<u>Energy</u>

Basic energy stuff

- **Energy:** Ability to do work

- **Useful energy source:** Source of energy that releases energy at a reasonable rate and produces minimal pollution

- **Conservation of energy:** The total energy is always constant, but the amount of useful energy available decreases, this is known as the degradation of energy

- Degradation of energy is usually via heat, degraded energy is energy that can no longer do work

- **Renewable energy source:** A source which can be naturally replenished at a rate faster than it is used and is thus theoretically abundant
    - Biomass
    - Solar
    - Wind
    - Tidal
    - Geothermal

- **Non-renewable energy source:** A source which is used at a rate faster than it can be replenished
    - Fossil fuels

- **Fuel:** A substance that releases energy when it undergoes a chemical or nuclear reaction

- **Specific energy:** Energy released per unit mass of fuel (Jkg^{-1})

$$E_s = \frac{Energy\ released}{Mass\ of\ fuel\ used}$$

- **Energy density:** Energy released per unit volume of fuel (Jm^{-3})

$$E_d = \frac{Energy\ released}{Volume\ of\ fuel\ used}$$

Fossil fuels

- **Fossil fuels:** Fuel formed by the reduction of biological matter containing carbon, nitrogen, oxygen, hydrogen,and sulfur under anaerobic conditions

- **Oil:** A complex mixture of straight-chained, branched aromatic, and cyclic hydrocarbons

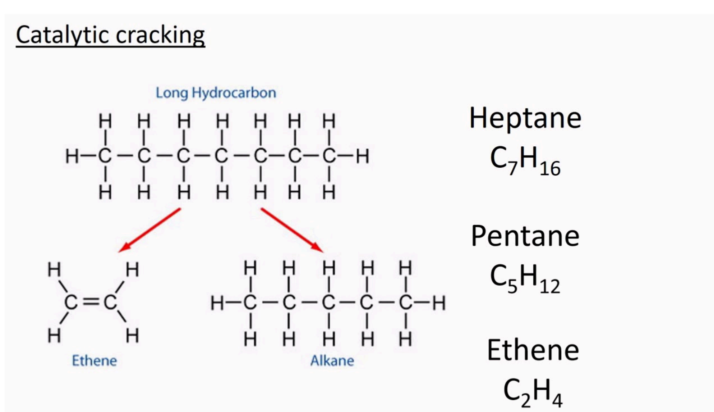
- Crude oil must be refined via fractional distillation

- Process of fractional distillation:
    1. A sample of crude oil is heated
    2. The level at which a fraction condenses depends on its boiling point and molar mass
        a. Smaller molecules (more volatile)rise to the top of the column
        b. Heavier molecules (less volatile) are collected at the bottom

- Heavier molecules have higher boiling point as there are greater london dispersion forces between molecules

- **Cracking:** Process by which large chain hydrocarbons are broken into smaller molecules (a large alkane is broken into a smaller alkane and alkene)
    - Heptane can be cracked into ethene and pentane

$$C_7H_{16} \rightarrow C_2H_4 + C_5H_{12}$$



- **Thermal cracking:** Cracking wherein the alkene is the major product; this can be used for the production of polymers (ethene to make polyethene)
  - Temp: 750 ℃
  - Pressure: 70 atm

- **Catalytic cracking:** Cracking wherein the alkane is the major product, these burn more evenly in car engines; a zeolite catalyst is used to conduct the process at a lower temperature

- **Auto-ignition:** The process in which fuel and air-mixture prematurely ignites, resulting in knocking
  - Knocking damages the engine and causes it to lose power

- **Octane number:** Measure of a fuel's ability to resist knocking in a car-engine
  - Measured on a scale where 0 to 100
  - Heptane has an octane number of 0 as it completely causes auto-ignition
  - 2,2,4-trimethylpentane has an octane number of 100 as it completely resists auto-ignition
  - A fuel with octane rating 93 is a fuel that has the same tendency to auto-ignite as a mixture of 93% 2,2,4-trimethylpentane and 7% heptane

- Higher octane-numbered fuels are more desirable

- Straight-chained fuels have low octane numbers (cause more auto-ignition)

- Small-chain, branched and cyclic fuels have high octane numbers (cause less auto-ignition)

- Why is ethanol added to gasoline:
  - Uses fossil fuels more slowly
  - Low carbon footprint
  - Increases octane rating

