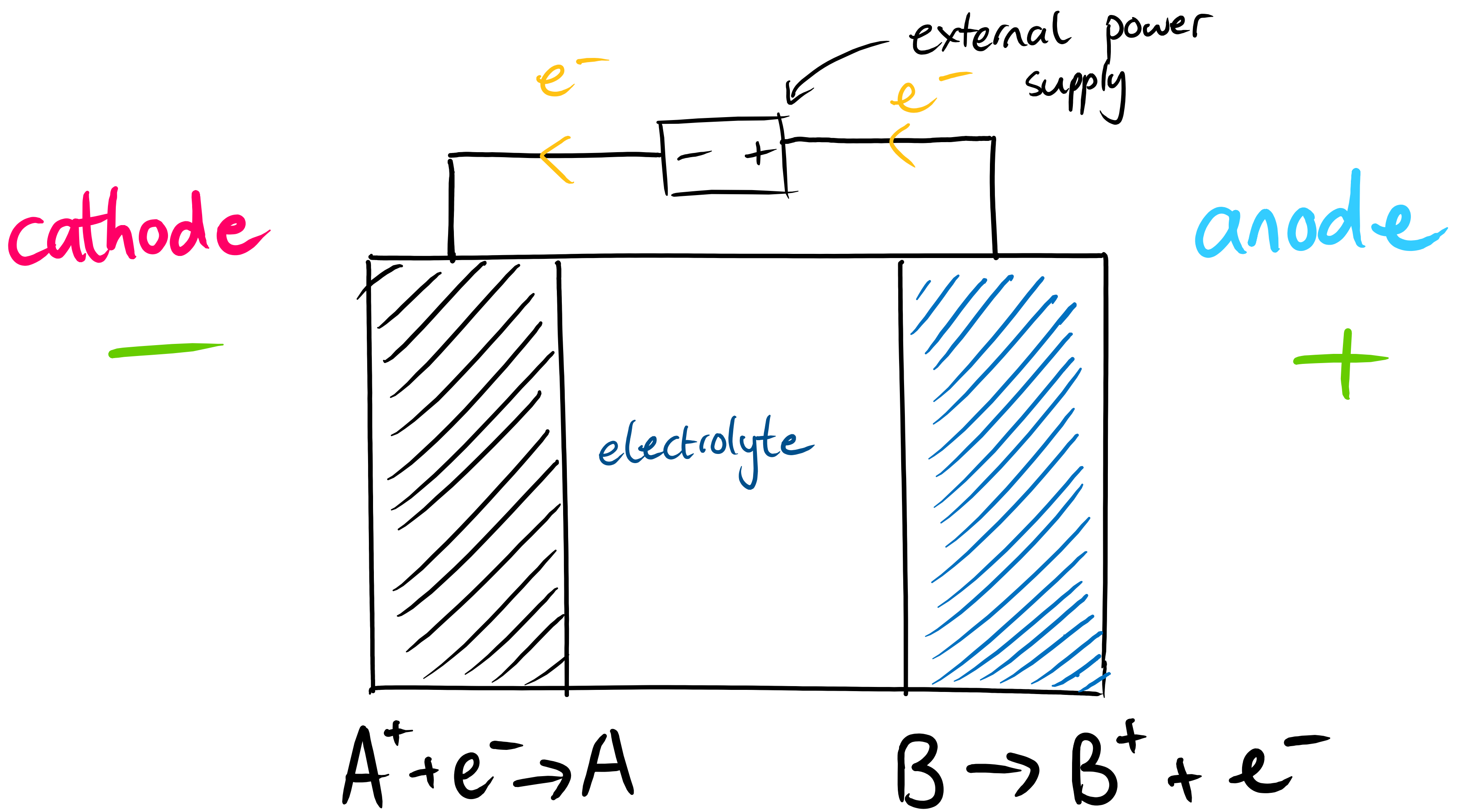
SECONDARY CELLS - DISCHARGE



$A \rightarrow A^+ + e^-$

$B^+ + e^- \rightarrow B$

SECONDARY CELLS - RECHARGE



$A^+ + e^- \rightarrow A$

$B \rightarrow B^+ + e^-$

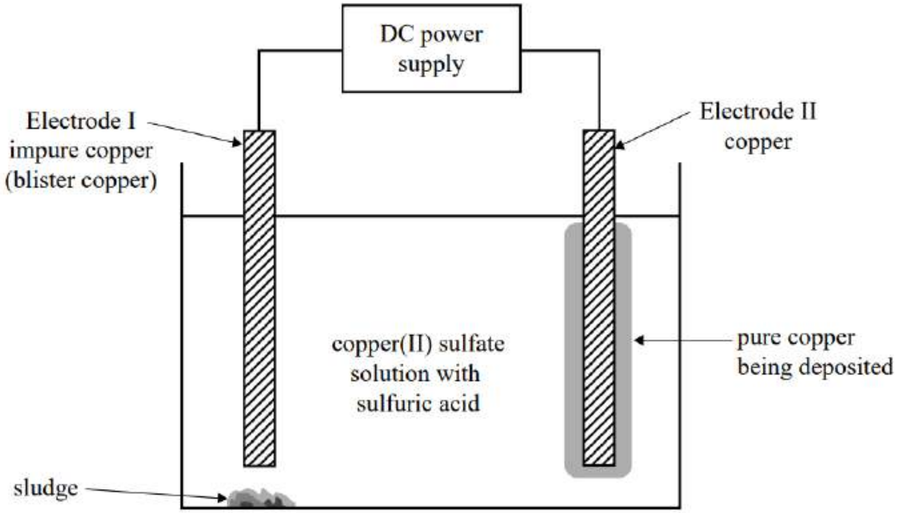
PRACTICE QUESTION

Use the following information to answer Questions 28–30.

An electrolytic cell is set up to obtain pure copper from an impure piece of copper called 'blister copper'.

The electrolyte solution contains both copper(II) sulfate and sulfuric acid. The blister copper, Electrode I, contains impurities such as zinc, cobalt, silver, gold, nickel and iron. The cell voltage is adjusted so that only copper is deposited on Electrode II. Sludge, which contains some of the solid metal impurities present in the blister copper, forms beneath Electrode I. The other impurities remain in solution as ions.

The diagram below represents the cell.



Question 29

Which of the following correctly shows both the equation for the reaction occurring at the cathode and the polarity of Electrode I?

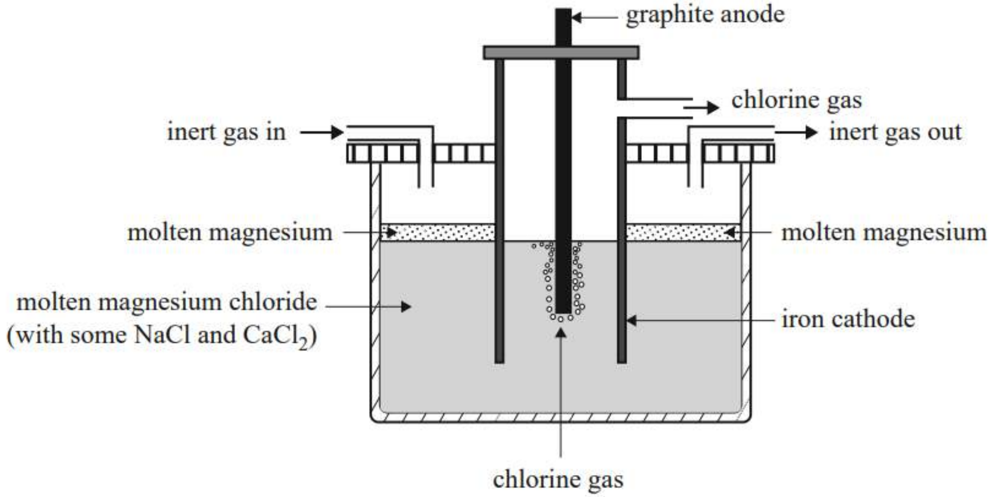
	Cathode reaction	Polarity of Electrode I
A.	$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	positive
B.	$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$	negative
C.	$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	negative
D.	$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$	positive

PRACTICE QUESTION

Question 9 (8 marks)

Magnesium is one of the most abundant elements on Earth. It is used extensively in the production of magnesium-aluminium alloys. It is produced by the electrolysis of molten magnesium chloride.

A schematic diagram of the electrolytic cell is shown below.



The design of this cell takes into account the following properties of both magnesium metal and magnesium chloride:

- Molten magnesium reacts vigorously with oxygen.
- At the temperature of molten magnesium chloride, magnesium is a liquid.
- Molten magnesium has a lower density than molten magnesium chloride and forms a separate layer on the surface.

a. Write a balanced half-equation for the reaction occurring at each of 2 ma

- the cathode

____

- the anode.

____

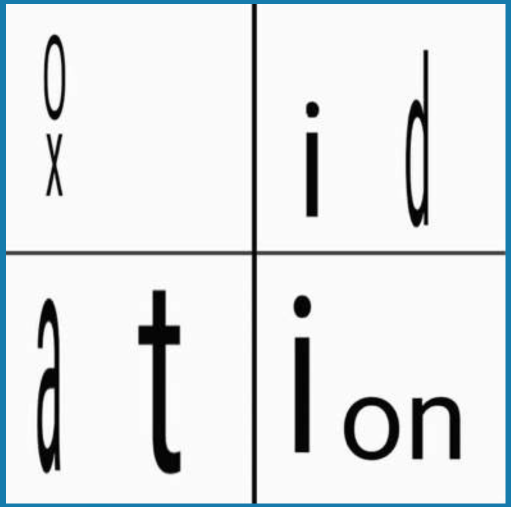
BLOCK 2 SUMMARY

- Redox basics
- Galvanic cells & the electrochemical series
- Fuel cells
- Electrolytic cells
- Coming up after the break:

→ KAHOOT! → Thermochemistry

BREAK 2 – 15 Minutes

QUESTIONS?



