Option C Energy SL Answers

IB CHEMISTRY SL

25	16		6	2	25
Mn	S	J	C	He	Mn
Manganese	Sulfur		Carbon	Helium	Manganese
54.938045	32.065		12.0107	4.002602	54.938045

C.1 Energy sources

Understandings:

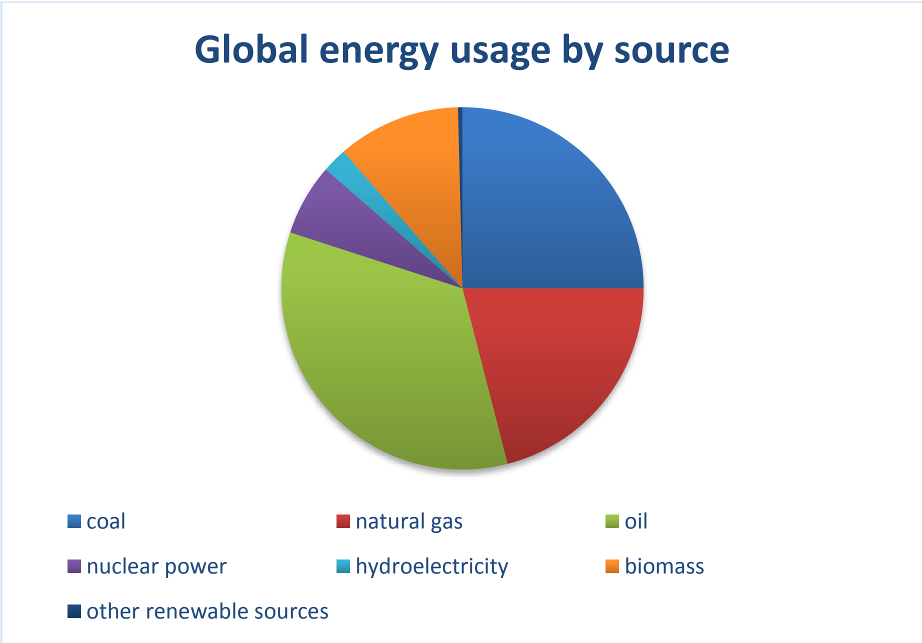
- A useful energy source releases energy at a reasonable rate and produces minimal pollution.
- The quality of energy is degraded as heat is transferred to the surroundings. Energy and materials go from a concentrated into a dispersed form. The quantity of the energy available for doing work decreases.
- Renewable energy sources are naturally replenished. Non-renewable energy sources are finite.

Applications and skills:

- Discussion of the use of different sources of renewable and non-renewable energy.
- Determination of the energy density and specific energy of a fuel from the enthalpies of combustion, densities and the molar mass of fuel.
- Discussion of how the choice of fuel is influenced by its energy density or specific energy.
- Determination of the efficiency of an energy transfer process from appropriate data.
- Discussion of the advantages and disadvantages of the different energy sources in C.2 through to C.8.

C.1 Energy sources

- Energy is the ability to do work and is measured in joules (J).
- Today's modern society is heavily dependent on energy (see chart below).



- A useful energy source releases energy at a reasonable rate and produces minimal pollution.
- Energy sources such as coal are a concentrated energy source.
- Energy sources can be classified as renewable or non-renewable.

Exercises:

1. Outline the difference between renewable and non-renewable energy sources.

   A renewable energy source is naturally replenished, whereas non-renewable energy sources are finite.

2. Discuss the advantages and disadvantages of each energy source.

Energy source	Advantage	Disadvantage
Solar	Renewable and sustainable	Not available at night
Wind	Renewable and sustainable	Wind turbines are unsightly and create noise
Hydroelectric	Renewable and sustainable	Large areas of land are flooded to create the reservoir

Energy source	Advantage	Disadvantage
Geothermal	Renewable and sustainable	Only suited to particular regions
Biomass	Only renewable and sustainable if crops are regrown	Land used to grow biomass crops could be used to grow food crops instead
Tidal	Renewable and sustainable	Can disrupt the migration of fish

Renewable and non-renewable energy sources

- Renewable energy sources are naturally replenished.

Examples of renewable energy sources:






- Non-renewable energy sources are finite.

Examples of non-renewable energy sources:




Energy degradation

- The First Law of Thermodynamics states that energy cannot be created or destroyed, it can only be converted from one form to another.
- As energy is converted from one form to another, the quality of energy becomes degraded as heat is transferred to the surroundings.
- Degraded energy is energy that is no longer able to do work.
- Although the total amount of energy is constant, the usefulness (or quality) of the energy decreases.
- The energy in coal (high quality energy source) goes from a concentrated form to a dispersed form.
- The quality of the energy decreases as heat is transferred to the surroundings – it becomes less available to do useful work.

Exercises:

1. Outline what is meant by degraded energy.

   Degraded energy is energy that is less available to do useful work.

2. Describe some ways in which energy is lost in a power station.

   Energy is lost mainly as heat loss to the surroundings.

Energy density and specific energy of fuels

Specific energy

- The specific energy of a fuel is the energy produced per unit mass.

$$\text{Specific energy} = \frac{\textbf{energy released from fuel}}{\textbf{mass of fuel consumed}}$$

Energy density

- The energy density of a fuel is the energy released per unit volume.

$$\text{Energy density} = \frac{\textbf{energy released from fuel}}{\textbf{volume of fuel consumed}}$$

- The higher the energy density of the fuel, the more energy may be stored or transported for the same volume.

Fuel	**Specific energy (MJ kg^{-1})**	**Energy density (MJ dm^{-3})**
^{238}U	8.06×10^{7}	1.54×10^{9}
Hydrogen	142	5.60
Natural gas	55.5	3.64×10^{-2}
Petrol (octane)	44.4	32.4
Coal	33.0	24.0
Wood	16.2	13.0

Exercises:

1. Define the terms energy density and specific energy.

   Energy density is the energy released per volume of fuel. Specific energy is the energy released per mass of fuel.

2. Using coal and natural gas as examples, state and explain which has a higher energy density.

   Coal as a high density be it is a solid – solids have higher densities than gases.

3. Propane (C_3H_8) has a density of 0.493 g cm^{-3}. The standard enthalpy of combustion ($\Delta H^o{}_c$) of propane is -2219 kJ mol^{-1}. Calculate the specific energy and energy density of propane. Molar mass (M) C_3H_8 = 44.1 g mol^{-1}

   Specific energy = 2219 / 44.1 = 50.3 kJ g^{-1} (note that specific energy cannot have a negative value).

   Energy density

   d = m/V, therefore, V = m/D = 44.1 / 0.493 = 89.5 cm^3

   Energy density = 2219 / 89.5 = 24.8 kJ cm^{-3}

Efficiency of energy transfers

- No energy transfer is 100% efficient – some energy is always degraded as heat is transferred to the surroundings (degraded energy is energy that is no longer able to do work).

$$\text{efficiency} = \frac{\textbf{useful output energy}}{\textbf{total input energy}} \times 100$$

- A process is more efficient if it transfers a greater percentage of the total input energy to the useful output energy required.

Efficiency of a coal fired power station

- A coal-fired power station has an efficiency of approximately 35 – 40 %.
- At each stage in the power station energy, energy is degraded as heat is transferred to the surroundings.

Example:

1. A coal-fired power station has an output energy of 1.73×10^{16} J of electrical energy per year. The total amount of input energy required to generate this amount is 4.82×10^{16} J. Calculate the efficiency of the power station.

$$\text{efficiency} = \frac{\textbf{useful output energy}}{\textbf{total input energy}} \times 100$$

$$\text{efficiency} = \frac{1.73\times10^{16}}{4.82\times10^{16}} \times 100 = 35.9\ \%$$

2. Calculate the mass of coal required to produce this amount of heat energy (assume that coal has the same $\Delta H^{\ominus}_c$ as graphite ($\Delta H^{\ominus}_c$ = -398 kJ mol^{-1}).

$$4.82 \times 10^{16}\ \text{J} = 4.82 \times 10^{13}\ \text{kJ}$$

One mole of carbon releases 394 kJ of heat energy

$$\frac{4.82\times10^{13}}{394} = 1.22 \times 10^{11}\ \text{mol of carbon}$$

$$1.22 \times 10^{11} \times 12.01 = 1.47 \times 10^{12}\ \text{g} = 1.47 \times 10^{9}\ \text{kg}$$

C.2 Fossil fuels

Understandings:

- Fossil fuels were formed by the reduction of biological compounds that contain carbon, hydrogen, nitrogen, sulfur and oxygen.