- Methods to increase octane-number of a fuel and reduce tendency to auto-ignite
  - Catalytic reforming
  - Isomerisation

- **Catalytic reforming:** Process through which a long-chain hydrocarbon is converted into an aromatic hydrocarbon
    - **Temperature:** 500 °C
    - **Pressure:** 20 atm
    - **Catalyst:** Platinum

- Hexane can be converted into benzene and hydrogen gas

$$C_6H_{14} \rightarrow C_6H_6 + 4H_2$$

- Heptane can be converted into methylbenzene and hydrogen gas

$$C_7H_{16} \rightarrow C_6H_5CH_3 + 4H_2$$

- **Isomerisation:** Process through which a long-chain hydrocarbon is converted into a branched hydrocarbon
    - The product of isomerisation is just an isomer of the reactant
    - **Catalyst:** Zeolite and platinum catalyst

- Pentane can be converted into 2-methylbutane

- **Coal gasification:** Process by which coal is converted into syngas (mixture of carbon monoxide and hydrogen gas) which can be used to produce methane (natural gas)

$$C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$$
$$CO(g) + 3H_2(g) \rightarrow CH_4(g) + H_2O(g)$$

- The carbon can be heated directly under hydrogen gas to give methane

$$2C(s) + 2H_2O(g) \rightarrow CH_4(g) + CO_2(g)$$

- **Coal liquefaction:** Process by which coal is converted into liquid hydrocarbons to be used as fuels
    - Occurs at high temperatures (500°C) and high pressures (15000 kPa)

$$nC(s) + (n+1)H_2(g) \rightarrow C_nH_{2n+2}(l)$$

- The process can also occur via the Fischer-Torpsch reaction:

$$(2n + 1)H_2\ nCO \rightarrow C_nH_{2n+2} + nH_2O$$

- **Carbon footprint:** Total amount of greenhouse gases produced during human activities, expressed in equivalent tons of carbon dioxide

Nuclear fusion and fission

- **Nuclear fusion:** Process by which lighter nuclei combine and fuse to form heavier nuclei, releasing energy in the process

- **Nuclear fission:** Process which heavy, unstable nuclei break down into smaller and more stable nuclei, releasing energy in the process

- Both fusion and fission cause binding energy per nucleon to increase

- **Critical mass:** Minimum amount of mass needed for a nuclear fission chain reaction to be self-sustaining

- **Disposing low-level nuclear waste:** Nuclear waste produced in areas where radioactive materials have been handled like cancer treatment facilities (gloves, towels, clothing etc)
  - Waste has short half-life but high volume
  - Stored in cooling ponds until radioactivity has fallen to normal levels

- **Disposing high-level nuclear waste:** Spent reactor fuel and waste from reprocessing spent fuel
  - Waste has large half-life but short volume
  - Waste converted into solid glass via vitrification and stored in stainless steel containers underground

- **Breeder reactors:** A reactor which generate's more fissile material (material capable of sustainaing a fission reaction) than it consumes

- Reactions in a fast breeder reactor:

$$^{238}U + n \rightarrow {}^{239}U$$
$$^{239}U \rightarrow {}^{239}Np + {}_{-}e$$
$$^{239}Np \rightarrow {}^{239}Pu\ {}_{-}e$$
$$^{239}Pu + n \rightarrow {}^{145}Ba + {}^{93}Sr + 2n$$

- **Effusion:** Process in which a gas escapes through a small hole in a container

- **Graham's law of effusion:** Rate of effusion of a gas is inversely proportional to its mass

$$\frac{Rate_1}{Rate_2} = \sqrt{\frac{M_2}{M_1}}$$

- This is derived from equating kinetic energies and dividing through (at same temperatures, average kinetic energy is constant)

- Uranium contains two isotopes (U-238 and U-235), U-238 is more abundant but U-235 is used in fission, therefore uranium is enriched to increase the abundance of U-235
    1. Uranium oxide (UO_2) is converted into uranium hexafluoride (UF_6)
        a. UO_2 is an ionic compound with a very high boiling point while UF_6 is an octahedral, non-polar molecule and so it sublimes at a low temperature
    2. There are two UF_6 molecules, one with U238 and one with U235 (the difference in mass allows gaseous diffusion or centrifugation to separate the two molecules
    3. Gaseous diffusion: Both UF_6 effuse through a porous membrane at different speeds
    4. Centrifugation: Gaseous mixture of the two isotopes is separated in a centrifuge
        a. Heavier molecule moves to the walls, lighter one is pumped out
    5. In both cases the process must be repeated several times