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KAHOOT!

Grab out a calculator, data booklet & some pen and paper!

KAHOOOOOOOOOOT

TOPIC 3:
FUELS & THERMOCHEM

WHAT IS A FUEL?

Definition:

*A **fuel** is a substance that can be reacted with other substances (e.g. O_2), leading to the release of energy that can be harnessed for a specific purpose.*

- Wording is important – don't say 'fuels can be combusted'! What about batteries? What about nuclear fission?
- Explicitly stated on the study design that you need to know a definition for a fuel, so remember one!

WHAT IS A FUEL?

- Fuels can be classified as renewable vs. non-renewable
- Definitions are important!

RENEWABLE

→ *A renewable resource can be replenished by natural processes within a relatively short period of time (short period = human timescale).*

NON-RENEWABLE

→ *A non-renewable resource cannot be replenished by natural processes within a relatively short period of time.*

WHAT IS A FUEL?

- We can also separate fuels into fossil fuels vs. biofuels

FOSSIL FUELS

→ Fuels derived from living matter compressed underground for millions of years.

→ Non-renewable

BIOFUELS

→ Derived from plant matter and can be produced at the same rate we consume it.

→ Renewable

FOSSIL FUELS VS. BIOFUELS

FOSSIL FUELS

- Coal
- Coal seam gas (CSG)
- Crude oil/Petroleum
- Liquefied Petroleum Gas (LPG)

BIOFUELS

- Biogas
- Bioethanol
- Biodiesel

Specifically, we need to be able to *compare* the fuels listed, with respect to:

- Energy content
- Renewability
- Environmental impacts relating to sourcing and combustion

FOSSIL FUELS FUELS SUMMARY

Type of fuel	Energy content (roughly)	Combustion environmental effects	Sourcing environmental effects
Crude oil/Petroleum		-Petrol produces more CO and particulates than smaller, gaseous fossil fuels; larger molecules result in a lower amount of complete combustion.	-Potential oil spills damaging aquatic ecosystems -Large amounts of energy required to power an oil rig, of which is mostly sourced from GHG emitting fossil fuels. -Risk of explosion releasing GHG into atmosphere.
LPG (C_3 – C_4)	See below		
Petrol (C_8-C_{12})	~47.9 MJ Kg^{-1} (octane)		
Kerosene (C_{10}-C_{18})	~46.2 MJ Kg^{-1}		
Petrodiesel (C_{12}-C_{20})	~48.0 MJ Kg^{-1} (more dense than petrol, more energy per litre.)		
Liquified Petroleum Gas (LPG) (propane and butane)	~46.2 MJ Kg^{-1}	-Burns 'more cleanly' than other liquid and solid fossil fuels, producing less particulates, less sulfur oxides, and less nitrogen oxides.	-See crude oil.
Coal seam gas (CSG) (96% methane, 2% CO2)	~55.6 MJ Kg^{-1} (methane)	-Burns 'more cleanly' than other liquid and solid fossil fuels, producing less particulates, less sulfur oxides, and less nitrogen oxides.	-Minor habitat destruction and fragmentation. -Contamination of local underground aquifers/water table as a result of fracking.
Coal (impure lumps of C(s))	Brown coal: 30 MJ Kg^{-1} Black coal: 35 MJ Kg^{-1}	-Releases large amounts of particulates/ash. -Inefficient combustion and energy transformations results in larger amounts of GHG emissions.	-Major habitat destruction -Large amounts of energy required to extract coal.

Note: VCAA does not require you to know specific energy content values.

FUELS SUMMARY

Type of fuel	Production	Energy content	Combustion environmental effects	Sourcing environmental effects
Biodiesel/FAME **(Fatty acid methyl esters)**	Produced from the transesterification of triglycerides, using a hydroxide catalyst and methanol.	~41 MJ Kg^{-1}	-May not produce SO_2 depending on source. -Relatively low CO_2 net emissions as CO_2 consumed during growing of crops. -Burns more completely, reducing particulates.	-Requires intensive farming, which may lead to land degradation and competition with land meant for food. -Crops required large amounts of energy to grow, resulting in large amounts of CO_2 emissions -Methanol required, which is usually made in an unrenewable fashion from fossil fuels.
Bioethanol **(Ethanol)**	Fermentation of glucose by yeast. Same structure as ethanol.	~29 MJ Kg^{-1}	-Releases CO_2 upon combustion. -Burns more completely than petrol, less unburnt hydrocarbon released. -Lower NO_x emissions. -Fewer particulates formed. -Lower energy content means more has to be combusted.	-Requires large amounts land and crops that could otherwise be used for food production. -Growing crops requires large amounts of energy, most of which is sourced from fossil fuels. -Relatively carbon neutral.
Biogas **(60% methane, 32% CO_2, small amounts of nitrogen gas, hydrogen sulphide, oxygen and hydrogen)**	Anaerobic decomposition of organic wastes in an anaerobic digester.	~34 MJ Kg^{-1}	-Releases CO_2, both in the combustion of CH_4 and as a large fraction of biogas. -H_2S is a toxic constituent.	-Utilises waste products that would otherwise go unused. -Gas leak may emit large amounts of CH_4 into the atmosphere.

Note: VCAA does not require you to know specific energy content values.

FOSSIL FUELS VS. BIOFUELS

FOSSIL FUELS

ADVANTAGES ✓

- High energy content
- Easy to release energy from
- Relatively easy to obtain
- Extensive existing infrastructure

DISADVANTAGES ✖

- NOT RENEWABLE!
- Emits large amounts of CO_2, a potent green house gas.
- Release other toxic chemicals, such as nitrogen & sulfur oxides
- Extraction extremely damaging to the environment

FOSSIL FUELS VS. BIOFUELS

BIOFUELS

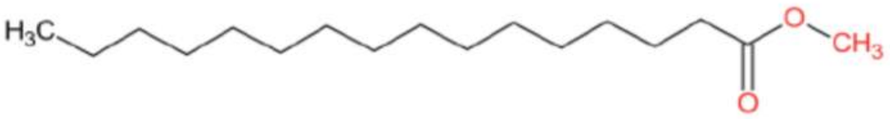
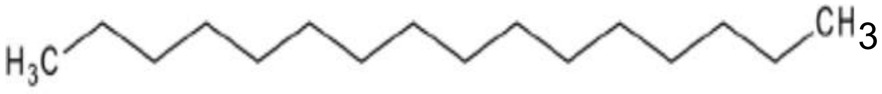
ADVANTAGES ✔

- → RENEWABLE!
- → *Relatively* carbon neutral; CO_2 released during combustion somewhat offset by CO_2 used by plant to grow.
- → Burn more cleanly than fossil fuels, less harmful chemicals released
- → Easy to source material used for production, can be produced from crop waste.

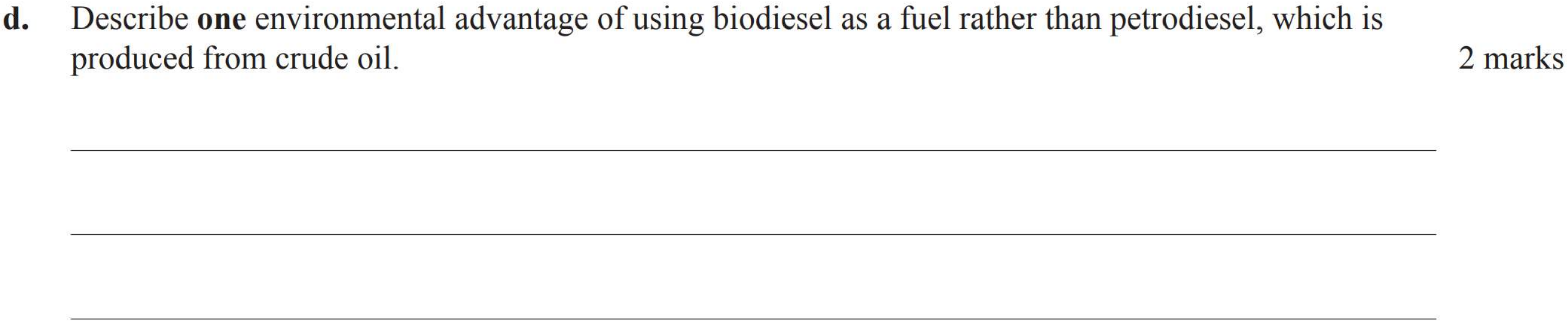
DISADVANTAGES ✖

- → Lower energy content than fossil fuels
- → Can be complicated and costly to produce; making fuel out of plants isn't as simple as digging up fuel from the ground!
- → Can require large amounts of water to grow crops.
- → Fertile land required to grow crops for fuel, which may compete with land to grow food.

BIODIESEL VS. PETRODIESEL

	BIODIESEL	PETRODIESEL
Source	-Can be produced from waste fats and oils or purposely grown oils. -Produced through a transesterification reaction, involving a triglyceride warmed with methanol in a hydroxide catalyst, forming glycerol and FAME. -Equilibrium reaction.	-A constituent of crude oil, obtained through fractional distillation. -Non-renewable
Chemical Structure	-Fatty acid methyl esters. 	-C_{10}-C_{15}, 75% aliphatic, 25% aromatic hydrocarbons 
Combustion Products	-Emits CO_2, but has a net lower impact as CO_2 has recently been consumed in the production of oils. -Emits no SO_2. -Burns more completely and produces less particulates.	-Emits CO_2 -Produces some SO_2. -Emits particulates and unburned hydrocarbons.
Fuel line flow	-Electronegative O atoms in biodiesel result in dipole-dipole bonding, increasing its viscosity. -Polar bonds also result in biodiesel being hydroscopic, which may increase corrosion of fuel lines, degradation of fuel and blockages of fuel lines. -Can gel at low temperatures, clogging fuel lines and hence inhibiting engine functioning.	-Lower viscosity and a lower cloud point. -Not hygroscopic. -Large, non-polar hydrocarbons, only bonded together by weak dispersion forces.
Environmental impacts of production	-Large amounts of biodiesel production requires dedicated farming of crops, using land and plants that could otherwise be food. -Large amounts of energy and resources required to cultivate crops. Much of this energy may come from GHG emitting fuels, increasing GHG production.	-Crude oil spills can significantly damage ecosystems. -Risk of fire and explosion, releasing large amounts of GHGs. -Significant emissions in refining.