- Petroleum is a complex mixture of hydrocarbons that can be split into different component parts called fractions by fractional distillation.

- Crude oil needs to be refined before use. The different fractions are separated by a physical process in fractional distillation.

- The tendency of a fuel to auto-ignite, which leads to “knocking” in a car engine, is related to molecular structure and measured by the octane number.

- The performance of hydrocarbons as fuels is improved by the cracking and catalytic reforming reactions.

- Coal gasification and liquefaction are chemical processes that convert coal to gaseous and liquid hydrocarbons.

- A carbon footprint is the total amount of greenhouse gases produced during human activities. It is generally expressed in equivalent tons of carbon dioxide.

Applications and skills:

- Discussion of the effect of chain length and chain branching on the octane number.

- Discussion of the reforming and cracking reactions of hydrocarbons and explanation how these processes improve the octane number.

- Deduction of equations for cracking and reforming reactions, coal gasification and liquefaction.
- Discussion of the advantages and disadvantages of the different fossil fuels.

- Identification of the various fractions of petroleum, their relative volatility and their uses.

- Calculations of the carbon dioxide added to the atmosphere, when different fuels burn and determination of carbon footprints for different activities.

Formation of fossil fuels

- Coal, oil and natural gas are fossil fuels.
- Fossil fuels were formed by the reduction of biological compounds that contain carbon, hydrogen, nitrogen, sulfur and oxygen.
- They were formed over millions of years, from the remains of dead organisms, in anaerobic conditions.
- Coal was formed from dead plant material.
- Oil and natural gas were formed from dead marine organisms.
- Oil (crude oil, petroleum) is a complex mixture of straight-chain, branched, cyclic, and aromatic hydrocarbons.
- Natural gas is composed mainly of methane, with varying amounts of ethane, propane, and butane as well as hydrogen sulfide.

Advantages and disadvantages of coal

Advantages	**Disadvantages**
Coal is relatively inexpensive	As with all fossil fuels, coal is finite (non-renewable)
Coal has a high specific energy and high energy density	When burned, coal produces CO_2 which is a greenhouse gas
Coal can be converted into liquid fuels and gases	When burned, coal also produces SO_2 which causes acid deposition
Coal is distributed throughout the world	The mining of coal can cause environmental damage

Advantages and disadvantages of crude oil / petroleum products

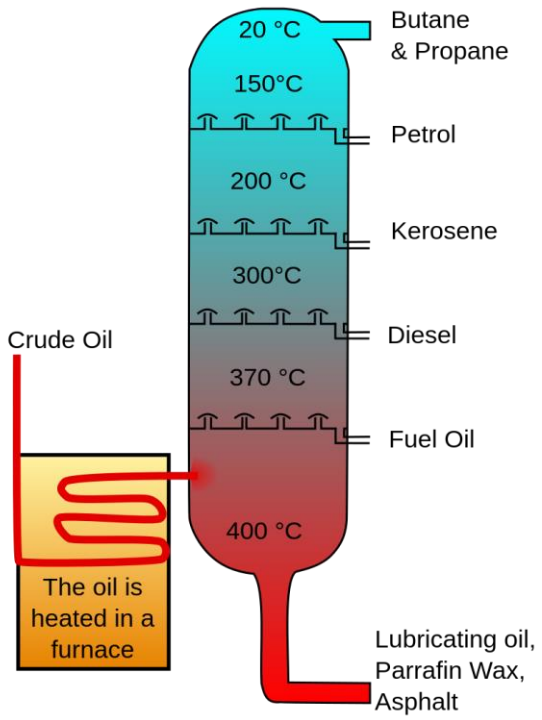
Advantages	**Disadvantages**
Petroleum products are relatively inexpensive	As with all fossil fuels, crude oil is finite (non-renewable)
Petroleum products generally have high specific energies and energy densities	When burned, petroleum products produce CO_2 which is a greenhouse gas
Ease of transport (gasoline)	Drilling for and transporting crude oil can cause environmental damage
Feedstock for petrochemicals	Uneven distribution worldwide

Advantages and disadvantages of natural gas

Advantages	**Disadvantages**
Natural gas is a relatively clean fuel	As with all fossil fuels, natural gas is finite (non-renewable)
Natural gas has a higher specific energy than coal and oil	When burned, natural gas produces CO_2 which is a greenhouse gas
Ease of transport (pressurized containers)	Lower energy density than coal and oil
Does not contribute to acid deposition	Uneven distribution in the world

Fractional distillation of crude oil

- Petroleum is a complex mixture of hydrocarbons that can be split into different component parts called fractions by fractional distillation (petroleum is a broad category that includes both crude oil and petroleum products).
- Crude oil needs to be refined before use. The different fractions are separated by a physical process in fractional distillation.



- The crude oil is separated depending on the boiling points of the different fractions.
- The crude oil is heated to about 400 °C
- The different fractions are vaporized and rise up the distillation column.
- The level at which the fractions condense depends on their boiling point (which depends on their molar mass).
- Smaller molecules rise to the top of the column and larger molecules collect at the bottom.

- As molar mass increases, the strength of the intermolecular forces (London dispersion forces) between the molecules also increases.
- More energy is required to overcome the attractive forces between the molecules, therefore, the boiling point increases.

Exercise: Explain how the different fractions of crude oil are separated.

The fractions of crude oil are separated by their boiling points. Fractions with higher molar masses have stronger London dispersion forces and boil at higher temperatures. Molecules with lower molar masses have lower boiling points. The temperature in the fractionating column decreases towards the top. As they boil, smaller molecules rise to the top of the column and are removed. Larger molecules settle at the bottom of the fractionating column where the temperatures are higher. Because of their different boiling points, the fractions condense at different points in the column.

Crude oil fractions and their uses

Fraction	Boiling point range (°C)	Number of C atoms	Uses
petroleum gas	< 40	1-4	fuel / feedstock for petrochemicals
gasoline/naphtha	40-170	5-10	gasoline: fuel naphtha: feedstock
kerosene	170-250	10-16	jet fuel domestic heating
diesel	250-350	11-18	fuel for trucks/agricultural machinery
fuel oil	350-450	20-25	fuel for ships/industry
residue	> 450	> 25	lubricating oils/bitumen for roads

Global demand vs typical supply from crude oil

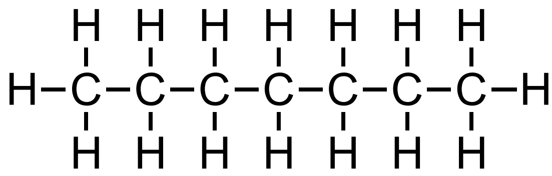
Fraction	Typical supply from crude oil (%)	Global demand (%)
gas	2	4
gasoline /naphtha	16	27
kerosene	13	8
diesel fuel	19	23
fuel oil/bitumen	50	38

- From the above table, the global demand for certain fractions (shorter chain hydrocarbons) exceeds their supply from crude oil.
- To address this issue, various techniques are used to produce shorter chain hydrocarbons from longer chain hydrocarbons.

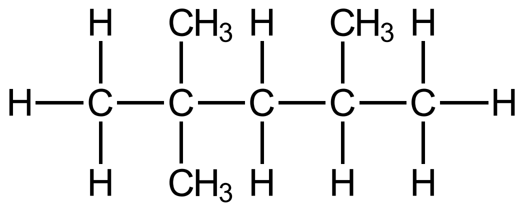
Octane number

- In a car engine, a mixture of fuel and air is compressed, then ignited by a spark.
- Premature ignition of the air and fuel mixture when compressed is called auto-ignition which causes knocking.
- The engine loses power and can also be damaged.
- Straight-chain hydrocarbons have a greater tendency to auto-ignite and cause knocking.

