HL Paper 3

Lutetium-177 is used in radiotherapy. It emits beta radiation when it decays.

a. State a nuclear equation to show the decay of lutetium-177. [2]

b. The half-life of lutetium-177 is 6.73 days. Determine the percentage of a sample of lutetium-177 remaining after 14.0 days. [2]

c. Explain the low environmental impact of most medical nuclear waste. [2]

Targeted Alpha Therapy (TAT) is a technique that involves using alpha-radiation to treat leukemia and other dispersed cancers.

Yttrium-90 and lutetium-177 are used in radiotherapy.

a.i. Explain why alpha-radiation is particularly suitable for this treatment. [2]

a.ii. Outline how the alpha-radiation in TAT is directed to cancer cells. [1]

b.i. Identify the type of radiation emitted by these two radioisotopes. [1]

b.ii. State an equation for the one-step decay of yttrium-90. [1]

b.iii. The half-life of lutetium-177 is 6.75 days. Calculate the percentage remaining after 27 days. [1]

A number of drugs have been developed to treat excess acidity in the stomach.

Outline how ranitidine (Zantac) functions to reduce stomach acidity.

Technetium-99m is the most widely used medical radioisotope. It is usually made on-site in medical facilities from isotopes of molybdenum.

a. Deduce equations for the following nuclear reactions: [2]

(i) Molybdenum-98 absorbs a neutron.

(ii) The isotope produced in (a) (i) decays into technetium-99m.

b. Molybdenum-99 has a half-life of 66 hours, while technetium-99m has a half-life of 6 hours. Outline why technetium-99m is made on-site. [1]

c. Outline **two** reasons, other than its half-life, why technetium-99m is so useful in medical diagnosis. [2]

d. Outline the nature of the radioactive waste that is generated by the use of technetium-99m in medical diagnosis. [1]

Taxol is produced using a chiral auxiliary. Describe how the chiral auxiliary functions to produce the desired product.

Aspirin, paracetamol (acetaminophen), morphine and diamorphine (heroin) are all pain killers. Their structures are given in Table 20 of the Data Booklet.

Suggest a reagent that could be used to convert morphine into diamorphine and state the name of the type of reaction taking place.

Radioactive isotopes are used in a variety of medical procedures including medical imaging and radiotherapy.

b. Lead-212 is a radioisotope that is used in the treatment of cancer. It is produced from another radioisotope by alpha decay. Formulate the equation for its production. [2]

c. Identify **one** advantage of using Targeted Alpha Therapy (TAT) and one form of cancer commonly treated by this method. [2]

Advantage:

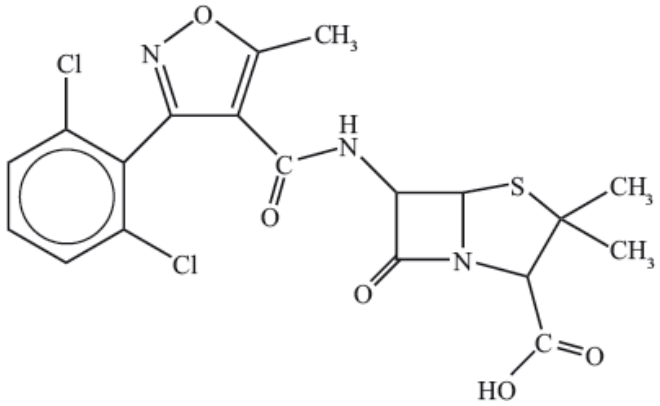
Cancer treatment:

d. Technetium-99m, used for radioimaging scans, has a half-life of 6.01 hours. Calculate the mass of a 5.80×10^{-9} g dose remaining after 24.04 hours. [2]

e. Outline an ethical implication of using nuclear treatments in medicine. [1]

The discovery of penicillin by Alexander Fleming in 1928 is often given as an example of serendipity in science.

The structure of a particular type of penicillin called dicloxacillin is shown below.

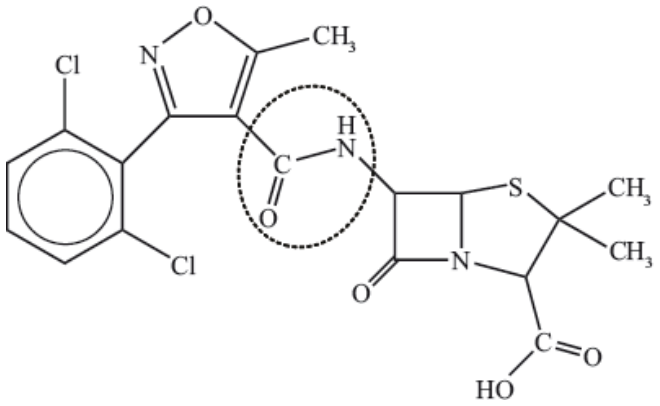


c. Describe what happens to bacteria when they come into contact with penicillin. [2]

d. (i) Identify the β-lactam ring by drawing a circle around it. [5]

(ii) Explain why the β-lactam ring is so important in the mechanism of the action of penicillin.