PRACTICE QUESTION

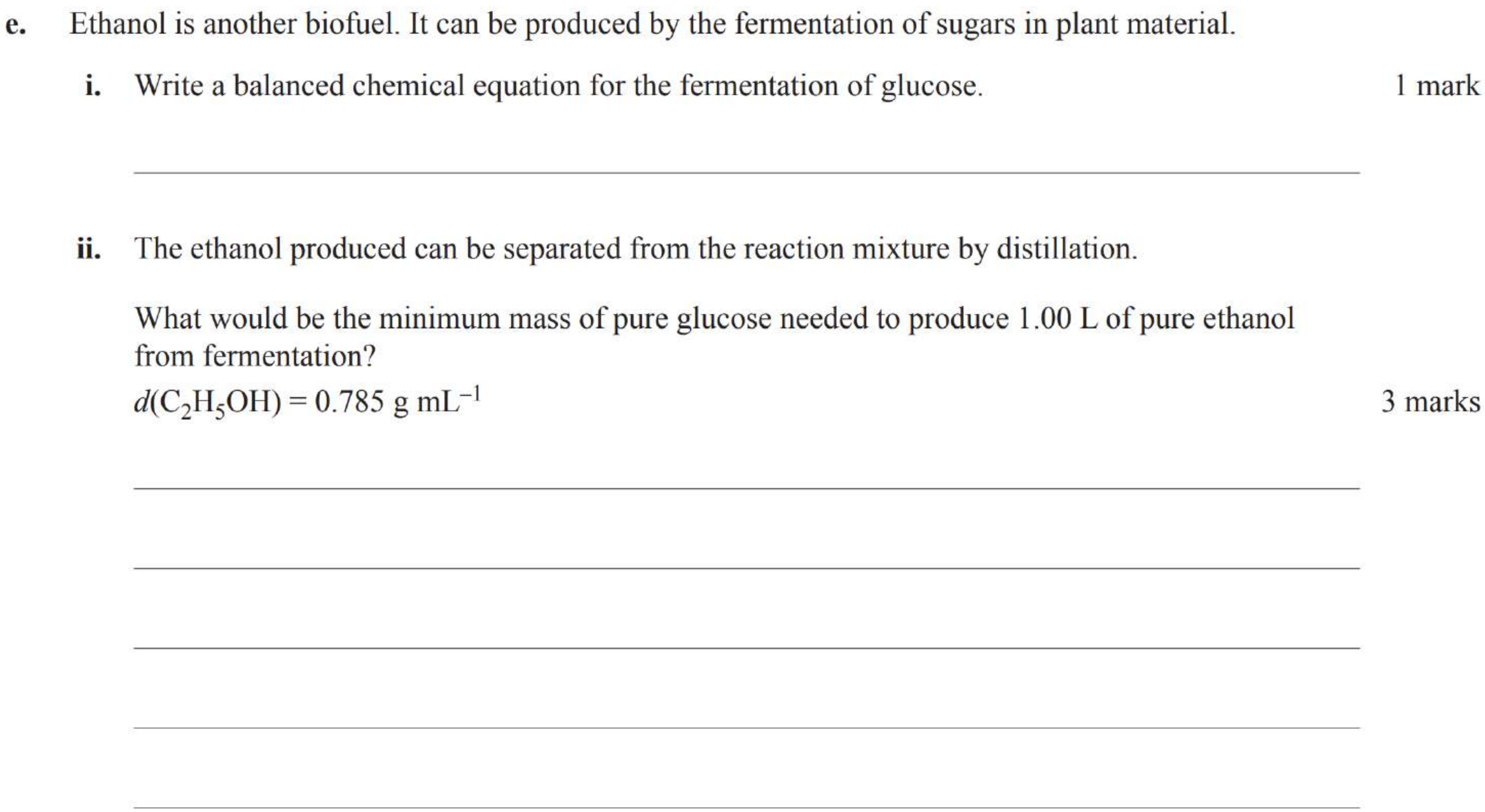


d. Describe **one** environmental advantage of using biodiesel as a fuel rather than petrodiesel, which is produced from crude oil. 2 marks

FUELS

VCAA 2016 Q3

PRACTICE QUESTION



e. Ethanol is another biofuel. It can be produced by the fermentation of sugars in plant material.

i. Write a balanced chemical equation for the fermentation of glucose. 1 mark

ii. The ethanol produced can be separated from the reaction mixture by distillation.

What would be the minimum mass of pure glucose needed to produce 1.00 L of pure ethanol from fermentation?

$d(C_2H_5OH) = 0.785\ \text{g mL}^{-1}$ 3 marks

UNIVERSAL GAS EQUATION

- Often we'll be given the volume of a gas at a certain temperature.
- *However*, volumes aren't really useful (we can't do stoichiometry with it usually), so we want to convert to an amount in mol.

$$PV = nRT$$

P = pressure (kPa)

V = volume (L)

n = amount in mole of gas (mol)

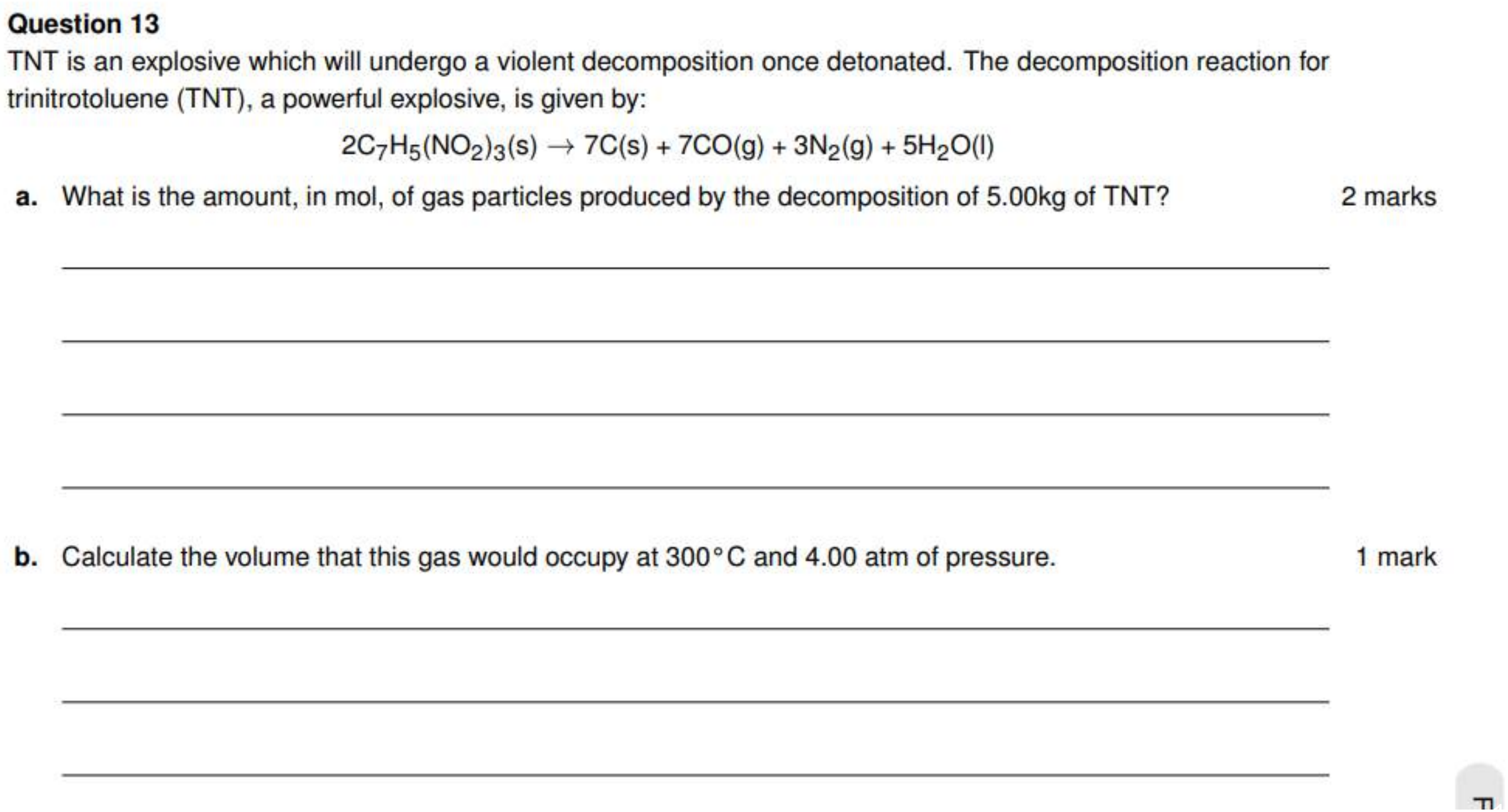
R = universal gas constant $(8.314\ J\ K^{-1}\ mol^{-1})$

T = temperature (K)

→ Key point: Make sure you use the correct units! Pay particular attention to temperature, this is often given in ℃!