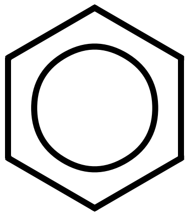
heptane C_7H_{16}



- Heptane (C_7H_{16}) has an octane number of zero.
- The octane number is a measure of a fuel's ability to resist knocking in a car engine – the higher the octane number, the greater the resistance to auto-ignition (and knocking).
- 2,2,4-trimethylpentane (iso-octane) has an octane number of 100.



- Branched hydrocarbons have higher octane numbers, therefore are more resistant to auto-ignition.
- Shorter-chain, cyclic, and aromatic hydrocarbons also have a lower tendency to auto-ignite (higher octane numbers).



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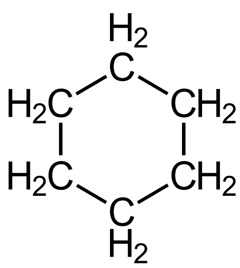

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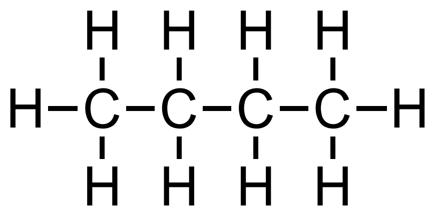

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octane numbers

- Petrol (gasoline) is given an octane rating.
- RON is the Research Octane Number.
- MON is the Motor Octane Number.
- An octane rating of 93 has the same tendency to auto-ignite as 93% 2,2,4-trimethylpentane and 7% heptane.
- The higher the octane rating, the more the fuel can be compressed without undergoing auto-ignition.

Summary:

- The scale used gives heptane an octane number of 0 and 2,2,4-trimethylpentane an octane number of 100.
- Octane number increases with a decrease in the carbon chain length.
- Octane number increases with increased carbon chain branching.
- Octane number increases in aromatic hydrocarbons and cyclic hydrocarbons.
- Catalytic cracking produces shorter-chain, aromatic and cyclic hydrocarbons which increase the octane number of the fuel.
- Isomerisation and catalytic reforming also increase the octane rating of gasoline.

Exercises:

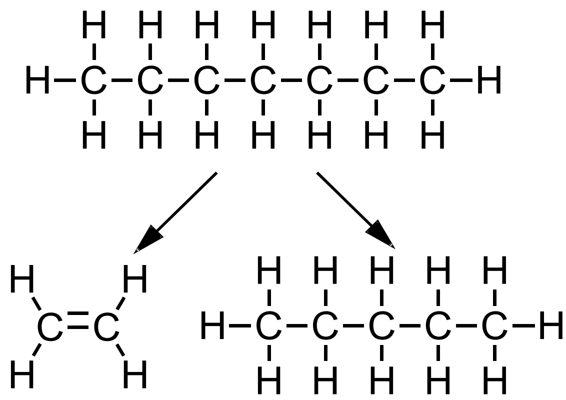
1. State what is meant by the octane number of a fuel.
   The octane rating (or number) is the is a measure of a fuel's ability to resist knocking in a car engine. A high octane rating means that the fuel can be compressed more without undergoing auto-ignition.

2. Describe the type of structures that have higher octane numbers.
   Short-chain, cyclic and aromatic hydrocarbons have higher octane numbers.

Cracking

- Cracking involves longer chain hydrocarbons being broken up into shorter chain hydrocarbons.
- Shorter chain hydrocarbons are more demand as they make better fuels.
- The two types of cracking are thermal and catalytic cracking.

Example: Heptane (C_7H_{16}) can be cracked into ethene (C_2H_4) and pentane (C_5H_{12})

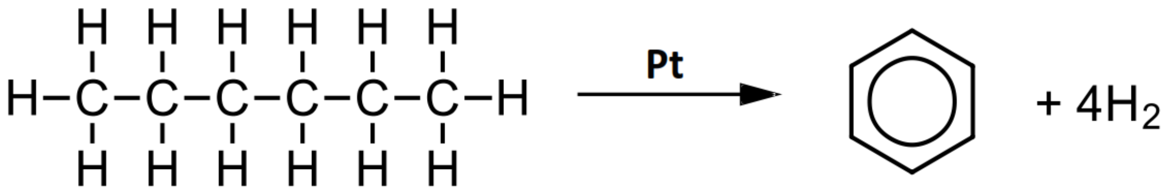


$$C_7H_{16} \rightarrow C_2H_4 + C_5H_{12}$$

Exercise: $C_{16}H_{34}$ can be cracked into two smaller hydrocarbons, both with 8 carbon atoms. Draw the full structural formula of the products and the equation for the overall reaction.

Catalytic reforming

- Reforming takes straight-chain hydrocarbons in the C_6 to C_8 range and rearranges them into aromatic compounds.

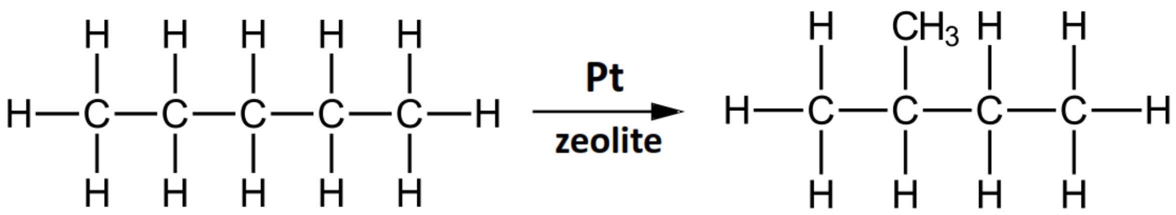


$$C_6H_{14} \rightarrow C_6H_6 + 4H_2$$

- Aromatic hydrocarbons have a much higher octane rating than straight-chain hydrocarbons.
- Catalytic reforming converts low octane straight-chain hydrocarbons into high octane aromatic hydrocarbons (used to increase the octane rating of petrol/gasoline).

Isomerisation

- Isomerisation converts straight-chain hydrocarbons with low octane numbers into branched hydrocarbons with higher octane numbers.



- Branched isomers have a higher resistance to auto-ignition, therefore, isomerisation increases the octane rating of gasoline.

Exercise: Describe the processes that are used to increase the octane number of gasoline.

Coal gasification

- Coal gasification is the process of converting coal into syngas. Syngas is a mixture of carbon monoxide (CO) and hydrogen gas (H_2).

$$C_{(s)} + H_2O_{(g)} \rightarrow CO_{(g)} + H_{2(g)}$$

- Syngas has 50% of the energy density of natural gas. It cannot be burnt directly but is used as a fuel source. The other use is as an intermediate to produce other chemicals.
- The environmental benefits of coal gasification are the low SO_x, NO_x and particulate emissions from burning coal-derived gases, when compared to normal coal.

- Syngas can be processed to form synthetic natural gas (CH_4) by reacting it with additional hydrogen.

$$\mathbf{CO_{(g)} + 3H_{2(g)} \rightarrow CH_{4(g)} + H_2O_{(g)}}$$

- Synthetic natural gas can also be produced by heating coal with steam.

$$\mathbf{2C_{(s)} + 2H_2O_{(g)} \rightarrow CH_{4(g)} + CO_{2(g)}}$$

Coal liquefaction

- Coal liquefaction is the process of converting coal into liquid hydrocarbons for use as fuels.
- In the Fischer–Tropsch process, CO and H_2 (from syngas) are converted into liquid hydrocarbons (from pentane onwards).
- The carbon monoxide is reduced to a hydrocarbon fuel through the use of a catalyst such as cobalt.

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

$$10CO_{(g)} + 21H_{2(g)} \rightarrow C_{10}H_{22(l)} + 10H_2O_{(l)}$$

Carbon footprint

- Carbon footprint is the total amount of greenhouse gases produced to directly and indirectly support human activities, expressed in equivalent tons of carbon dioxide (CO_2).
- Carbon dioxide is produced during the combustion of fossil fuels (coal, oil and natural gas).
- The mass of CO_2 produced can be calculated and the carbon footprint of different fuels can be compared.