(iii) State the name of the functional group in dicloxacillin, circled below.



e. Comment on the fact that many bacteria are now resistant to penicillins. [2]

Nuclear radiation is dangerous because of its ability to damage cells but it can also be used in nuclear medicine.

Iodine-131 is released in nuclear explosions but is used in scanners for thyroid cancer. The half-life of iodine-131 is 8.02 days.

a. Yttrium-90 is used in treating certain cancers. [1]

Formulate a nuclear equation for the beta decay of yttrium-90.

b. Lutetium-177 is a common isotope used for internal radiation therapy. [1]

Suggest why lutetium-177 is an ideal isotope for the treatment of certain cancers based on the type of radiation emitted.

c.i. Calculate the rate constant, λ, in day^{-1}, for the decay of iodine-131 using section 1 of the data booklet. [1]

c.ii. Calculate the time, in days, for 90% of the sample to decay. [2]

d. A breathalyser measures the blood alcohol content from a breath sample. Formulate half-equations for the reactions at the anode (negative electrode) and the cathode (positive electrode) in a fuel cell breathalyser. [2]

Anode (negative electrode):

. . . . . .

Cathode (positive electrode):

. . . . . .

Ethanol slows down the reaction time of a driver leading to traffic accidents. Explain how the concentration of ethanol in a sample of breath can be determined using a fuel cell breathalyser.

Some drugs can be converted into ionic salts in order to increase their solubility in water.

a.i. State the equation for the formation of the ionic salt of aspirin, $CH_3COO(C_6H_4)COOH$. [1]

b. Chiral auxiliaries are used in drug design. Describe how a chiral auxiliary works. [2]

A polarimeter can be used to determine the optical rotation of an optically active substance.

a. Describe what happens to plane-polarized light when it passes through a solution of an optically active compound. [1]

b. A mixture of enantiomers shows optical rotation. [1]

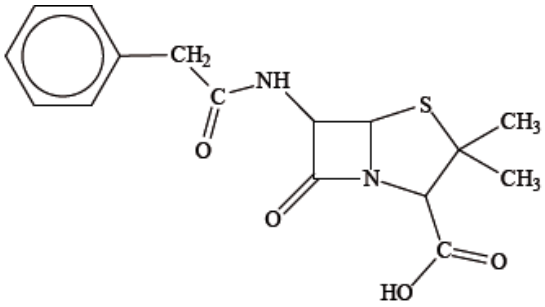
Suggest a conclusion you can draw from this data.

Amphetamine and methamphetamine are widely abused drugs.

d. Amphetamine exists as optical isomers. Describe how chiral auxiliaries can be used to synthesize only the desired enantiomeric form of a drug from a non-chiral starting compound. [3]

e. The structures of morphine and heroin are shown in Table 20 of the Data Booklet. Explain the increased potency of heroin compared to morphine. [2]

The first penicillin to be used was benzylpenicillin (Penicillin G), its structure is shown below.



The active part of penicillins is the beta-lactam ring. Determine the functional group present in the beta-lactam ring and explain why the ring is important in the functioning of penicillin as an antibacterial.

Some drugs are extracted from natural sources and others are synthetic.

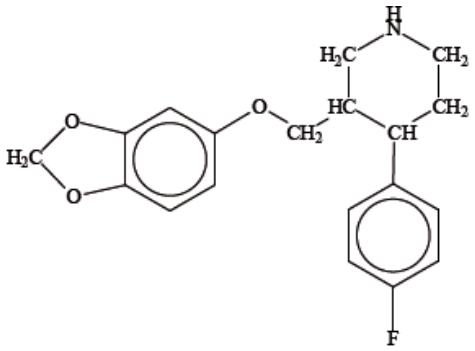
Explain the role of the chiral auxiliary in the synthesis of Taxol.

Analgesics are used to relieve pain in the body. Aspirin and paracetamol (acetaminophen) are both mild analgesics.

The structures of the strong analgesics morphine and heroin (diamorphine) can be found in Table 20 of the Data Booklet.