Note: By using this equation, we assume the gas follows *ideal* behaviour. Ask me during a break if you wanna talk about this :)

PRACTICE QUESTION



Question 13

TNT is an explosive which will undergo a violent decomposition once detonated. The decomposition reaction for trinitrotoluene (TNT), a powerful explosive, is given by:

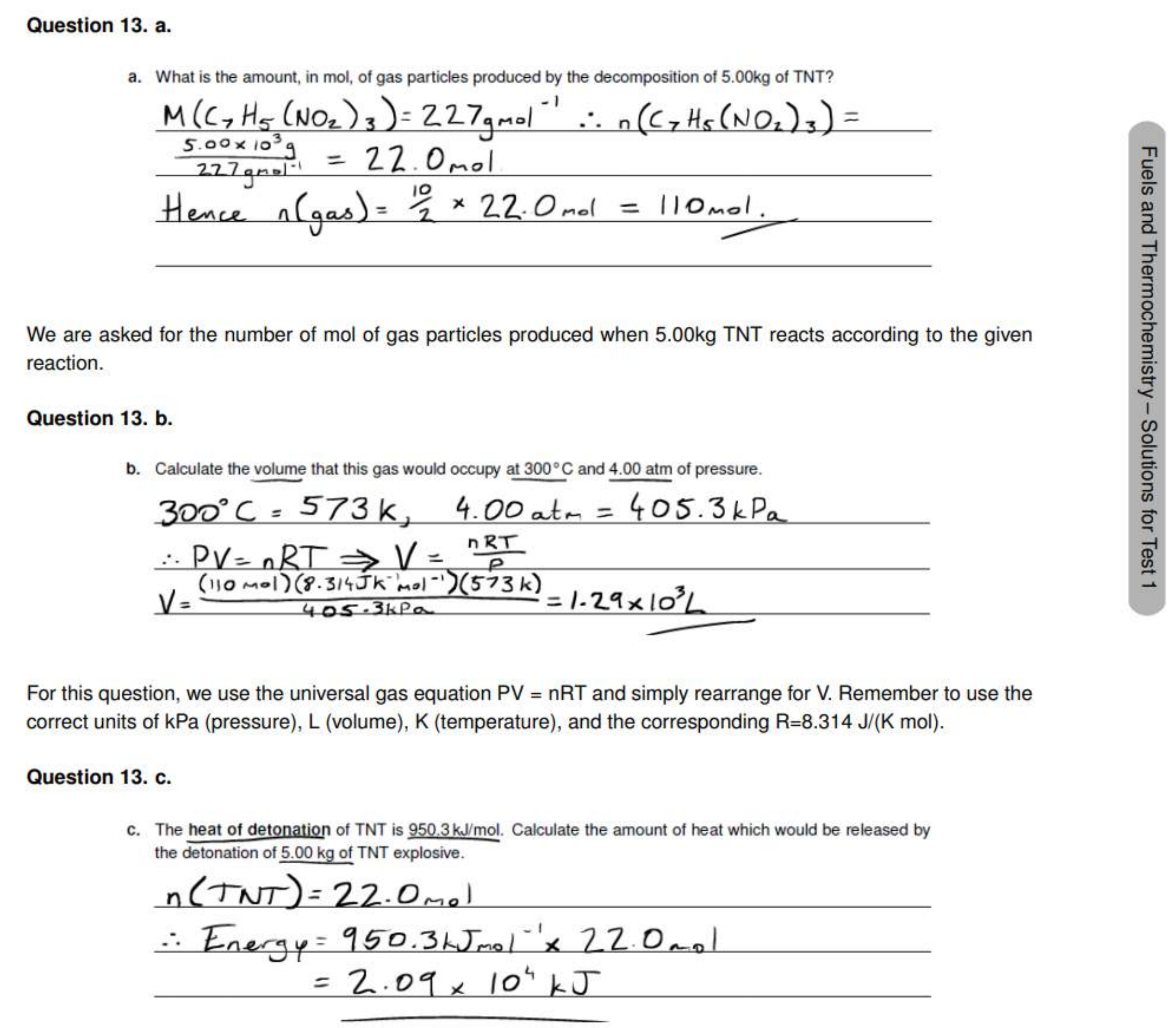
$$2C_7H_5(NO_2)_3(s) \rightarrow 7C(s) + 7CO(g) + 3N_2(g) + 5H_2O(l)$$

a. What is the amount, in mol, of gas particles produced by the decomposition of 5.00kg of TNT? 2 marks

b. Calculate the volume that this gas would occupy at 300°C and 4.00 atm of pressure. 1 mark

Question source: ATAR Notes Chemistry 3&4 Topic Tests

PRACTICE QUESTION



Question 13. a.

a. What is the amount, in mol, of gas particles produced by the decomposition of 5.00kg of TNT?

$M(C_7H_5(NO_2)_3) = 227\,g\,mol^{-1}$ $\therefore$ $n(C_7H_5(NO_2)_3) = \frac{5.00\times10^3\,g}{227\,g\,mol^{-1}} = 22.0\,mol$

Hence $n(gas) = \frac{10}{2} \times 22.0\,mol = 110\,mol.$

We are asked for the number of mol of gas particles produced when 5.00kg TNT reacts according to the given reaction.

Question 13. b.

b. Calculate the volume that this gas would occupy at 300 °C and 4.00 atm of pressure.

$300^\circ C = 573\,K$, $4.00\,atm = 405.3\,kPa$

$\therefore PV = nRT \Rightarrow V = \frac{nRT}{P}$

$V = \frac{(110\,mol)(8.314\,J\,K^{-1}\,mol^{-1})(573\,K)}{405.3\,kPa} = 1.29\times10^3\,L$

For this question, we use the universal gas equation PV = nRT and simply rearrange for V. Remember to use the correct units of kPa (pressure), L (volume), K (temperature), and the corresponding R=8.314 J/(K mol).

Question 13. c.

c. The **heat of detonation** of TNT is 950.3 kJ/mol. Calculate the amount of heat which would be released by the detonation of 5.00 kg of TNT explosive.

$n(TNT) = 22.0\,mol$

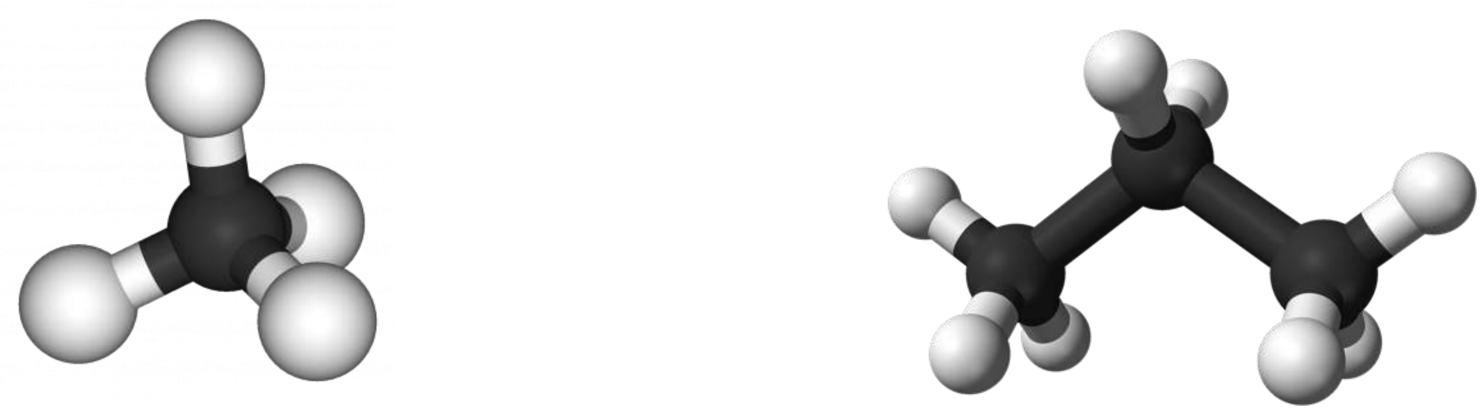
$\therefore Energy = 950.3\,kJ\,mol^{-1} \times 22.0\,mol$

$= 2.09 \times 10^4\,kJ$

Fuels and Thermochemistry – Solutions for Test 1

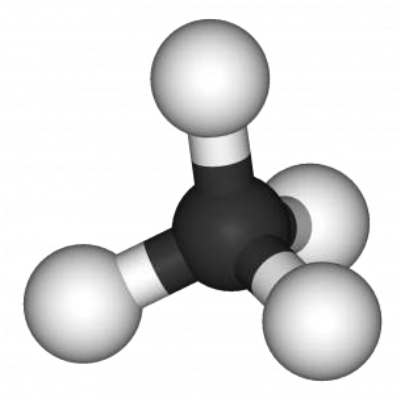
Question source: ATAR Notes Topic Tests

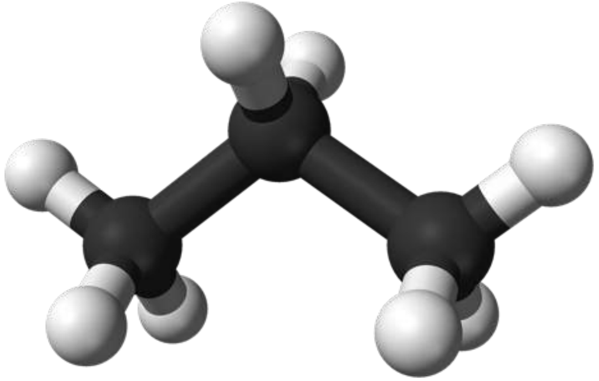
MOLAR VOLUMES



- Suppose we have 6 mol of methane gas, and 6 mol of propane gas. Assuming they're in the same environment (same pressure and temp), which will take up a larger volume? Discuss!
  - Answer: They will take up the *same* volume.