Exercises:

1) Determine the mass of CO_2 (in kg) emitted into the atmosphere by the complete combustion of octane (C_8H_{18}) to produce 1.00×10^6 kJ of energy.

2) A nuclear power station produces 4.50×10^{10} kJ of energy over a 24-hour period. Determine the mass of CO_2 (in kg) emitted into the atmosphere if the same amount of energy were produced by the combustion of (i) coal, and (ii) wood, and which fuel has the smallest carbon footprint.

C.3 Nuclear fission and nuclear fusion

Understandings:

Nuclear fusion

- Light nuclei can undergo fusion reactions as this increases the binding energy per nucleon.
- Fusion reactions are a promising energy source as the fuel is inexpensive and abundant, and no radioactive waste is produced.
- Absorption spectra are used to analyse the composition of stars.

Nuclear fission

- Heavy nuclei can undergo fission reactions as this increases the binding energy per nucleon.
- ^{235}U undergoes a fission chain reaction:
- The critical mass is the mass of fuel needed for the reaction to be self- sustaining.
- ^{239}Pu, used as a fuel in "breeder reactors", is produced from ^{238}U by neutron capture.
- Radioactive waste may contain isotopes with long and short half-lives.
- Half-life is the time it takes for half the number of atoms to decay.

Applications and skills:

Nuclear fusion

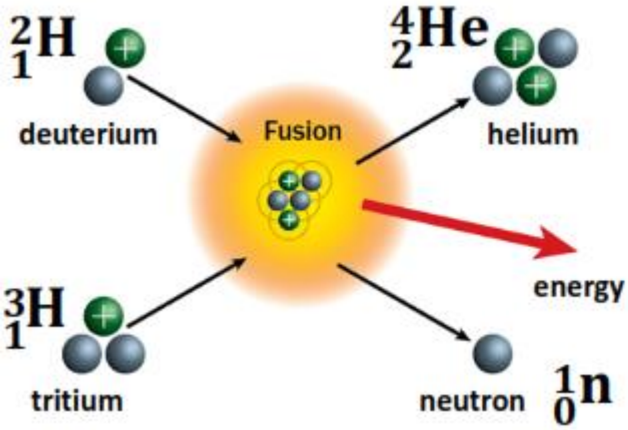
- Construction of nuclear equations for fusion reactions.
- Explanation of fusion reactions in terms of binding energy per nucleon.
- Explanation of the atomic absorption spectra of hydrogen and helium, including the relationships between the lines and electron transitions.

Nuclear fission

- Deduction of nuclear equations for fission reactions.
- Explanation of fission reactions in terms of binding energy per nucleon.
- Discussion of the storage and disposal of nuclear waste.
- Solution of radioactive decay problems involving integral numbers of half-lives.

Nuclear fusion

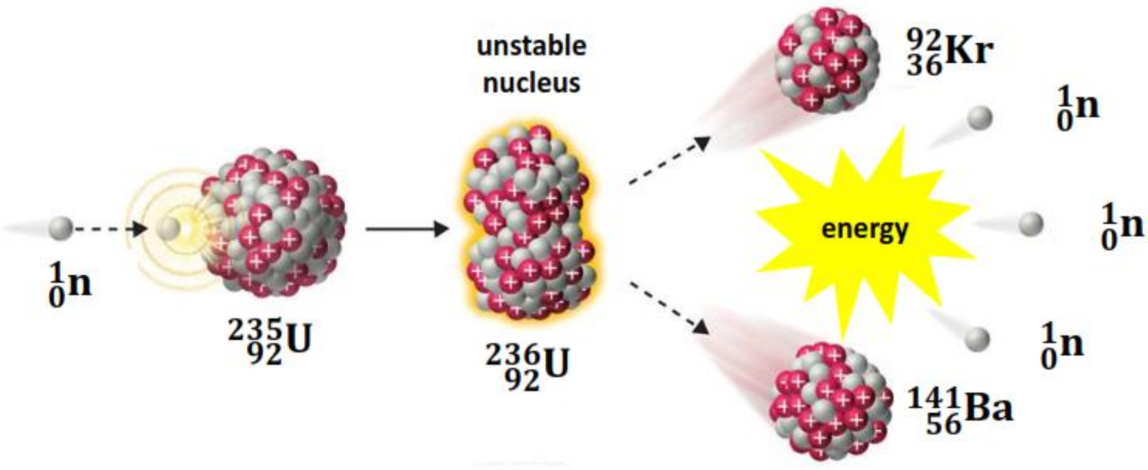
- In nuclear fusion lighter nuclei fuse together to form heavier nuclei, releasing energy in the process.
- The fusion of hydrogen nuclei is the source of the Sun's energy.
- Deuterium and tritium undergo nuclear fusion releasing vast amounts of energy.



$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

Nuclear fission

- In nuclear fission, large unstable nuclei break down into smaller more stable nuclei (releasing energy).

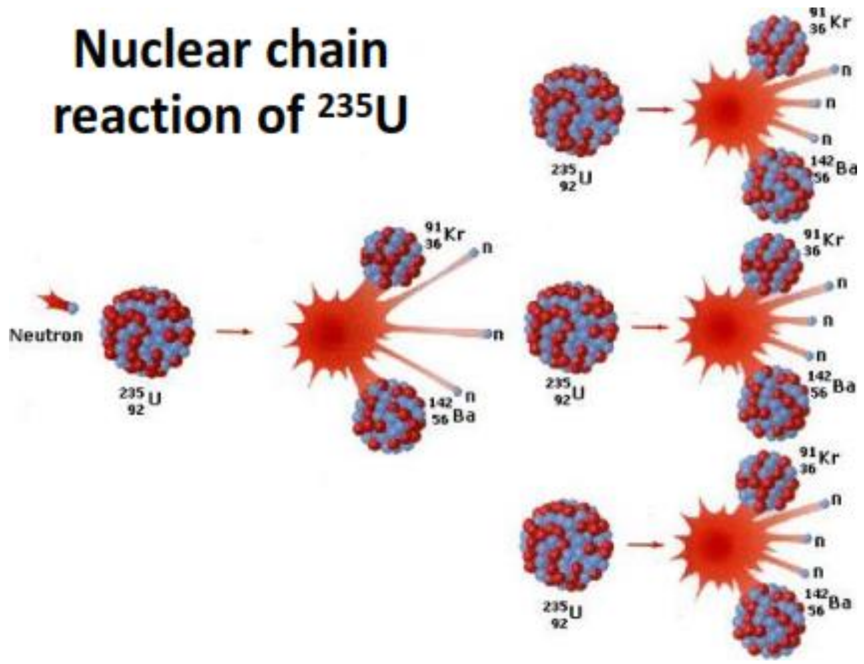


$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$$

- The three neutrons produced go on to collide with other U-235 nuclei to initiate a self-sustaining chain reaction.

Chain reaction and critical mass

- The minimum mass of fuel for the reaction to be self-sustaining is known as the critical mass.
- The critical mass is the mass of fuel required so that (on average) each fission results in a further fission.
- In a chain reaction, a neutron is captured by the ^{235}U nucleus, which undergoes fission and releases many more neutrons which cause further fission.