Explain the increased potency of heroin (diamorphine) compared to morphine.

Paroxetine, whose structure is shown below, is a drug prescribed to people suffering from mental depression.



a. Identify the **two** chiral carbon atoms in the structure above with an asterisk (*). [2]

b. Explain, with an example, the importance of chirality in drug action. [2]

c. Describe the use of chiral auxiliaries to synthesize the desired enantiomer of a drug. [2]

Diseases may be caused by bacteria or viruses.

a.ii. The beta-lactam ring is highly reactive and enables penicillins to be effective antibacterials. The general structure of penicillin is given in table 20 of the data booklet. Explain, in terms of hybridization and bond angles, why the beta-lactam ring is strained. [2]

b.i. Cytovaricin is an antibiotic that is produced using a chiral auxiliary. Suggest why it may be necessary to use a chiral auxiliary during its production. [1]

b.ii. Describe how a chiral auxiliary is involved in the synthesis of a drug. [3]

Morphine and its derivatives work by temporarily bonding to receptor sites in the brain, preventing the transmission of pain impulses.

Explain why the change in functional groups makes diamorphine (heroin) more potent than morphine.

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a. State **two** ways in which viruses are different from bacteria. [2]

b. Describe **two** ways in which antiviral drugs work. [2]

c. Discuss **three** of the difficulties associated with solving the AIDS problem. [3]

The development of new and improved medications for the reduction and management of pain is an important part of 21st-century medicine.

a. Discuss **two** advantages and **two** disadvantages of the medical use of morphine and its derivatives. [2]

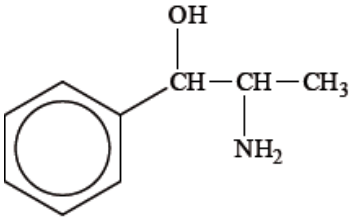
Advantages:

Disadvantages:

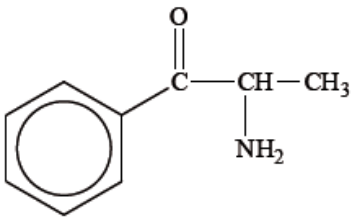
b. Explain the increased potency of diamorphine (heroin) compared to morphine. [2]

There is some concern that increased use of the recreational drug khat is causing social problems.

The structures of two substances found in khat are shown below.



Cathine



Cathinone

Cathine and cathinone are both classed as sympathomimetic drugs.

Phenylpropanolamine (PPA) is an optical isomer of cathine used in cough medicines.

c.i. Outline how PPA and not cathine could be synthesized from the same non-chiral starting materials. Details of reagents and conditions are not required. [3]

c.ii. Explain why this is the generally preferred method for the synthesis of optically active drugs. [2]

c.iii Suggest how the aqueous solubility of cathine or PPA could be increased to facilitate its distribution around the body. [1]

Alcohol abuse is a major problem in many countries, especially when associated with driving. Many police forces now use instruments that detect the presence of ethanol on a person's breath by its absorption of electromagnetic radiation.

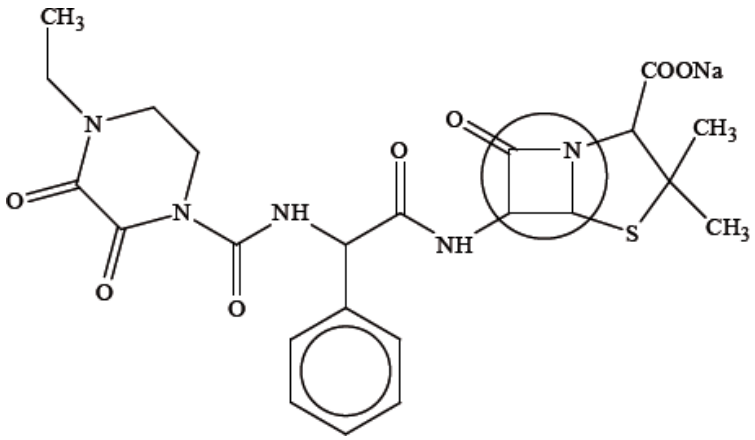
Identify the region of the electromagnetic spectrum used to detect the presence of ethanol.

Radiotherapy is one type of treatment for cancer.