MOLAR VOLUMES





$$PV = nRT$$

$$V \propto n$$

→ **Key point:** The volume taken up by gas depends only on amount, NOT on the type of gas involved!

MOLAR VOLUMES

- For *constant conditions*, the volume occupied *per mol* of gas is **constant**.

SLC → 24.8 L mol^{-1}

- The volume taken up per mol of an ideal gas is known as the ***molar volume***.

$$V_m = 24.8\ \text{L mol}^{-1}$$

Where does this number come from?

NOTE: In the older study design the V_m at SLC was 24.5, so if you're doing old exams use this value.

MOLAR VOLUMES

$$V = \frac{nRT}{P} = \frac{n \times 8.314 \times 298}{100}$$

P = 100 kPa

T = 298 K

R = 8.31 $J\ K^{-1}\ mol^{-1}$

$$V = n \times 24.8$$

$$V = n \times V_m$$

$$n = \frac{V}{V_m}$$ → Formula in data booklet

THERMOCHEMICAL EQUATIONS

- To compare the amounts of energy released or absorbed by systems, we use the concept of ***enthalpy change/heat of reaction***.

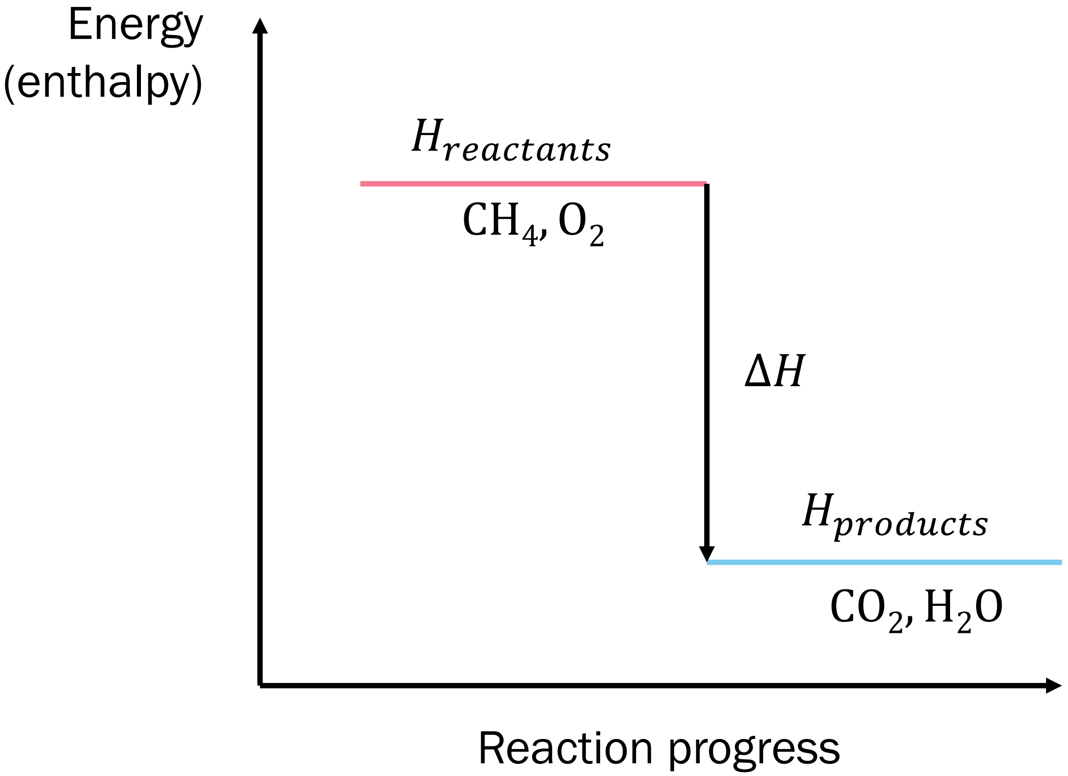
- For the scope of VCE chemistry, the best way to think about enthalpy change is that its just fancy way of saying how much energy is released or absorbed.

$$enthalpy\ change\ (\Delta H) \approx energy\ change^*$$

- Enthalpy change is represented by ΔH.

*In case you're curious, enthalpy is technically defined as $H = U + PV$, but you don't need to know this :p

THERMOCHEMICAL EQUATIONS



$$\Delta H = H_{\text{products}} - H_{\text{reactants}}$$

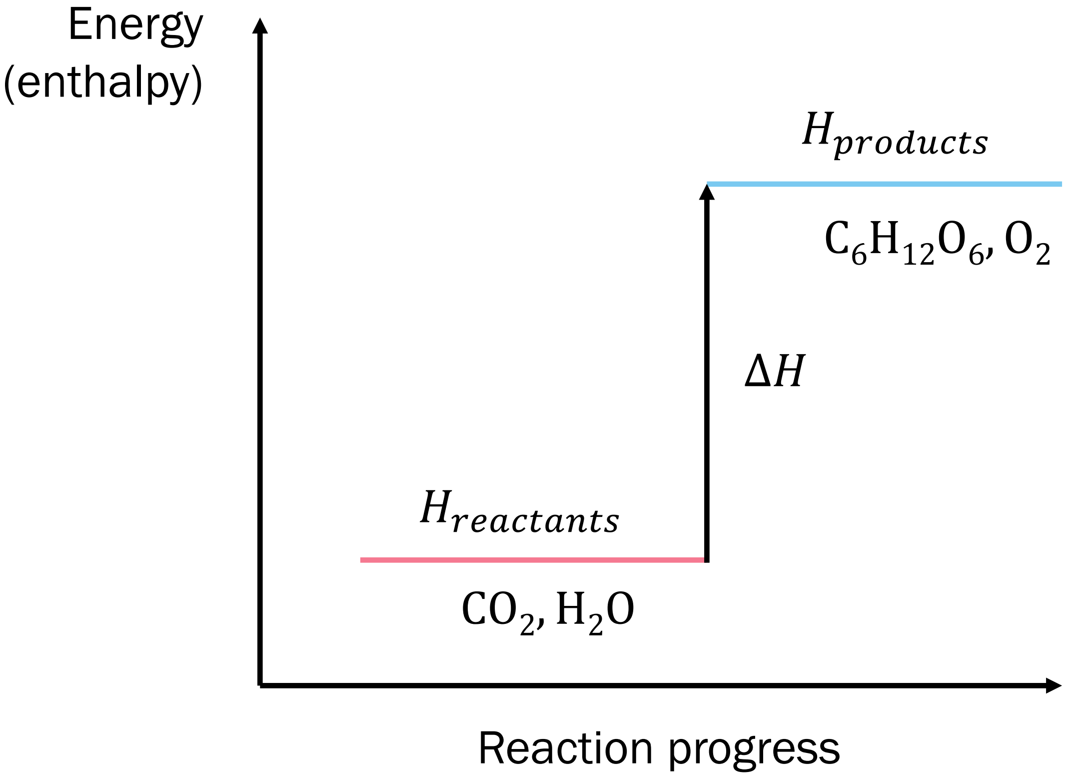
EXOTHERMIC REACTION

$$\Delta H < 0$$

'Releases energy'

$CH_4(g) + O_2(g) \longrightarrow CO_2(g) + 2H_2O(l) \quad \Delta H = -890\ kJ\ mol^{-1}$

THERMOCHEMICAL EQUATIONS



$$\Delta H = H_{\text{products}} - H_{\text{reactants}}$$

ENDOTHERMIC REACTION

$$\Delta H > 0$$

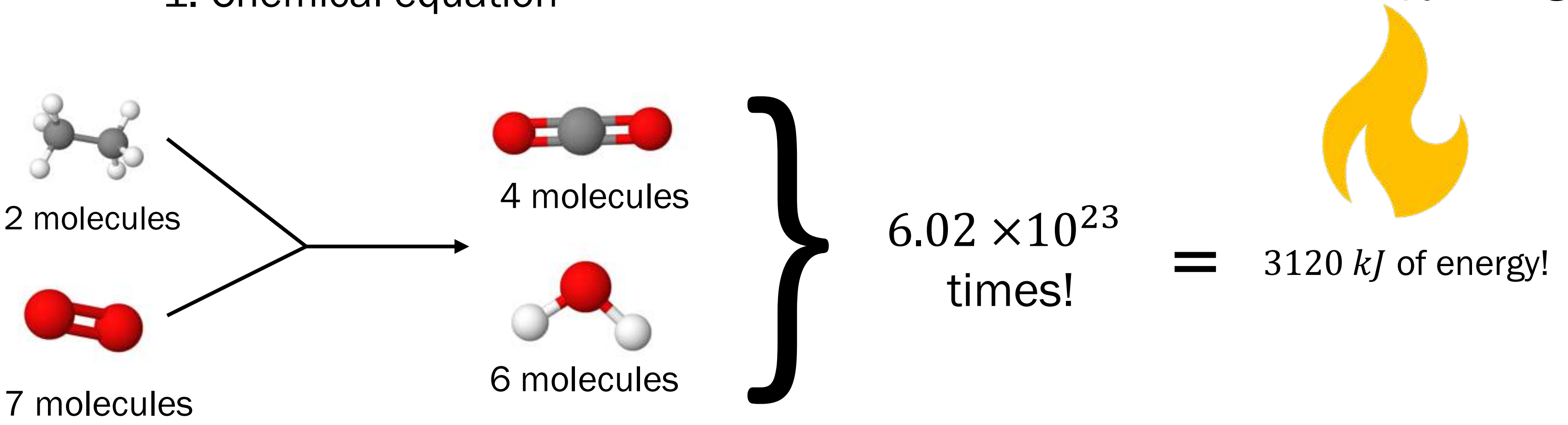
'Consumes energy'

$6CO_2(g) + 6H_2O(l) \longrightarrow C_6H_{12}O_6 + 6O_2 \quad \Delta H = +2816\ kJ\ mol^{-1}$

THERMOCHEMICAL EQUATIONS

- ***Thermochemical equations*** are made of two parts:

$$\underbrace{2C_2H_6(g) + 7O_2(g) \longrightarrow 4CO_2(g) + 6H_2O(l)}_{\text{1. Chemical equation}} \qquad \underbrace{\Delta H = -3120\ kJ\ mol^{-1}}_{\text{2. Enthalpy change value}}$$



6.02×10^{23} times! = 3120 kJ of energy!