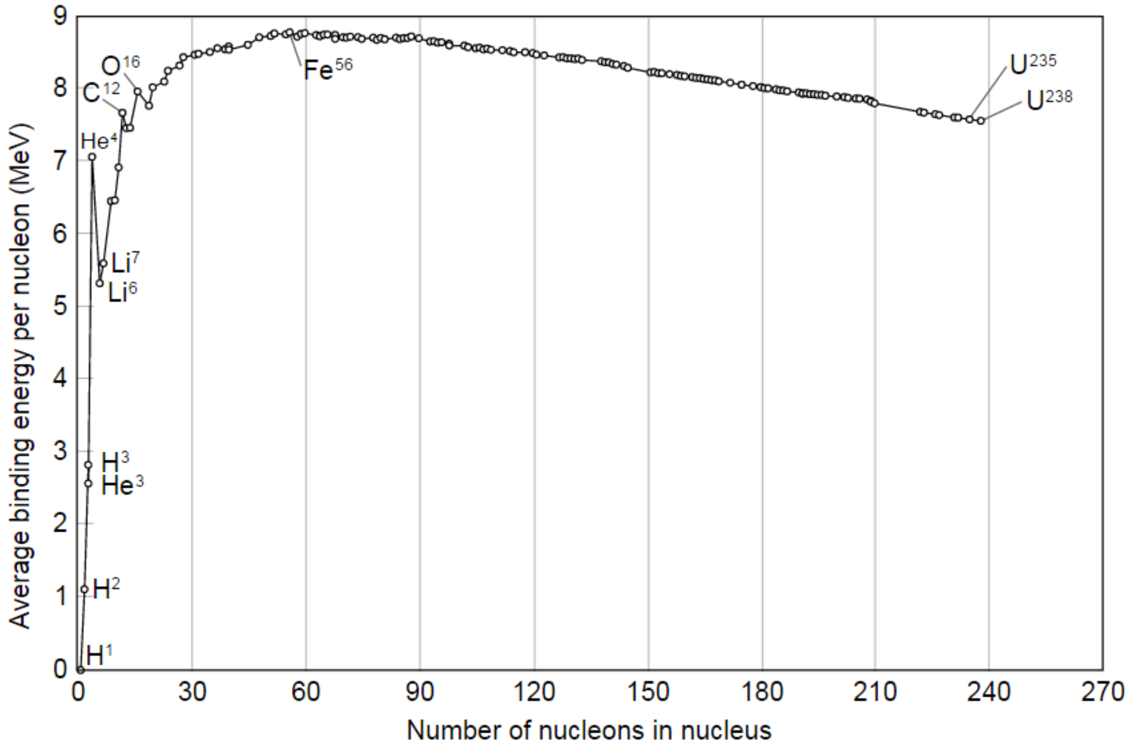


Uses of nuclear fusion and nuclear fission

- Nuclear fusion has the potential to provide an almost unlimited source of energy.
- The fuel is inexpensive and abundant, and no radioactive waste is produced.
- Various challenges remain meaning that nuclear fusion on Earth is not yet a viable energy source.
- Nuclear fission is used to generate electricity in a nuclear power station.
- Nuclear power stations have low greenhouse gas emissions but instead produce radioactive waste.
- Nuclear accidents in Chernobyl (1986) and Fukushima (2011) highlight the risks involved in using nuclear fission to generate electricity.
- Both nuclear fission and nuclear fusion have been used to produce nuclear weapons.

Nuclear binding energy

- Binding energy is the energy required to disassemble an atomic nucleus into its component parts (nucleons).



- The binding energy curve indicates the stability of atomic nuclei; the higher the curve the more stable the nucleus.
- ^{56}Fe has the most stable nuclei.
- Larger nuclei undergo nuclear fission, which increases the nuclear binding energy per nucleon.
- Smaller nuclei undergo nuclear fusion, which increases the nuclear binding energy per nucleon.
- The higher the nuclear binding energy per nucleon, the more stable the nucleus.
- In both nuclear fusion and nuclear fission, the product nuclei have higher binding energy (therefore are more stable) than the reactant nuclei.
- Nuclei to the right of ^{56}Fe undergo nuclear fission, those to the left, nuclear fusion.

Types of radioactive decay

Alpha (α) decay

- In alpha decay, the nucleus of an atom loses two protons and two neutrons (an alpha particle).

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$

Beta minus (β^-) decay

- In beta minus decay, a neutron is transformed into a proton and an electron is ejected from the nucleus.

$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}\mathrm{e}$$

Beta positive (β^+) decay

- In beta positive decay, a proton is transformed into a neutron and a positron is ejected from the nucleus.

$$^{15}_{8}\mathrm{O} \rightarrow {}^{15}_{7}\mathrm{N} + {}^{0}_{+1}\mathrm{e}$$

Gamma (γ) decay

- In gamma decay, a nucleus changes from a higher energy state to a lower energy state through the emission of high energy electromagnetic radiation.

$$^{240}_{94}\mathrm{Pu} \rightarrow {}^{240}_{94}\mathrm{Pu} + \gamma$$

Electron capture

- In electron capture, the nucleus of an atom draws in an electron from an orbital of the lowest energy level.

$$^{11}_{6}\mathrm{C} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{11}_{5}\mathrm{B}$$

Fast breeder reactors

- A breeder reactor is a nuclear reactor that generates more fissile material than it consumes (fissile material is material capable of sustaining a nuclear fission chain reaction).
- Fast breeder reactors were developed because the supply of fissile ^{235}U is limited (non-fissile ^{238}U is much more abundant than fissile ^{235}U).

Exercise: Identify the type of radioactive decay in each step.

$$^{238}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{239}_{92}\mathrm{U}$$

$$^{239}_{92}\mathrm{U} \rightarrow ^{239}_{93}\mathrm{Np} + ^{0}_{-1}\mathrm{e}$$

$$^{239}_{93}\mathrm{Np} \rightarrow ^{239}_{94}\mathrm{Pu} + ^{0}_{-1}\mathrm{e}$$

$$^{239}_{94}\mathrm{Pu} + ^{1}_{0}\mathrm{n} \rightarrow ^{145}_{56}\mathrm{Ba} + ^{93}_{38}\mathrm{Sr} + 2^{1}_{0}\mathrm{n}$$

Radioactive waste

Low-level radioactive waste

- Low-level nuclear waste includes gloves, paper towels or protective clothing that has been used in areas where radioactive materials have been handled (cancer treatment in hospitals).
- This type of waste has a short half-life and low radioactivity but is produced in high volumes.
- Low-level waste can be stored in cooling ponds until the radioactivity has fallen to safe levels.

High-level radioactive waste

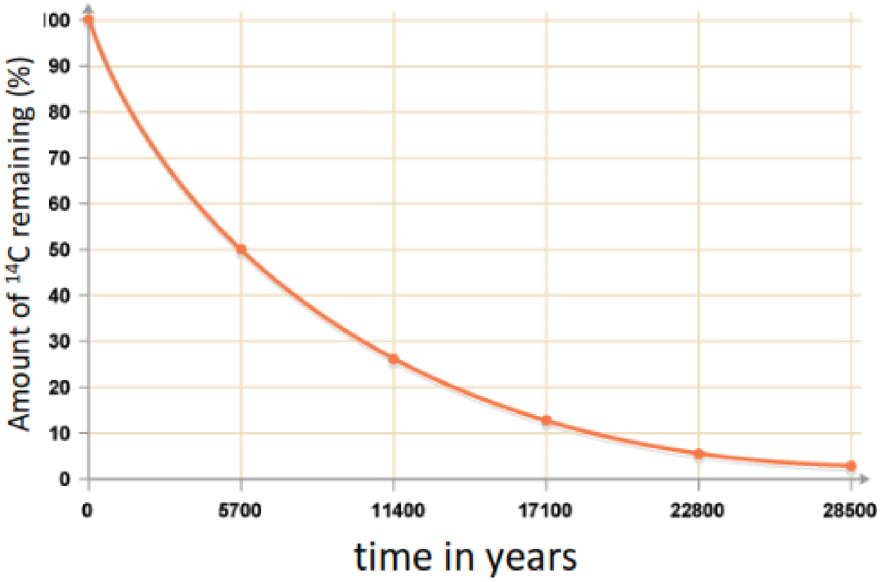
- High-level nuclear waste includes spent reactor fuel and waste from the reprocessing of spent fuel.
- It has high levels of radioactivity and the isotopes have long half-lives (half–life ^{238}U = 4.5 × 10^9 years).
- High-level waste can be converted into a solid glass (vitrification) and stored in stainless steel containers.

- The containers are stored deep within the Earth in geologically stable locations.

Half-life ($t_{1/2}$)

- The half-life of a radioisotope is the time taken for half the radioactive nuclei in a sample to undergo radioactive decay.