- The decay of radioactive isotopes is a first order reaction

$$\text{Rate} = \lambda[N]$$

- λ is the decay constant which is the probability a nucleus decays per unit time

- To identify the elemental composition of a star, we must analyse the light from it and obtain an absorption spectrum
    - Each element has a unique absorption spectrum that is produced when electrons transition to higher energy levels

Solar Energy

- **Photosynthesis:** Process by which light energy from the sun is converted into chemical energy

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

- Photosynthesis only occurs in green plants as they have a light absorbing pigment called chlorophyll

- Chlorophyll is green as it absorbs red light and so the complementary colour (green) is observed

- **Conjugated systems:** Alternating single and double bonds

- Biological pigments have extensive conjugated systems that enable it to absorb light
    - The larger the conjugated system, the lower wavelength of light is absorbed

- **Biofuels:** Fuels whose energy is obtained from biological carbon fixation
    - Carbon fixation is the process by which CO_2 is converted into organic compounds
    - Photosynthesis is an example of carbon fixation, the glucose produced can be used to produce ethanol which is a biofuel

- Ethanol is produced by fermenting glucose

- Carried out in 37°C in anaerobic conditions with a yeast enzyme to catalyse the reaction

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

- Vegetable oils have energy contents similar to that of regular diesel fuel but are too viscous and so must undergo a transesterification process
    - The high viscosity is due to the large molar mass, resulting in strong london dispersion forces between molecules

- Transesterification reaction (either methanol or ethanol is the alcohol in the reactant)
    - Strong base is used as a catalyst

$$RCOOR_1 + R_2OH \rightarrow R_1OH + RCOOR_2$$

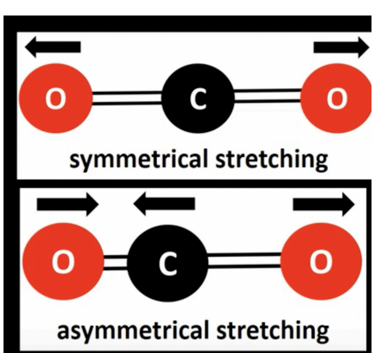
Greenhouse effect

- Greenhouse gases (CH_4, CO_2, H_2O) allow the passage of short-wavelength UV light

- The earth's surface then re-radiates this back into the atmosphere as longer wavelength infrared radiation, greenhouse gases absorb this and re-radiate it in all directions, especially towards the earth

- The greenhouse effect is a natural process but it is enhanced by increased concentrations of greenhouse gases which result in more infrared reradiated

- When a greenhouse gas like CO_2 absorbs infrared radiation, its bonds vibrate at a natural frequency equal to the frequency of infrared radiation



- Asymmetrical stretching and bending results in a dipole change in the molecule, this allows it to absorb infrared radiation

- Oxygen and nitrogen are not greenhouse gases as their bonds are non-polar and have only one vibrational mode: stretching and compressing which does not result in a dipole change

Gas	Main source	Greenhouse factor	Relative abundance
H_2O	Evaporation of oceans and lakes	0.1	0.10
CO_2	Combustion of fossil fuels	1	0.036
CH_4	Anaerobic decay of organic matter by livestock	30	0.0017
N_2O	Artificial fertilizers	160	0.0003
CFCs	Refrigerants and solvents	20000	0.00001

- Water and O_2 are significant because of their abundance while methane and CFCs are significant because of their greenhouse factor

- **Greenhouse factor:** Ability of a gas to absorb infra-red radiation on a scale where CO_2 is 1

- Methods to reduce CO_2 emissions:
    1. Increased use of insulation and energy efficient appliances
    2. Use public transport and drive more fuel efficient cars
    3. Increased use of renewable energy sources

4. Carbon capture and storage (CO_2 captured from fossil fuel burning power stations and stored underground)

- Effect of increasing amount of greenhouse gases:
    - Rising sea levels through thermal expansion of water and melting of polar ice caps and glaciers
    - Effects on food production through droughts, changes in yield