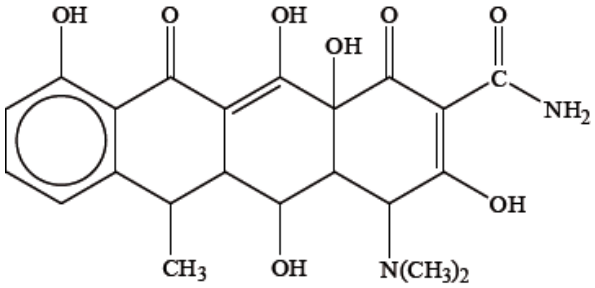
a. Describe how ionizing radiation destroys cancer cells. [2]

b. Outline how Targeted Alpha Therapy (TAT) is used for treating cancers that have spread throughout the body. [2]

The structure of a drug is shown below:



Another drug that can have a similar effect to the one shown in (a) is doxycycline, shown below.



a.i. Identify the class of drugs to which this particular drug belongs. [[N/A

a.ii. Explain the high reactivity of the part of the drug that is enclosed in the circle. [2]

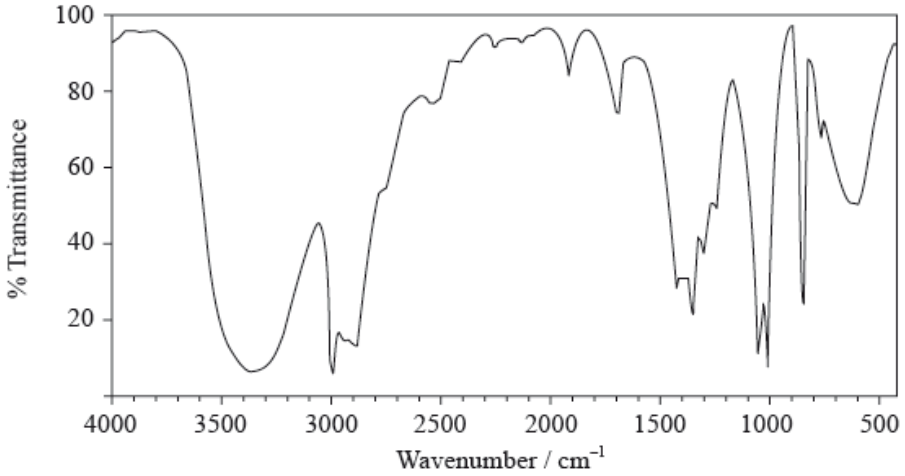
a.iii Suggest why the drug is administered as its sodium salt. [2]

b.i. Because it contains several –OH groups and an amine group, doxycycline is slightly polar. Identify the amine group by drawing a circle around it on the structure above **and** state whether it is a primary, secondary or tertiary amine. [2]

b.ii. Suggest **one** way in which the polarity of doxycycline could be substantially increased. [1]

b.iii. Deduce the number of chiral carbon atoms in doxycycline **and** explain why chirality is important when considering its action in the body. [2]

A modern method for accurately determining ethanol concentrations in the breath is based on the infrared (IR) spectrum of the molecule.



a.i. Use Table 17 of the Data Booklet to identify the wavenumber range used in the determination. [1]

a.ii. State why the absorption in the range 3200 to 3600 cm^{-1} is not used. [1]

b. The concentration of ethanol is determined by passing IR radiation through a breath sample. Outline how the transmittance of IR radiation changes when increased levels of ethanol are present. [1]

Analgesics can be prescribed for treating various types of pain.

a.i. The structure of aspirin is shown in table 20 of the data booklet. Suggest a suitable reagent for the conversion of aspirin to its sodium salt. [1]

a.ii. Explain the advantage of converting aspirin into its sodium salt. [2]

b.ii. Suggest a reagent that could be used to convert morphine into diamorphine. [1]

c. Explain why diamorphine is a more potent drug than morphine. [2]

A variety of techniques can be used to determine the ethanol concentration of the breath, blood or urine.

a.i. The breathalyser, one of the earliest tests, uses the reaction between ethanol and acidified potassium dichromate(VI). Ethanol is first oxidized to ethanal. [1]

Deduce the half-equation for the reaction of ethanol to ethanal.

a.ii. Outline why the colour changes from orange to green. [1]

b. Explain how the ethanol concentration in the breath can be measured by an intoximeter using infrared absorption. [2]

The efficiency of a drug depends on the polarity of its molecule. Explain how the polarity of a drug can be modified in order to increase its solubility in water and how it affects the distribution of the drug around the body.

Mild analgesics such as aspirin, and strong analgesics such as opiates, differ not only in their potency but also in the ways they act on the central nervous system.

Explain why heroin is a more potent drug than morphine.