→ If we do this reaction 1 mole times we release 3120 kJ of energy, but how much energy is released by the combustion of 1 mole of ethane?

THERMOCHEMICAL EQUATIONS

- It follows that when we *manipulate* thermochemical equations, we should alter the ΔH as follows:

→ Multiply coefficients of equation ⇒ multiply ΔH

$$2C_2H_6(g) + 7O_2(g) \longrightarrow 4CO_2(g) + 6H_2O(l) \quad \Delta H = -3120\ kJ\ mol^{-1}$$

$$4C_2H_6(g) + 14O_2(g) \longrightarrow 8CO_2(g) + 12H_2O(l) \quad \Delta H = -6240\ kJ\ mol^{-1}$$

→ Reverse the equation ⇒ negate ΔH

$$6CO_2(g) + 6H_2O(l) \longrightarrow C_6H_{12}O_6 + 6O_2 \quad \Delta H = +2816\ kJ\ mol^{-1}$$

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2(g) + 6H_2O(l) \quad \Delta H = -2816\ kJ\ mol^{-1}$$

→ Add two equations ⇒ add their ΔH values!

$$\begin{array}{lll} & I_2(l) \rightarrow I_2(s) & \Delta H = -16\ kJ\ mol^{-1} \\ + & I_2(s) \rightarrow I_2(g) & \Delta H = +62\ kJ\ mol^{-1} \\ \hline & I_2(l) \rightarrow I_2(g) & \Delta H = +46\ kJ\ mol^{-1} \end{array}$$

THERMOCHEMICAL EQUATIONS

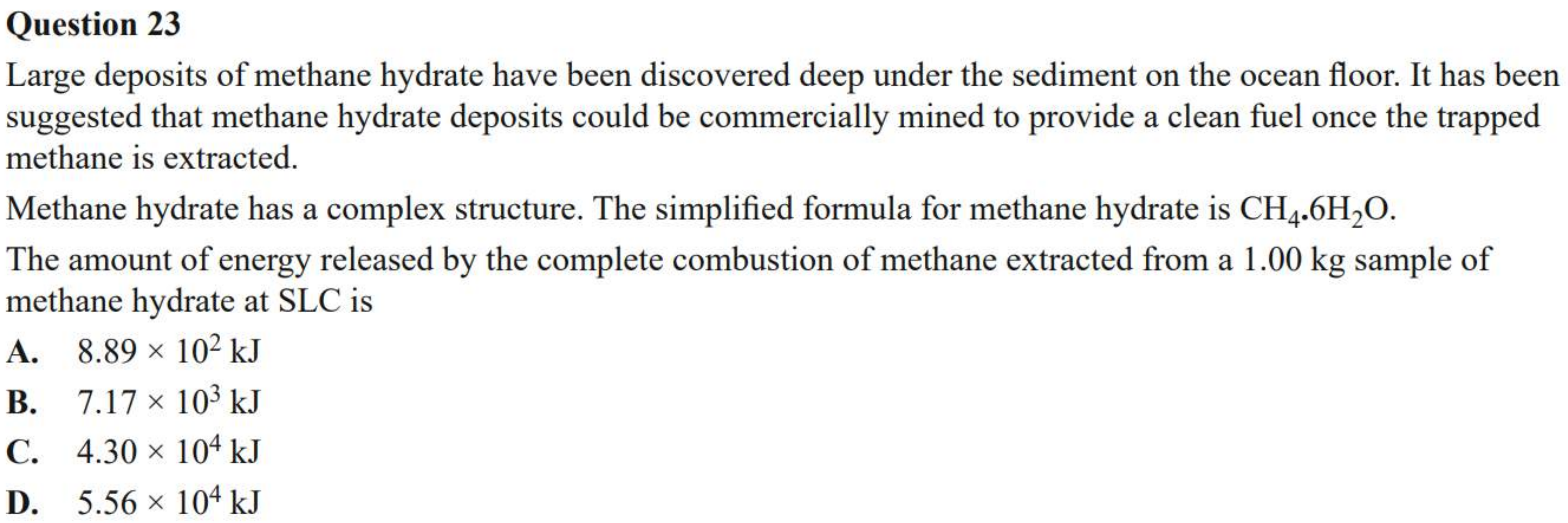
→ Key point: DON'T FORGET THE ΔH SIGN >:-[

$6CO_2(g) + 6H_2O(l) \longrightarrow C_6H_{12}O_6 + 6O_2 \quad \Delta H = \ 2816\ kJ\ mol^{-1}$ ☹

$6CO_2(g) + 6H_2O(l) \longrightarrow C_6H_{12}O_6 + 6O_2 \quad \Delta H = \ +2816\ kJ\ mol^{-1}$ ☺

- You will lose marks if you forget and more importantly you'll make me disappointed…

PRACTICE QUESTION



Question 23

Large deposits of methane hydrate have been discovered deep under the sediment on the ocean floor. It has been suggested that methane hydrate deposits could be commercially mined to provide a clean fuel once the trapped methane is extracted.

Methane hydrate has a complex structure. The simplified formula for methane hydrate is $CH_4.6H_2O$.

The amount of energy released by the complete combustion of methane extracted from a 1.00 kg sample of methane hydrate at SLC is

A. 8.89×10^2 kJ

B. 7.17×10^3 kJ

C. 4.30×10^4 kJ

D. 5.56×10^4 kJ

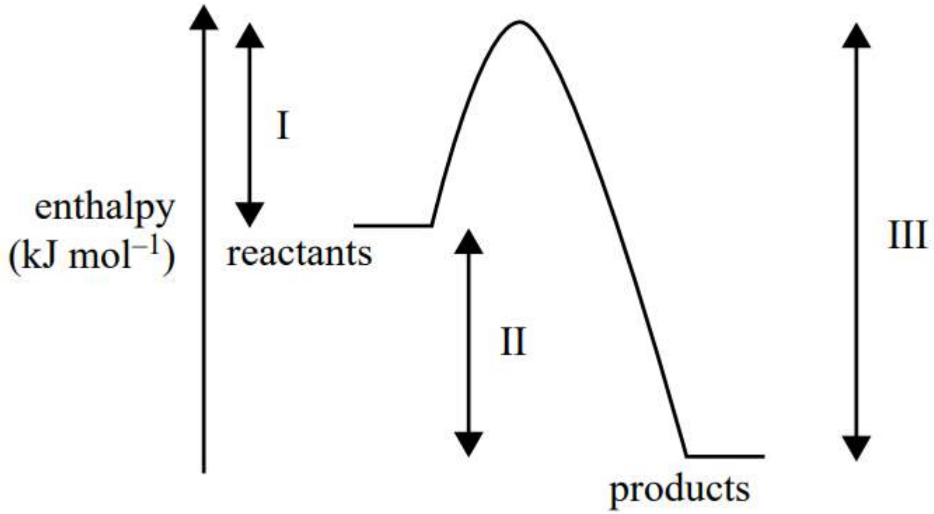
FUELS

VCAA 2014 Q23

PRACTICE QUESTION

Question 16

Consider the following energy profile for a particular chemical reaction, where I, II and III represent enthalpy changes during the reaction.



Which one of the following statements is correct?