- **Global dimming:** Decrease in the amount of solar radiation reqaching the syrface of the earth because of particulate matter in the atmosphere that absorbs and reflects solar radiation back into space
    - The particulate matter is caused by combustion of coal, oil and biomass
    - Water droplets containing particulate matter can form polluted clouds which reflect more solar radiation

Cells

- **Primary cells:** Cells that work through a non-reversible electrochemical reaction
    - As the reaction is non-reversible, they cannot be recharged and must be discarded after use

- **Secondary cells:** Cells that work through reversible redox reaction
    - The reaction is reversible, they can be recharged

- The thermodynamic efficiency of a cell is given by:

$$\eta = \frac{\Delta G}{\Delta H} \times 100$$

- The nernst equation is used to calculate the cell potential of a cell under non-standard conditions:

$$E = E^{\ominus} - \frac{RT}{nF} ln(Q)$$

Q: reaction quotient (K_c expression at non-equilibrium)

- **Concentration cells:** Cells that contain two electrodes made of the same metal and the same electrolyte but electrolytes of different concentrations
  - Half-cell with lower concentration of electrolyte will undergo oxidation so the concentration increases
  - Half-cell with higher concentration of electrolyte will undergo reduction so the concentration decreases
  - The standard cell potential of a concentration cell is 0

Photovoltaic cells and DSSCs

- **Semiconductors:** Materials that have electrical conductivity between a metal and insulator

- Metals are good electrical conductors as they have delocalised electrons that become mobile in an electric field

- Silicon is a poor electrical conductor as its electrons are held in fixed positions in covalent bonds
  - Silicon is held in a lattice with each atom being sp^3 hybridised

- How conductivity changes with temperature
  - **Metal:** Higher temperature decreases conductivity
    - Higher temperature increases vibrations of metal cations which restrict flow of electrons
  - **Semiconductor:** Higher temperature increases conductivity as electrons have more energy to move to conduction band

- Increasing temperature of silicon increases its electrical conductivity as some electrons in the covalent bond are free to move within the structure

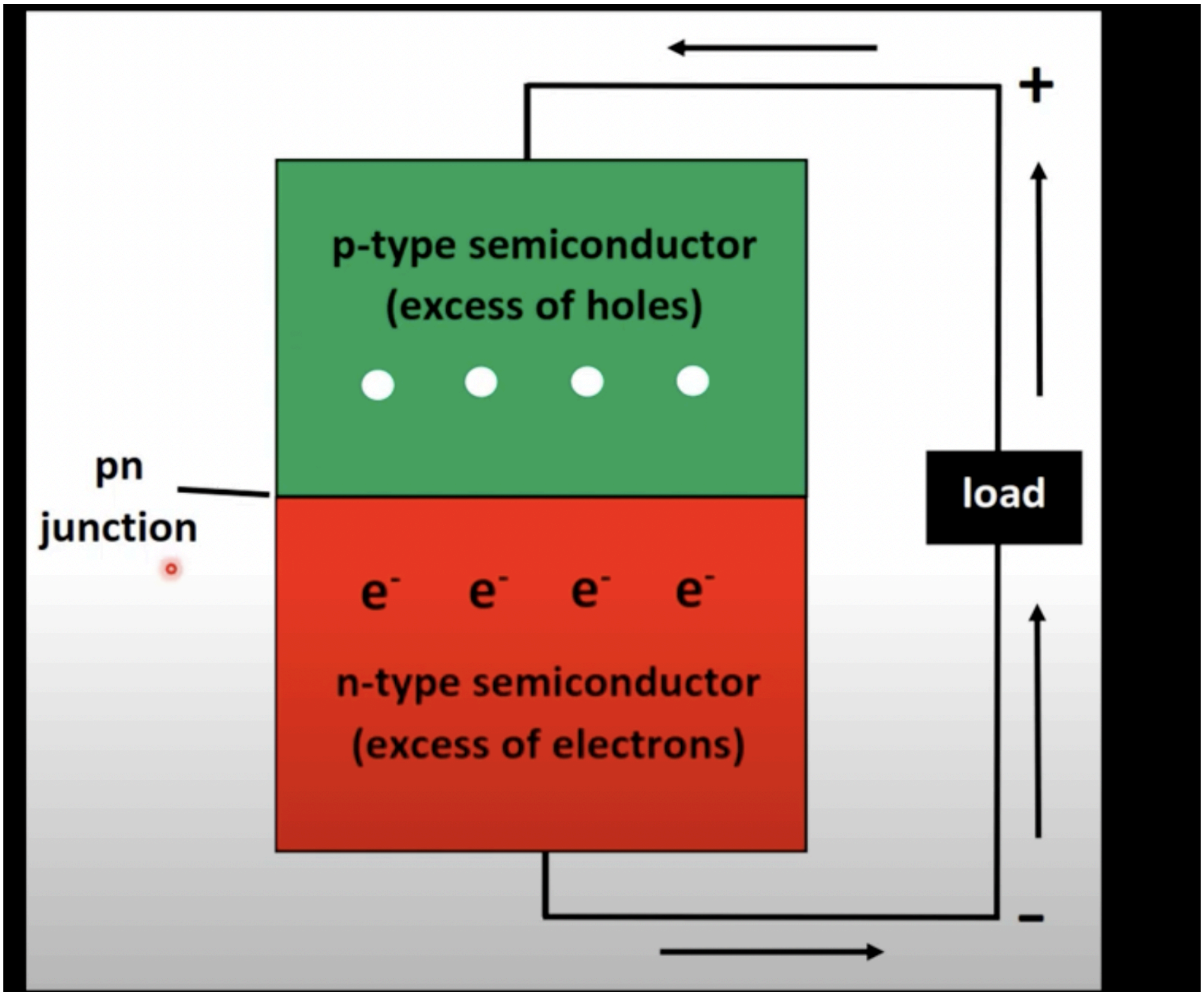
- **Doping:** Process of increasing electrical conductivity of a semiconductor by mixing small amounts of impurities into the silicon lattice
  - Doping reduces the gap between the valence and conduction bands