Ethanol can be detected by a variety of instruments.

a. Fuel cells use an electrochemical process to determine the concentration of ethanol. [1]

   Formulate the overall equation for this process.

b. Predict the chemical shifts and integration for each signal in the ^{1}H NMR spectrum for ethanol using section 27 of the data booklet. [3]

Radioisotopes can be used to treat a wide variety of diseases.

a. Phosphorous-32 undergoes beta decay. Formulate a balanced nuclear equation for this process. [1]

b. The half-life of phosphorus-32 is 14.3 days. Calculate the mass, in g, of ^{32}P remaining after 57.2 days if the initial sample contains 2.63×10^{-8} mol. Use table 1 of the data booklet and $M_r = 31.97$ g mol^{-1}. [2]

c. Explain the targeted alpha therapy (TAT) technique and why it is useful. [3]

Many diseases are the result of infection of the body by either bacteria or viruses.

Identify the particular structural feature of penicillins that is responsible for their action and explain how this prevents bacteria multiplying.

Three factors which can influence the mechanism of the action of a drug include geometrical isomerism, polarity and ring strain.

a. For each of the following drugs, identify which **one** of these factors is involved. [3]

Increased potency of diamorphine compared to morphine:

Penicillin:

b. Explain the action of penicillin with reference to your answer in part (a). [2]

Chemists can change structures of substances in order to produce chemicals with desired properties.

Aspirin is virtually insoluble in water. Use Table 20 in the Data Booklet to explain how aspirin can be made more water-soluble. Write an equation for the reaction.

Many drugs, including aspirin, penicillin, codeine and taxol, have been modified from compounds that occur naturally.

Many drugs are chiral. Explain how a polarimeter can be used to determine the relative proportion of two enantiomers.

The discovery of penicillin was one of the most significant scientific discoveries of the last century.

State the type of hybridization of each of the carbon atoms (**I**, **II**, and **III**) in the β-lactam ring of ampicillin by completing the table below, and explain why the amide group is highly reactive.

Carbon atom	I	II	III
Hybridization			

Taxol was originally obtained from the bark of the Pacific yew tree.

Outline how Green Chemistry has improved the process of obtaining Taxol.

Excess stomach acid leads to medical conditions that affect many people worldwide. These conditions can be treated with several types of medical drugs.

Omeprazole exists as a racemic mixture whereas esomeprazole is a single enantiomer. Outline how, starting from a non-chiral molecule, esomeprazole but not omeprazole, could be synthesized. Details of chemicals and conditions are not required.

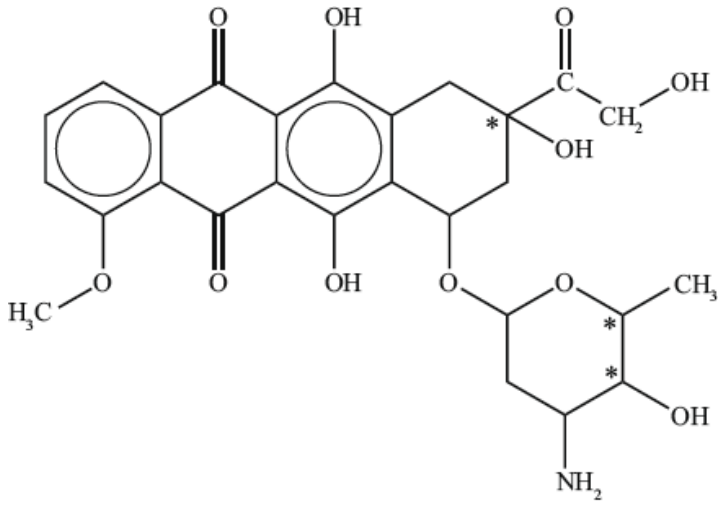
Solubility plays an important role in the bioavailability of drugs in the body.

Some mild analgesics contain a solid mixture of acidic aspirin and a non-acidic organic chemical of similar polarity to asprin.

Discuss how acid-base properties and the process of solvent extraction can be used to separate aspirin from the mixture.

Thalidomide is currently used to treat several different diseases including certain types of cancer. Research to compare its effectiveness with other cancer drugs, such as doxorubicin, is ongoing.

(i) Doxorubicin contains six different chiral carbon atoms. Three of them are identifi ed with an asterisk, *. Identify the locations of the other three by placing circles around the relevant carbon atoms.



Doxorubicin

(ii) Only one of the possible enantiomers is really effective as an anti-cancer drug.