A. The activation energy for the reverse reaction is (III–II).

B. The net energy released for the forward reaction is represented by II.

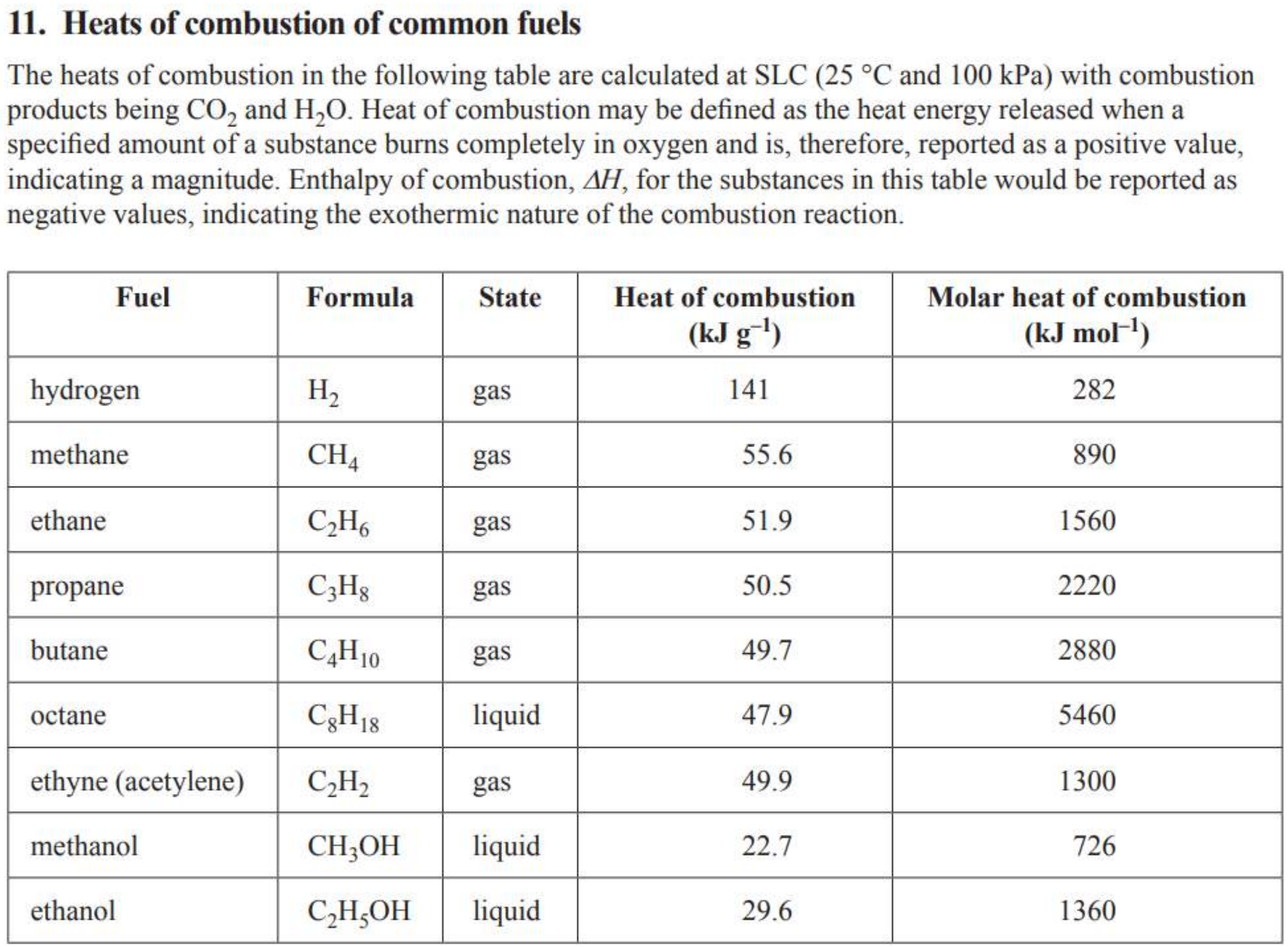
C. The energy required to break the reactant bonds is represented by II.

D. The energy released by the formation of new bonds is represented by I.

FUELS

VCAA 2015 Q16

HEAT OF COMBUSTION



11. Heats of combustion of common fuels

The heats of combustion in the following table are calculated at SLC (25 °C and 100 kPa) with combustion products being CO_2 and H_2O. Heat of combustion may be defined as the heat energy released when a specified amount of a substance burns completely in oxygen and is, therefore, reported as a positive value, indicating a magnitude. Enthalpy of combustion, ΔH, for the substances in this table would be reported as negative values, indicating the exothermic nature of the combustion reaction.

Fuel	Formula	State	Heat of combustion (kJ g^{-1})	Molar heat of combustion (kJ mol^{-1})
hydrogen	H_2	gas	141	282
methane	CH_4	gas	55.6	890
ethane	C_2H_6	gas	51.9	1560
propane	C_3H_8	gas	50.5	2220
butane	C_4H_{10}	gas	49.7	2880
octane	C_8H_{18}	liquid	47.9	5460
ethyne (acetylene)	C_2H_2	gas	49.9	1300
methanol	CH_3OH	liquid	22.7	726
ethanol	C_2H_5OH	liquid	29.6	1360

VCAA Chemistry Data Booklet, Page 10

HEAT OF COMBUSTION

- The ***heat of combustion*** of a fuel is the amount of energy released when a specified amount (1 mol, 1 g, etc.) of that fuel undergoes complete combustion.
- Heat of combustion is denoted by the symbol ΔH_c

→ Hydrogen, $H_2(g)$ $\Delta H_c = 282\ \text{kJ mol}^{-1}$

→ Ethyne, $C_2H_2(g)$ $\Delta H_c = 1300\ \text{kJ mol}^{-1}$

→ Butane, $C_4H_{10}(l)$ $\Delta H_c = 2880\ \text{kJ mol}^{-1}$

- It is *very similar* to enthalpy change/heat of reaction/ΔH, but there are some subtle but *key differences!*

HEAT OF COMBUSTION

- One of the key differences between ΔH and ΔH_c is what the 'per mol' part means in each!

→ ΔH gives us the amount of release *per mol of reaction*

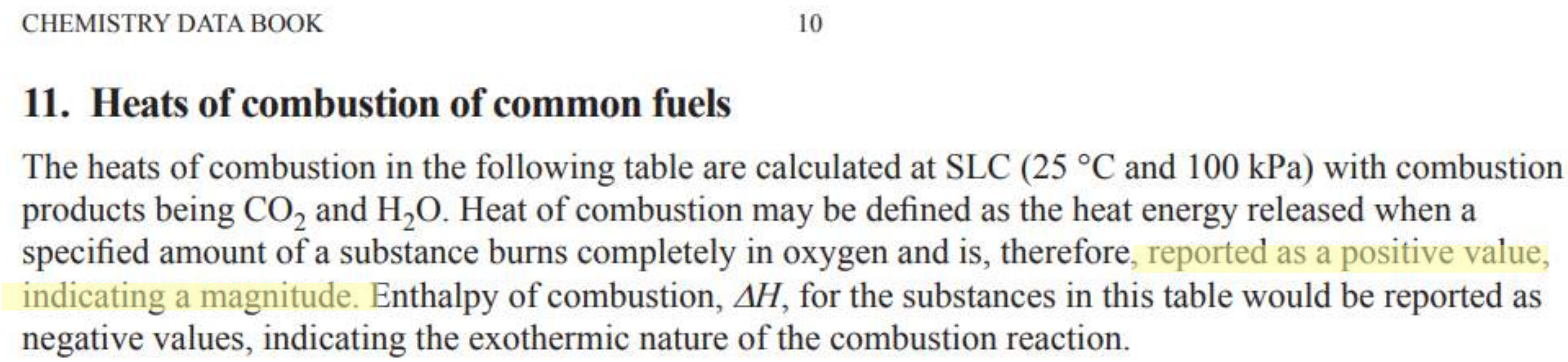
→ ΔH_c gives us the amount of release *per mol of fuel used*

$$2CH_3OH(l) + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 4H_2O(g) \qquad \Delta H = -1452 \text{ kJ mol}^{-1}$$

However, from data book, we have $\Delta H_{c(methanol)} = 726 \text{ kJ mol}^{-1}$

→ Key point: ΔH is linked to the equation, ΔH_c is linked to the fuel.

HEAT OF COMBUSTION



CHEMISTRY DATA BOOK 10

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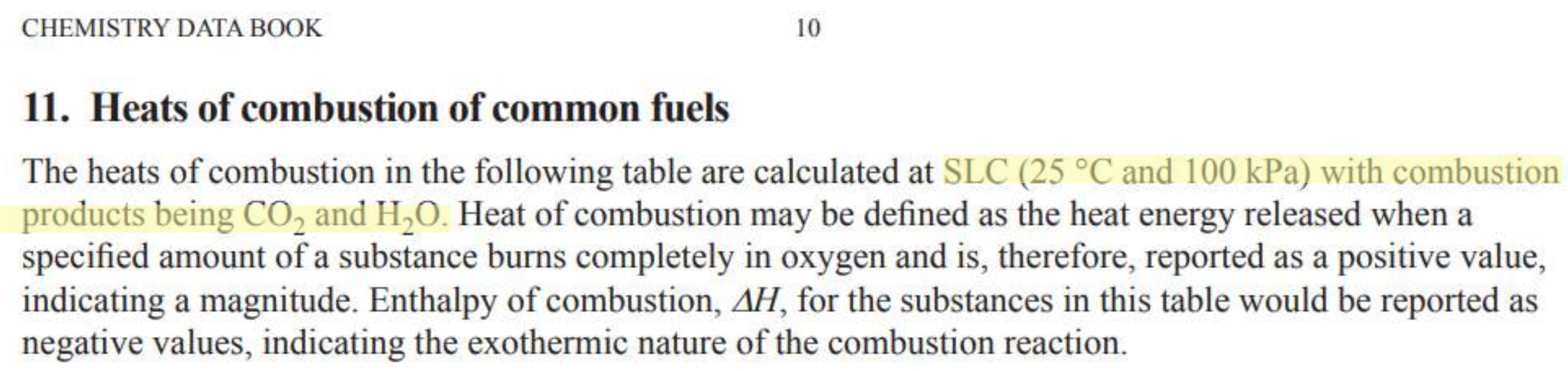
→ Key point: Heat of combustion is defined to be a ***positive number***!!! *When writing it down, you do not need to include any sign!* For example…

$$\mathrm{C_2H_5OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l)} \quad \Delta H = -1360\ kJ\ mol^{-1}$$

$$\Delta H_c(ethanol) = 1360\ kJ\ mol^{-1}$$

HEAT OF COMBUSTION



CHEMISTRY DATA BOOK 10

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→ Key point: When writing thermochemical equations under SLC conditions, water should *technically* be shown in the liquid state.

$$C_2H_5OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l) \quad \Delta H = -1360\ kJ\ mol^{-1}$$

HEAT OF COMBUSTION

ΔH VS ΔH_c

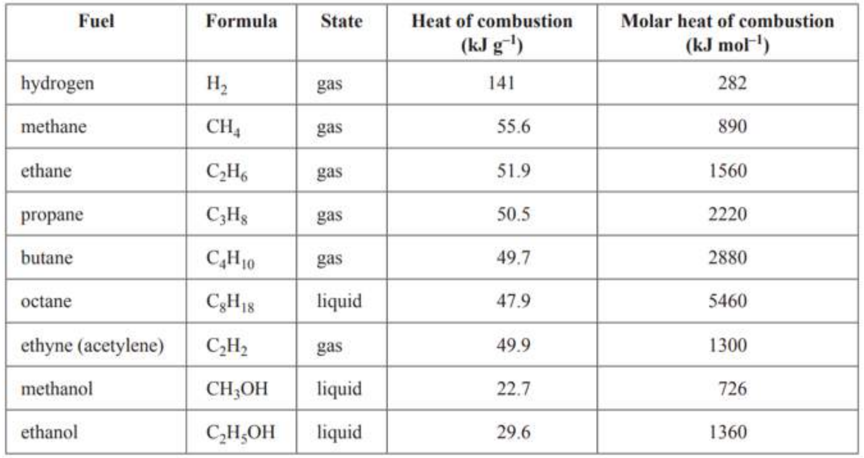
- ‘per mol of reaction’
- Changes depending on reaction
- Needs a + or – sign

- ‘per mol of fuel’
- Always the same value
- Has no sign

HEAT CALCULATIONS

- Okay cool cool cool, so we know all about how fuels each have a heat of combustion, but how can we figure these values out in the first place???