Graph showing decay of ^{14}C



- The time taken for half the radioactive ^{14}C nuclei to decay is 5700 years; this is the half-life of ^{14}C

Exercises:

1. The half-life of ^{222}Ra is 3.8 days. How much of a 100 g sample remains after 15.2 days?

2. ^{212}Bi has a half-life of 1 hour. How long would it take for 16.00 g of this isotope to decay to 2.00 g?

3. A 208 g sample of ^{24}Na decays to 13.0 g in 60.0 hours. What is the half-life of this radioactive isotope?

C.4 Solar energy

Understandings:

- Light can be absorbed by chlorophyll and other pigments with a conjugated electronic structure.
- Photosynthesis converts light energy into chemical energy:

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

- Fermentation of glucose produces ethanol which can be used as a biofuel:

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

- Energy content of vegetable oils is similar to that of diesel fuel but they are not used in internal combustion engines as they are too viscous.
- Transesterification between an ester and an alcohol with a strong acid or base catalyst produces a different ester:

$$RCOOR^1 + R^2OH \rightarrow RCOOR^2 + R^1OH$$

- In the transesterification process, involving a reaction with an alcohol in the presence of a strong acid or base, the triglyceride vegetable oils are converted to a mixture mainly comprising of alkyl esters and glycerol, but with some fatty acids.
- Transesterification with ethanol or methanol produces oils with lower viscosity that can be used in diesel engines.

Applications and skills:

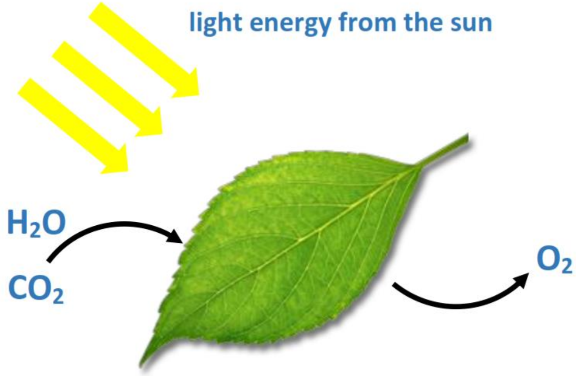
- Identification of features of the molecules that allow them to absorb visible light.
- Explanation of the reduced viscosity of esters produced with methanol and ethanol.
- Evaluation of the advantages and disadvantages of the use of biofuels.
- Deduction of equations for transesterification reactions.

Theory of knowledge:

- The claims of “cold fusion” were dismissed as the results are not reproducible.
- Is it always possible to obtain replicable results in the natural sciences? Are
- reproducible results possible in other areas of knowledge?

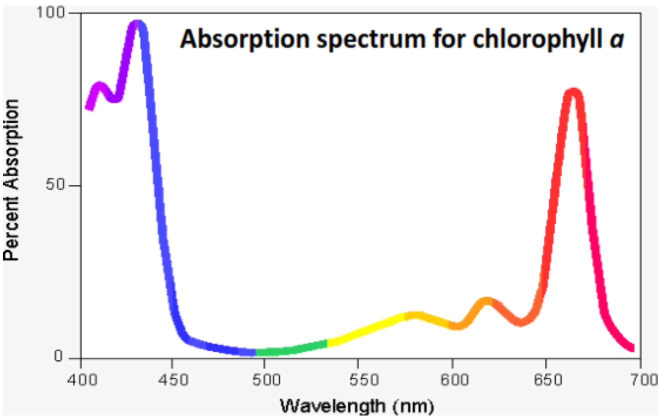
Photosynthesis

- In photosynthesis, light energy from the sun is converted into chemical energy.
- It occurs in green plants in the presence of a light absorbing pigment called chlorophyll.



$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2 \quad \Delta H \textit{ positive}$$

- Chlorophyll is a biological pigment - coloured compounds produced by living organisms.
- Pigment molecules absorb light in the visible region of the electromagnetic spectrum (400 – 700 nm).

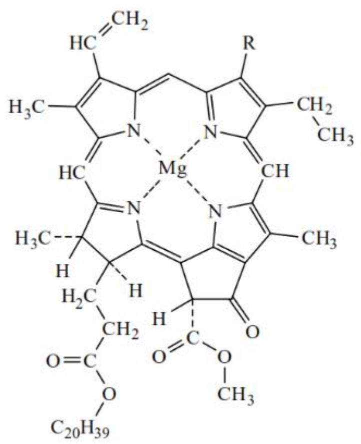


- Chlorophyll appears green because it absorbs wavelengths of visible light at 430 and 660 nm and reflects the remaining wavelengths.

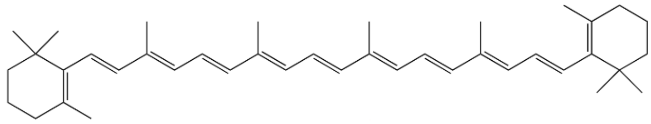
Biological pigments

- Biological pigments have highly conjugated systems (alternating single and double bonds).

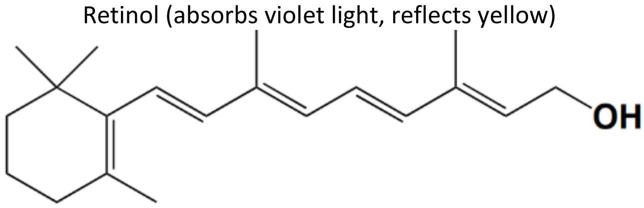
chlorophyll



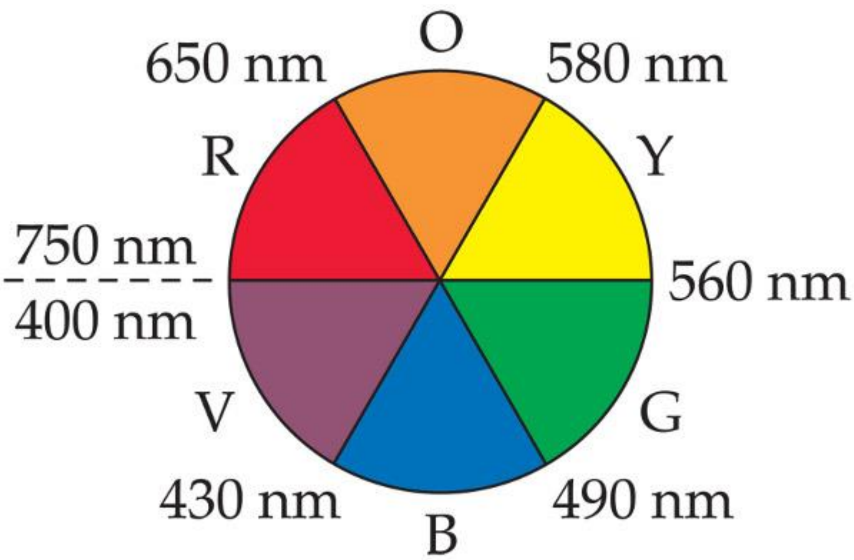
β-carotene (absorbs blue light, reflects orange)



Retinol (absorbs violet light, reflects yellow)



- A colour wheel can be used to determine the colour of a pigment.
- The colour that is reflected (the colour that we see) is the complementary colour of the colour that is absorbed.



- A pigment that absorbs wavelengths of green light will appear red (the complementary colour).

Biofuels

- Biofuels are fuels whose energy is obtained from biological carbon fixation.
- Carbon fixation is a process that takes inorganic carbon (CO_2) and converts it into organic compounds.

$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$

- The glucose produced in photosynthesis can be fermented to produce ethanol which can be used as a biofuel.
- Ethanol can be produced by fermenting starchy plants such as corn, wheat, barley or potatoes.

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

- This process is carried out at a temperature of $37^{o}C$ in anaerobic conditions (without oxygen) by yeast which provides an enzyme to catalyze the reaction.
- The ethanol produced in fermentation can be mixed with gasoline (petrol).
- Gasohol is a mixture of 90 % gasoline and 10 % ethanol.
- Brazil was one of the first countries to make widespread use of ethanol blended with gasoline. The ethanol is produced from sugarcane.