- **N-type semiconductors:** Semiconductors doped with group 15 elements (phosphorous or arsenic)
    - N stands for negative, group 15 elements provide extra electrons (the extra electrons are free to move, increasing electrical conductivity)

- **P-type semiconductors:** Semiconductors doped with group 13 elements (boron or gallium)
    - P stands for positive, there are now holes which implies more positive charge carriers, thereby increasing electrical conductivity

- N-type doping results in an excess of electrons while p-type doping results in an excess of holes
    - Both increase electrical conductivity

- **Photovoltaic cells:** Cells that convert solar energy into electrical energy
    - Made from both p-type and n-type silicon semiconductors



- Steps in photovoltaic cell:
    1. Excess lectrons in the n-type semiconductor diffuse across the pn junction into the p-type semiconductor, causing holes in the n-type semiconductor
    2. Holes diffuse across the p-n junction causing negative charges in the p-type material
    3. When light is incident on the photovoltaic panel, electrons flow to the n-type semiconductor while holes flow to the p-type, this causes a potential difference
    4. Electrons flow through an external circuit to the p-type semiconductor, this produces an electric current

- **DSSCs:** Dye-sensitized photovoltaic cells (convert solar energy into elec trical energy)

    - A dye coats the panel which traps light photons and releases electrons
    - The dye contains an extensive conjugated system which allows for visible light to be absorbed

- Steps in DSSCs:
    1. Light passes through transparent anode and excites dye molecules
    2. Excited dye molecules inject electrons into TiO_2 layer which acts as a semiconductor
    3. Electrons flow through external circuit into platinum cathode and then into the iodide electrolyte
    4. Iodide electrolyte transports electrons back into dye molecules where dye is reduced
    5. This process generates an electric current

- In terms of oxidation and reduction:
    - Dye is first oxidised (triiodide ions reduced)
    - Dye is then reduced by iodide electrolyte (iodide ions are oxidised to produce triiodide ions)

- Nanoparticles are coated with light-absorbing dye to increas effective surface area enables more light to be absorbed over a wide range of the visible spectrum to be absorbed
    - DSSC can absorb more light under cloudy conditions than regular photovoltaic cells

- Differences between photovoltaic cells and DSSCs:
    - Silicon acts as source of photoelectrons and electric field in PV cell while semiconductor only used for charge transport while dye act as source of photoelectrons in DSSC
    - DSSCs are simpler and cheaper to manufacture while PV cells are more complex and expensive
    - DSSCs absorb light of longer wavelength (has a greater conjugated system)