Describe the general principles behind the use of chiral auxiliaries to form the desired enantiomer when several different enantiomers of a drug exist.

(iii) From its structure it can be seen that doxorubicin contains several polar hydroxyl groups. However, when it is given intravenously it needs to be in an ionic form to make it even more soluble in an aqueous medium. Describe how doxorubicin can be converted into a salt.

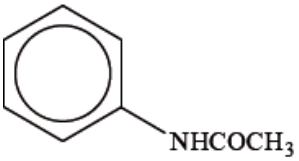
Morphine is a strong analgesic which is administered parenterally.

Diamorphine (heroin) is a more effective painkiller than morphine. The structures of morphine and diamorphine are shown in Table 20 of the Data Booklet. Explain at the molecular level why diamorphine is absorbed into fatty tissue more rapidly than morphine.

Many factors can be involved in the action of a particular drug.

The structures of morphine and diamorphine (heroin) are given in Table 20 of the Data Booklet. With reference to the structures, explain why diamorphine (heroin) is more potent than morphine.

The drug Antifebrin was first used as a medicine in 1886.



Antifebrin

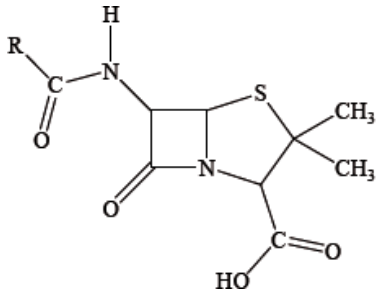
The structures of some medicines and drugs are given in Table 20 of the Data Booklet.

a.i. Identify the molecule which is most similar to Antifebrin in terms of size and structure. [1]

a.ii. State the names of the **two** functional groups that both molecules have in common. [1]

c. Outline why some drugs can be less effective when taken orally rather than through other methods of administration. [1]

Antibacterials are drugs that kill or inhibit the growth of microorganisms that cause infectious diseases. The general structure of penicillin, an antibacterial, is given below.



Describe the composition and structure of the beta-lactam ring in penicillin and explain its importance.

The first commercially available antibiotic came from a class of compounds known as the penicillins.

b. Explain how penicillins work and why it is necessary to continually modify the side-chain. [3]

c. Explain the importance of the beta-lactam ring in the action of penicillin. [3]

A commonly used mild analgesic is aspirin, 2-acetoxybenzoic acid, whose structure is given in Table 20 of the Data Booklet.

One form of soluble aspirin is $\mathrm{Ca(C_9H_7O_4)_2}$.

Morphine, codeine and diamorphine (heroin) are examples of strong analgesics.

Their structures are given in Table 20 of the Data Booklet.

a. Describe how mild analgesics function. [1]

b. (i) Outline why this substance is more soluble than standard aspirin in water. [2]

(ii) Deduce the balanced ionic equation for the reaction that occurs between soluble aspirin and the acid in the stomach.

c. (i) Deduce **two** named functional groups present in both aspirin and diamorphine. [8]

(ii) Deduce **one** named functional group present in morphine but not in diamorphine.

(iii) State **two** short-term advantages and **two** long-term disadvantages of using codeine as a strong analgesic.

Short-term advantages:

Long-term disadvantages:

(iv) Explain the increased potency of diamorphine compared to morphine.

Acquired immune deficiency syndrome (AIDS), a disease caused by the HIV virus, has resulted in millions of deaths worldwide since it was first identified in 1981.

Explain why viral infections, such as AIDS, are generally more difficult to treat than bacterial infections.

Organic solvents are commonly used in the pharmaceutical industry.

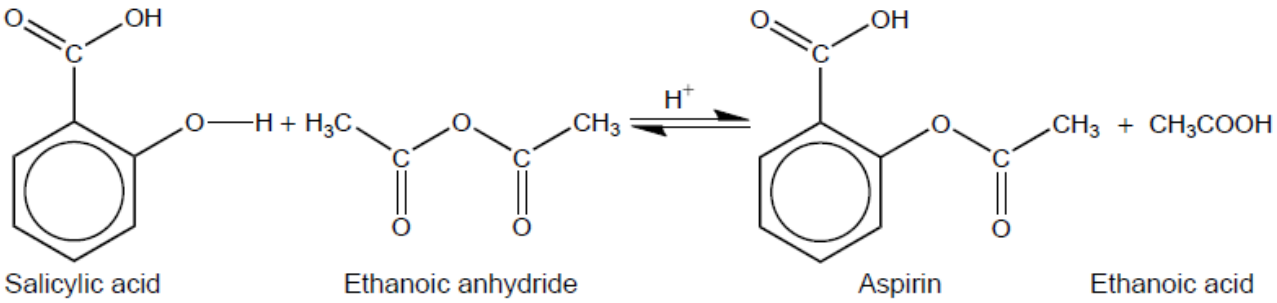
a. Hexane and propanone have vapour pressures of 17 kPa and 24 kPa respectively at 20 °C. [1]