Advantages of biofuels:

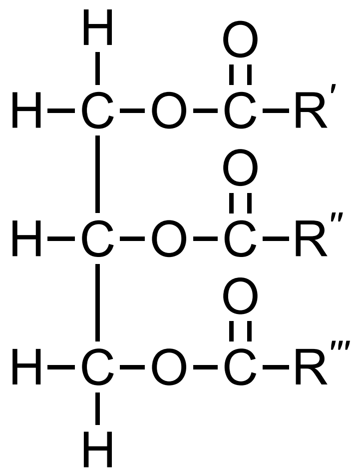
- Biofuels are renewable and readily available.
- If crops are regrown, biofuels can be sustainable.

Disadvantages of biofuels:

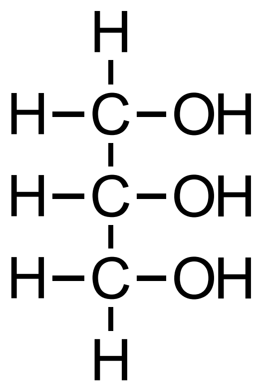
- The production of crops for biofuels means less land is available for food crops.
- Biofuels have lower specific energy than fossil fuels.
- Growing and harvesting crops for biofuels produces large amounts of CO_2

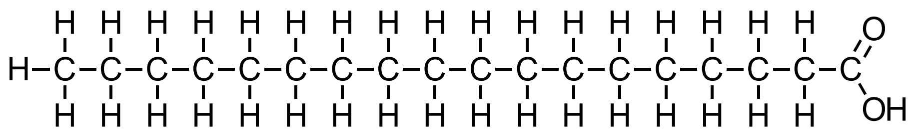
Transesterification

- The energy content of vegetable oils is similar to that of diesel.
- Vegetable oils cannot be used as fuels in unmodified diesel engines as they are too viscous (due to their high molar mass).
- Vegetable oils are composed of triglycerides.
- A triglyceride is composed of a glycerol backbone and three fatty acids.



- Triglycerides are produced in condensation reactions between a molecule of glycerol and 3 fatty acids.

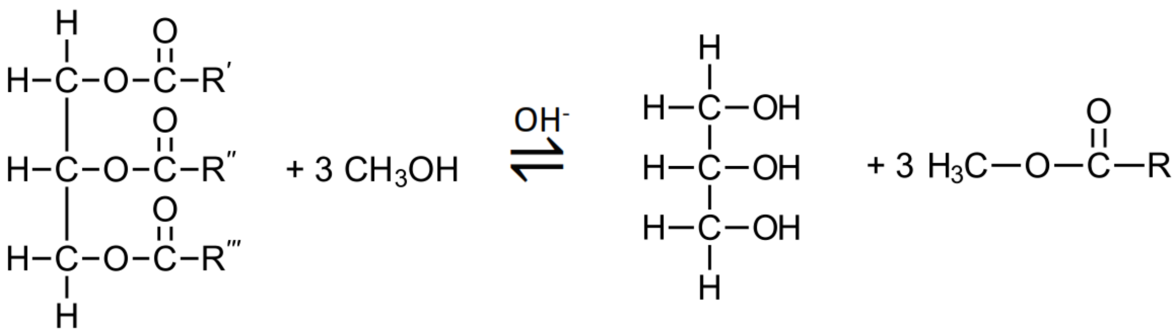




fatty acid

glycerol (propane-1,2,3-triol)

- Vegetable oil can be converted into a usable fuel, known as biodiesel, in a transesterification reaction.



- The three alkyl ester molecules produced have similar energy content to the triglyceride but are less viscous (due to their lower molar mass) and are therefore suitable for use in diesel engines.
- Biodiesel for use in diesel engines can be made in a transesterification reaction from waste cooking oils or from crops such as rapeseed oil.
- Biodiesel is much less toxic and more biodegradable than regular diesel.

C.5 Environmental impact—global warming

Understandings:

- Greenhouse gases allow the passage of incoming solar short wavelength radiation but absorb the longer wavelength radiation from the Earth. Some of the absorbed radiation is re-radiated back to Earth.
- There is a heterogeneous equilibrium between concentration of atmospheric carbon dioxide and aqueous carbon dioxide in the oceans.
- Greenhouse gases absorb IR radiation as there is a change in dipole moment as the bonds in the molecule stretch and bend.
- Particulates such as smoke and dust cause global dimming as they reflect sunlight, as do clouds.

Applications and skills:

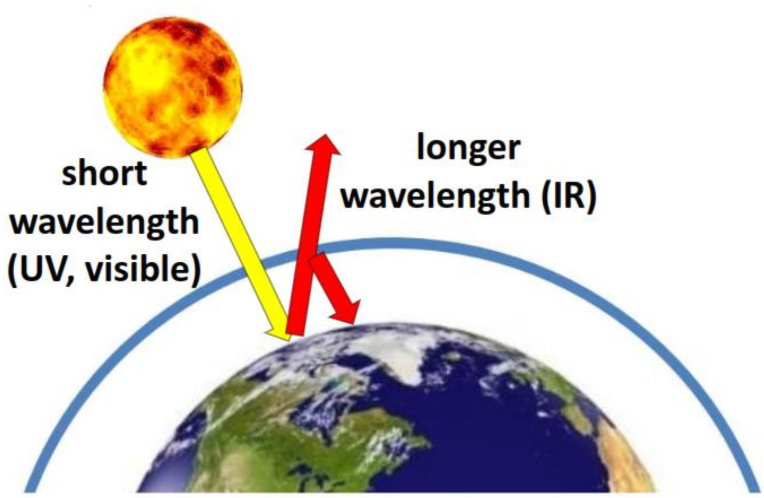
- Explanation of the molecular mechanisms by which greenhouse gases absorb infrared radiation.
- Discussion of the evidence for the relationship between the increased concentration of gases and global warming.
- Discussion of the sources, relative abundance and effects of different greenhouse gases.
- Discussion of the different approaches to the control of carbon dioxide emissions.
- Discussion of pH changes in the ocean due to increased concentration of carbon dioxide in the atmosphere.

Guidance:

- Greenhouse gases to be considered are CH_4, H_2O and CO_2.

The greenhouse effect

- Greenhouse gases allow the passage of incoming short wavelength solar radiation.
- The Earth's surface reradiates some of this radiation back into the atmosphere as longer wavelength radiation.
- Greenhouse gases in the atmosphere absorb the longer wavelength radiation and reradiate it back to the surface of the Earth.



- The greenhouse effect is a natural process that keeps the Earth at a temperature suitable for life to exist.
- The enhanced greenhouse effect is caused by the emission of greenhouse gases such as CO_2, CH_4, N_2O and CFCs into the atmosphere.
- Increasing concentrations of greenhouse gases in the atmosphere means that more IR radiation is reradiated back to the Earth's surface, causing global warming.

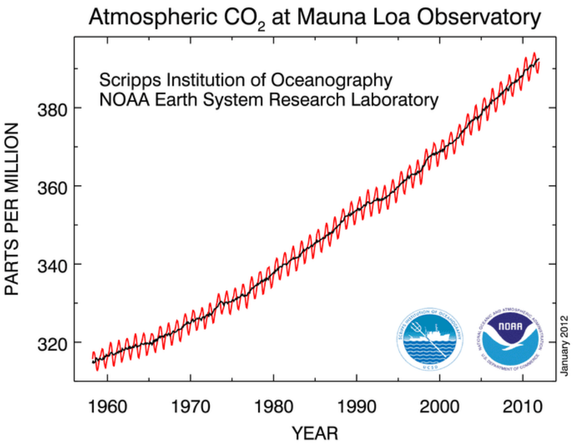
Sources of greenhouse gases

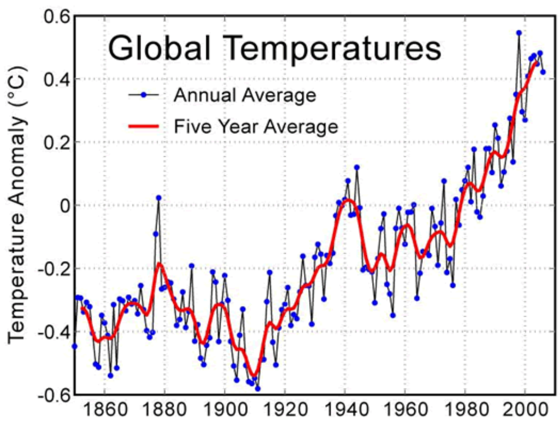
- The main greenhouse gases are CH_4, H_2O, CO_2, N_2O and chlorofluorocarbons (CFCs).
- The significance of a greenhouse gas on global warming depends on the relative abundance and the greenhouse factor of the gas.
- The greenhouse factor is the ability of a gas to absorb infrared radiation, compared to carbon dioxide.
- Gases with a high greenhouse factor and high relative abundance are more significant for global warming.