DSSC

- Dye - traps photons or releases electrons

- TiO2 - semiconductor or conducts electricity
- Electrolyte - reduces the oxidized dye
- The use of nanoparticles coated with light-absorbing dye increases the effective surface area and allows more light over a wider range of the visible spectrum to be absorbed
- Reduction of Electrolyte in a Gratzel Cell:
  $I^{3-} + 2e^- \rightarrow 3I^-$
- Advantages:
  - Cheaper and easier to manufacture
  - Uses light of lower energy, use of nanoparticles provides large surface area for exposure to sunlight, can absorb better under cloudy conditions
  - Operate at lower temperatures
  - Better conductivity
  - More flexible/durable
- Disadvantage:
  - Electrolyte can freeze at low temperatures and expand at high temperatures which can damage the cell

Photovoltaic Cell

- N-type (Group 15) and P-type (Group 13) silicon layers
- Potential difference/charge separation created between layers of silicon
- Free electrons flow between layers from p-type to n-type
- Excess electrons move from n-type to p-type through an external circuit

Electrochemistry, Rechargeable batteries and Fuel Cells

Distinction between Fuel Cells and Primary Cells:
Material provides fuel in fuel cells (or) fuel is continually added in fuel cells

Batteries/Fuel Cells	Electrodes and Electrolyte	Discharging (Voltaic Cell)
Lead-Acid Battery - used in heavy power applications, internal combustion engines	Positive Electrode: Lead Negative Electrode: Lead + Lead(IV) Oxide Electrolyte: Sulfuric Acid	Oxidation (Anode): $Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2e^-$ Reduction (Cathode): $PbO_2(s) + 3H^+(aq) + HSO_4^-(aq) + 2e^- \rightarrow$

		$PbSO_4(s) + 2H_2O(l)$
Nickel-Cadmium Battery	Positive Electrode: Nickel Negative Electrode: Cadmium Electrolyte: Aqueous Potassium Hydroxide	Oxidation: $Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$ Reduction: $NiO(OH) + H_2O + e^- \rightarrow Ni(OH)_2 + OH$
Lithium Ion Battery - lightweight, good for portable batteries	Positive Electrode: $LiMnO_2$ Negative Electrode: Li Electrolyte: Polymer	Oxidation: $Li \rightarrow Li^+ + e^-$ Reduction: $Li^+ + MnO_2 + e^- \rightarrow LiMnO_2$
Hydrogen-Oxygen Fuel Cell (Alkaline Electrolyte)	Positive Electrode (Cathode): Oxygen Negative Electrode (Anode): Hydrogen Electrolyte: Alkaline	Oxidation: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$ Reduction: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
Hydrogen-Oxygen Fuel Cell (Acidic Electrolyte)	Positive Electrode (Cathode): Oxygen Negative Electrode (Anode): Hydrogen Electrolyte: Acid	Oxidation: $2H_2 \rightarrow 4H^+ + 4e^-$ Reduction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Direct Methanol Fuel Cell (DMFC)	Positive Electrode: Oxygen Negative Electrode: Methanol	Oxidation: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$ Reduction: $6H^+ + 1.5O_2 + 6e^- \rightarrow 3H_2O$
Microbial Fuel Cells (Glucose)		Oxidation: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$ Reduction: $O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$
Microbial Fuel Cells (Ethanoic Acid, Geobacter Bacteria)		Oxidation: $CH_3COO^- + 2H_2O \rightarrow 2CO_2 + 7H^+ + 8e^-$ Reduction: $2O_2 + 8H^+ + 8e^- \rightarrow 4H_2O$

Fuel cell/battery	Advantages	Disadvantages
fuel cell	• more efficient than direct combustion as more chemical energy is converted to useful energy • no pollution • low density	• hydrogen is a potentially explosive gas • hydrogen must be stored and transported in large/ heavy containers • very expensive; technical problems due to catalytic failures, leaks, and corrosion
lead–acid	• can deliver large amounts of energy over short periods	• heavy mass • lead and sulfuric acid could cause pollution
cadmium nickel	• longer life than lead–acid batteries	• cadmium is very toxic • produces a low voltage • very expensive
lithium ion	• low density • high voltage • does not contain a toxic heavy metal	• expensive • limited life span

Reactions to memorise:

Name	Reaction
Cracking	Long alkane → Alkene + alkane $C_7H_{16} \rightarrow C_2H_4 + C_5H_{12}$
Catalytic reforming (long chain hydrocarbon to cyclic aromatic compounds)	Hexane → Benzene + Hydrogen gas $C_6H_{14} \rightarrow C_6H_6 + 4H_2$ Heptane → Methylbenzene + Hydrogen gas $C_7H_{16} \rightarrow C_6H_5CH_3 + 4H_2$
Coal gasification (coal used to produce natural gas)	1. $C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$ 2. $CO(g) + 3H_2(g) \rightarrow CH_4(g) + H_2O(g)$ $2C(s) + 2H_2O(g) \rightarrow CH_4 + CO_2(g)$

Coal liquefaction (coal used to produce liquid hydrocarbon fuels)	$nC(s) + (n+1)H_2(g) \rightarrow C_nH_{2n+2}(l)$ Fischer-Torpsch: $nCO(g) + (2n+1)H_2 \rightarrow C_nH_{2n+2} + nH_2O$
Photosynthesis	$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O2$
Production of ethanol from glucose	$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
Transesterification ● **Catalyst:** Strong acid or base ● **Reagent:** Methanol or ethanol	$RCOOR_1 + R_2OH \rightarrow R_1OH + RCOOR_2$
Ocean acidification	$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$ $H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ Increasing CO_2 concentration causes both equilibriums to shift to the right so H^+ concentration increases so oceans become more acidic
Discharging Lead acid batteries Anode: Pb(s) Cathode: $PbO_2(s)$ Electrolyte: $H_2SO_4(aq)$	Anode (oxidation): $Pb(s) + HSO_4^-(aq) \rightleftharpoons PbSO_4(s) + H^+(aq) + 2e^-$ Cathode (reduction): $PbO_2(s) + 3H^+(aq) + HSO_4^-(aq) + 2e^- \rightleftharpoons PbSO_4(s) + 2H_2O(l)$
Discharging nickel-cadmium batteries Anode: NiO(OH)(s) Cathode: Cd(s) Electrolyte: KOH(aq)	Anode (oxidation) $Cd(s) + 2OH^-(aq) \rightleftharpoons Cd(OH)_2(s) + 2e^-$ Cathode (reduction): $2NiO(OH)(s) + 2H_2O(l) + 2e^- \rightleftharpoons 2Ni(OH)_2(s) + 2OH^-(aq)$

Discharging Lithium ion batteries Anode: Li(graphite) Cathode: $LiMnO_2(s)$ Electrolyte: polymer	Anode (oxidation): $Li(s) \rightarrow Li^+(polymer) + e^-$ Cathode (reduction): Li+(polymer) + MnO2(aq) + e- → LiMnO2(s)
Hydrogen fuel cell (acidic electrolyte) Anode: Hydrogen Cathode: Oxygen Electrolyte: Acid (PEM is needed to allow H^+ ions to move from anode to cathode)	Anode (oxidation): $2H_2(g) \rightleftharpoons 4H^+(aq) + 4e^-$ Cathode (reduction): $O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$
Hydrogen fuel cell (alkaline electrolyte) Anode: Hydrogen Cathode: Oxygen Electrolyte: Alkaline like KOH	Anode (oxidation): $2H_2(g) + 4OH^- \rightleftharpoons 4H_2O(l) + 4e^-$ Cathode (reduction): $2H_2O(l) + O_2(g) + 4e^- \rightleftharpoons 4OH^-(aq)$
Methanol fuel cell Anode: Water + methanol Cathode: Oxygen	Anode (oxidation): $CH_3OH(l) + H_2O(l) \rightleftharpoons CO_2(g) + 6H^+(aq) + 6e^-$ Cathode (reduction): $6H^+(aq) + \frac{3}{2}O_2(g) + 6e^- \rightleftharpoons 3H_2O(l)$

Microbial fuel cells (bacteria used to generate electric current) Geobacter used to oxidise ethanoate ions anaerobically	Anode (oxidation): $CH_3COO^-(aq) + 2H_2O(l) \rightleftharpoons 2CO_2(g) + 7H^+(aq) + 8e^-$ Cathode (reduction): $2O_2(g) + 8H^+(aq) + 8e^- \rightleftharpoons 4H_2O(l)$
Microbial fuel cells (bacteria used to generate electric current) Glucose is oxidized aerobically	Anode (Oxidation): $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$ Cathode (Reduction): $O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$
Microbial fuel cells (glucose)	Oxidation: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$ Reduction: $O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$
Gratzel cell	$I_3^- + 2e^- \rightarrow 3I^-$