   Calculate the vapour pressure, in kPa, at 20 °C of a mixture containing 60% hexane and 40% propanone by mole fraction, using Raoult's law and assuming the mixture is ideal.

b. Explain how hexane and propanone may be separated by fractional distillation. [3]

Aspirin is one of the most widely used drugs in the world.

Aspirin was synthesized from 2.65 g of salicylic acid (2-hydroxybenzoic acid) (M_r = 138.13) and 2.51 g of ethanoic anhydride (M_r = 102.10).



a.iii Suggest **two** absorbances, other than the absorbances due to the ring structure and C–H bonds, that would be present in the infrared (IR) spectrum of aspirin. [2]

a.iv State **two** techniques, other than IR spectroscopy, which could be used to confirm the identity of aspirin. [2]

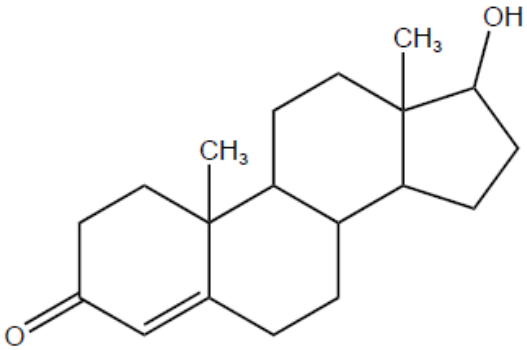
The use of performance-enhancing drugs presents a challenge in the world of competitive sports. New regulations have lowered the acceptable concentrations of certain drugs in athletes' bodies.

a. Suggest what may have led to these changes in acceptable concentrations. [1]

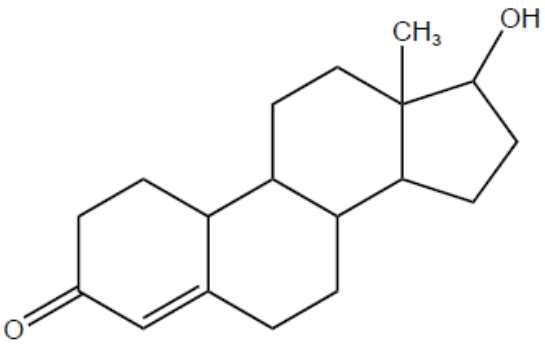
b. One class of performance-enhancing drugs is the anabolic steroids. Detection of these drugs in urine samples uses a combination of gas chromatography and mass spectrometry (GC/MS). [4]

(i) Describe how gas chromatography enables the components of urine to be analysed.

(ii) The structures of two steroids, testosterone and nandrolone, are given below.