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

Evidence for global warming

- The graphs below show the concentration of CO_2 in the atmosphere since 1960 and the change in global temperature since 1860.

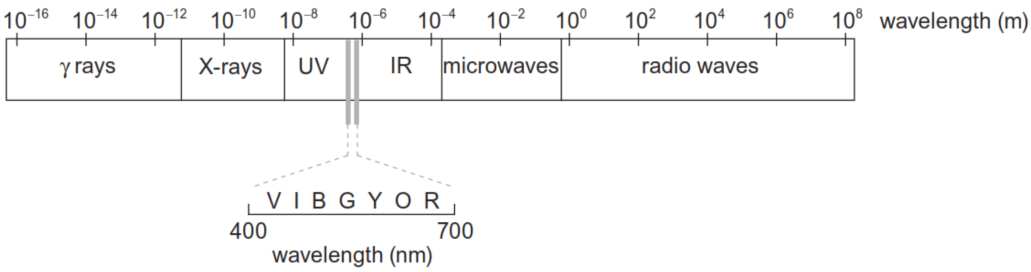




- Increasing CO_2 levels and the Earth's average temperature show clear correlation, but wide variations in the surface temperature of the Earth have occurred frequently in the past.

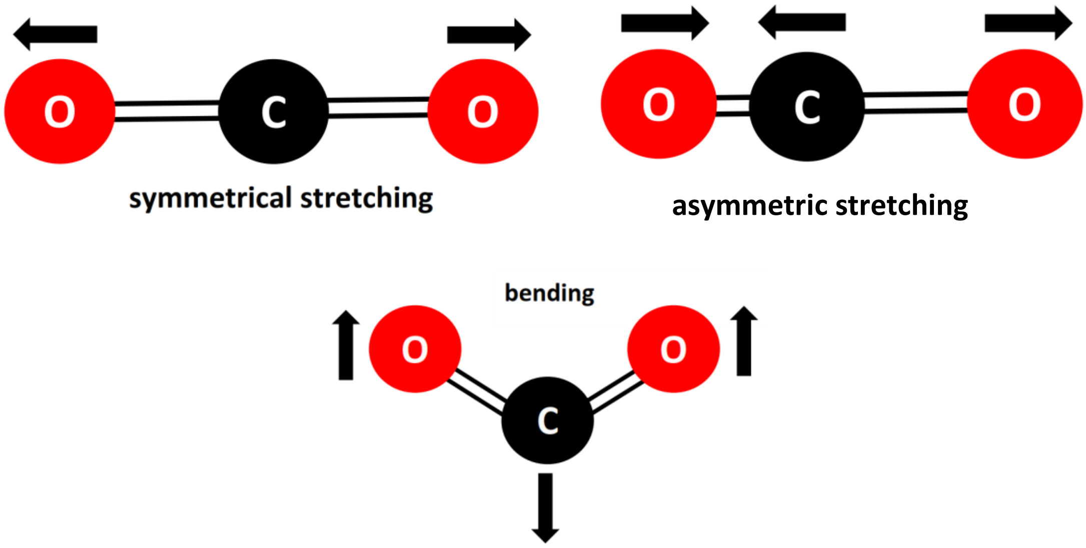
IR absorption by greenhouse gases

- Carbon dioxide strongly absorbs electromagnetic radiation with a wavelength of 1×10^{-5} m.
- This wavelength falls within the infrared (IR) region of the electromagnetic spectrum.



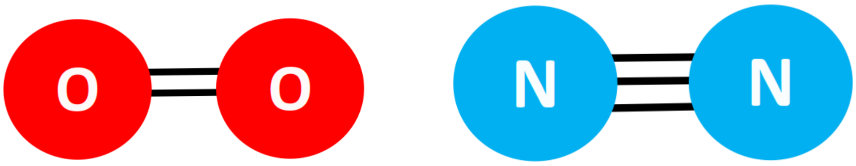
- Infrared (IR) radiation causes the bonds in the CO_2 molecule to vibrate (bend and stretch).
- The natural frequency at which the bonds in the CO_2 molecule vibrate corresponds to the frequency of infrared (IR) radiation.

Types of bending and stretching in the CO_2 molecule



- Asymmetric stretching and bending produces a change in the dipole moment of the CO_2 molecule.
- In order to absorb IR radiation, there must be a change in the dipole moment of the molecule as the bonds stretch and bend.

- Diatomic non-polar molecules such as N_2 and O_2 are not greenhouse gases.



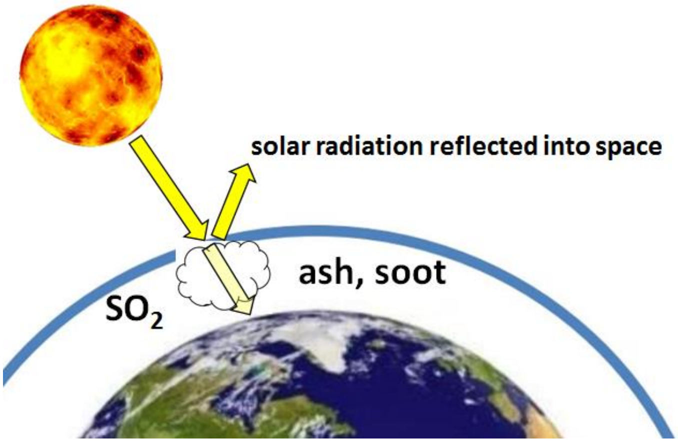
- Oxygen and nitrogen have one vibrational mode, involving a stretching and compression of the bond length.
- This does not create a temporary dipole moment in the molecule, therefore they do not absorb infrared radiation.

Reducing greenhouse gas emissions

- Increased use of insulation and energy efficient electrical appliances in the home.
- Using public transport and driving more fuel-efficient cars.
- Increased use of renewable energy sources (solar, wind, hydroelectric, etc).
- Carbon capture and storage (CCS) – CO_2 can be captured from fossil fuel burning power stations and stored underground.

Global dimming

- Global dimming is the decrease in the amount of solar radiation reaching the surface of the Earth.
- Particulate matter in the atmosphere directly absorbs solar radiation and reflects it back into space before it reaches the surface of the Earth.



- Water droplets containing particulate matter form polluted clouds. These polluted clouds reflect more solar radiation than non-polluted clouds.

Ocean acidification

- Approximately 30% of anthropogenic carbon dioxide is absorbed by the oceans (carbon sink).
- CO_2 dissolves in sea water:

$$CO_{2(g)} \rightleftharpoons CO_{2(aq)}$$

- A heterogeneous equilibrium exists between concentrations of gaseous carbon dioxide in the atmosphere and aqueous carbon dioxide dissolved in the oceans.

$$CO_{2(aq)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3(aq)}$$

- Carbonic acid (H_2CO_3) is a weak acid which partially dissociates in solution to produce $H^+_{(aq)}$.

$$H_2CO_{3(aq)} \rightleftharpoons H^+_{(aq)} + HCO_3^-{}_{(aq)}$$

- The increasing concentration of $H^+_{(aq)}$ causes the pH of the oceans to decrease.
- Since the beginning of the industrial revolution, the pH of the oceans has decreased by 0.1 pH units.
- Continued acidification of the oceans could have harmful effects on marine organisms.