¯_(ツ)_/¯



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ethyne (acetylene)	C_2H_2	gas	49.9	1300
methanol	CH_3OH	liquid	22.7	726
ethanol	C_2H_5OH	liquid	29.6	1360

Answer:

H_2O

Stay hydrated kiddos

→ Key point: We know ***exactly*** how much energy it takes to heat water. We can use that information to help us calculate how much energy a fuel releases.

HEAT CALCULATIONS

$$c_{water} = 4.18\ \mathrm{J\ g^{-1}K^{-1}}$$

What does this physically mean?

→ Key point: The specific heat capacity (c) of a substance is defined as the amount of energy required to heat 1 gram of the substance by 1 degree.

HEAT CALCULATIONS

- You might remember this equation from last year!
- This is how we relate the mass, temperature change, and flow of energy from a substance!

$$q = mc\Delta T$$

→ q = energy absorbed or released (warning: **J, not kJ**)

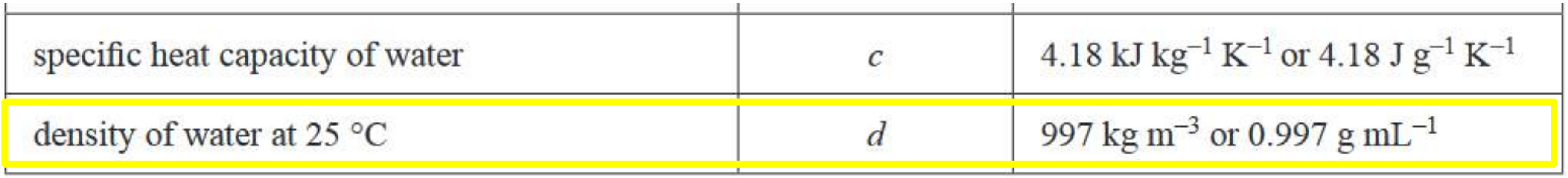
→ m = mass of substance (g) (NOT VOLUME)

→ c = **specific heat capacity** of substance (J g^{-1} °C^{-1} or J g^{-1} K^{-1})

→ ΔT = change in temperature of substance (°C or K)

HEAT CALCULATIONS

Warning: VCAA will no longer accept that: 1 g = 1 mL

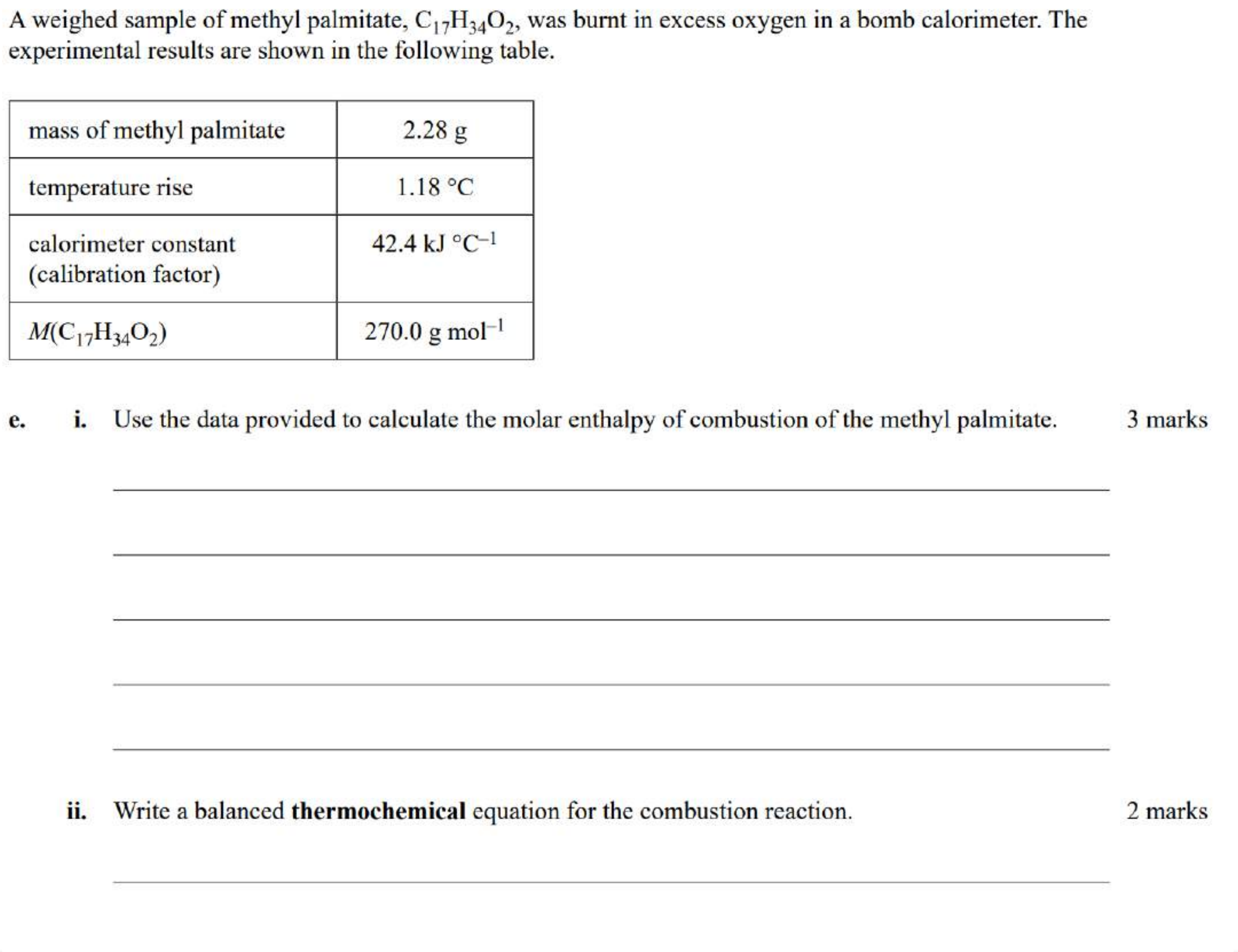


specific heat capacity of water	c	4.18 kJ kg^{-1} K^{-1} or 4.18 J g^{-1} K^{-1}
density of water at 25 °C	d	997 kg m^{-3} or 0.997 g mL^{-1}

If given the volume of water, must used density to calculate mass.

$$density = \frac{mass}{volume}$$

PRACTICE QUESTION



A weighed sample of methyl palmitate, $C_{17}H_{34}O_2$, was burnt in excess oxygen in a bomb calorimeter. The experimental results are shown in the following table.

mass of methyl palmitate	2.28 g
temperature rise	1.18 °C
calorimeter constant (calibration factor)	42.4 kJ $°C^{-1}$
$M(C_{17}H_{34}O_2)$	270.0 g mol^{-1}

e. **i.** Use the data provided to calculate the molar enthalpy of combustion of the methyl palmitate. 3 marks

ii. Write a balanced **thermochemical** equation for the combustion reaction. 2 marks

PRACTICE QUESTION

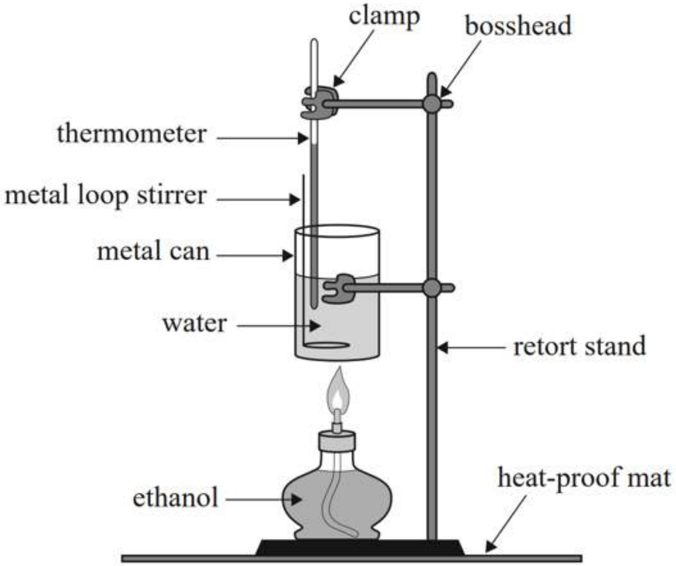
THERMOCHEMISTRY

Question 3 (9 marks)

The enthalpy for the combustion of ethanol is provided in the data book. This combustion of ethanol is represented by the following equation.

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$

A spirit burner used 1.80 g of ethanol to raise the temperature of 100.0 g of water in a metal can from 25.0 °C to 40.0 °C.



a. Calculate the percentage of heat lost to the environment and to the apparatus.

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BLOCK 3 SUMMARY

- Brief skim over fuels
- Universal gas equation
- Thermochemical equations
- Enthalpy change vs. heat of combustion
- Heat calculations

ATAR Notes

GOOD LUCK FOR THE REST OF THE YEAR :D