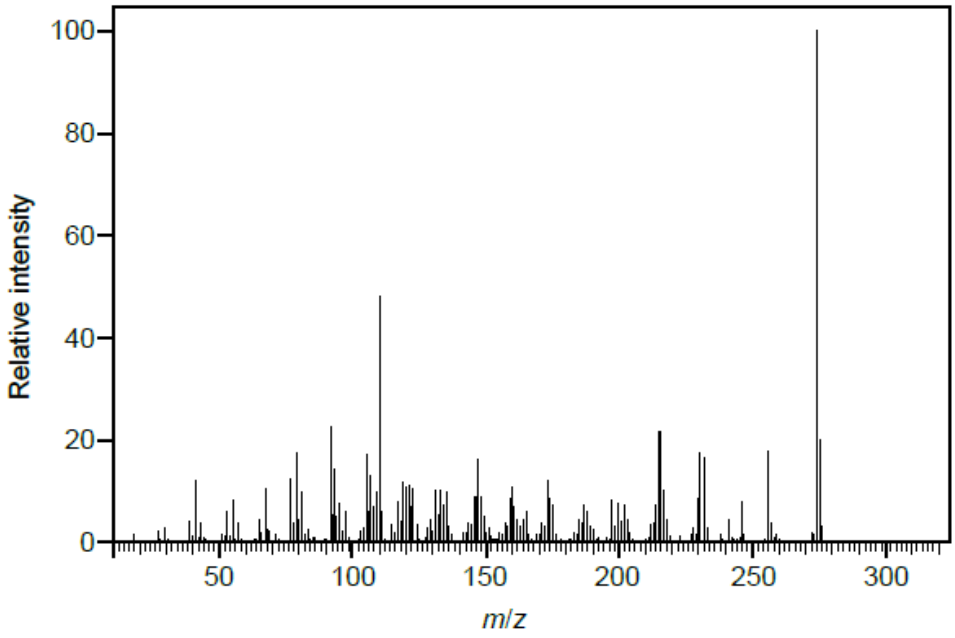


Testosterone $C_{19}H_{28}O_2$



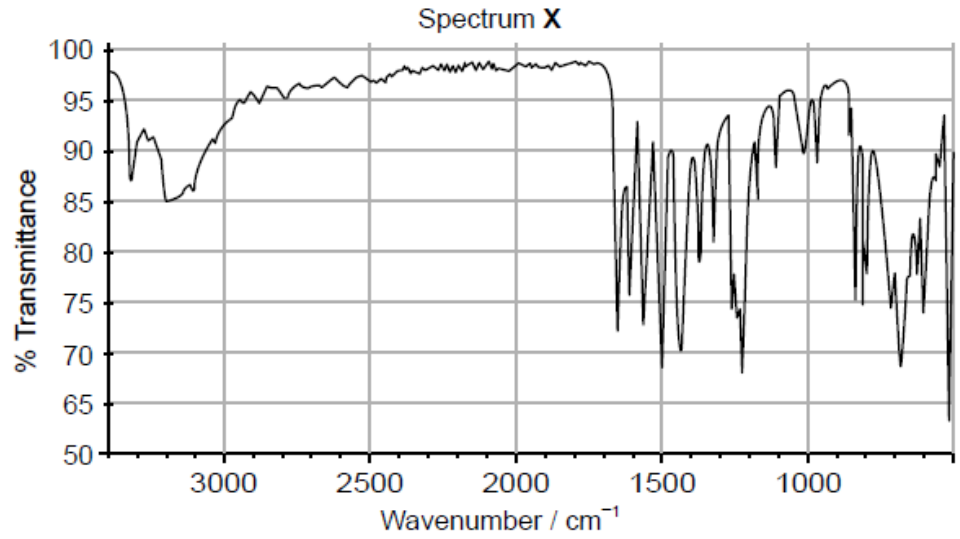
Nandrolone $C_{18}H_{26}O_2$

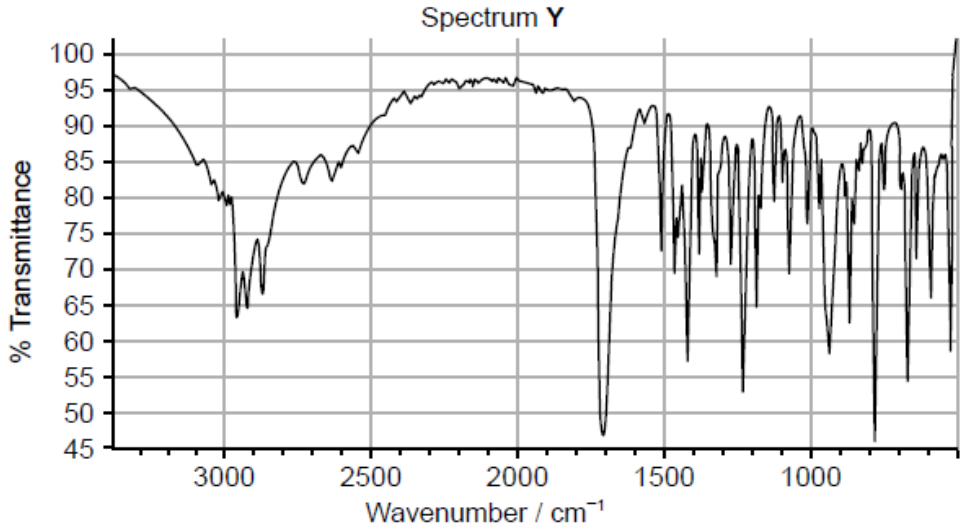
With reference to the molar masses of the two steroids, determine, with a reason, which can be identified from the mass spectrum below.



[Source: http://sdbs.db.aist.go.jp/ accessed 2015-08-23]

Ibuprofen and paracetamol are mild analgesics. One of the IR spectra below belongs to ibuprofen and the other to paracetamol. The structures of both compounds are given in section 37 of the data booklet.





[Source: chemspider.com]

a.i. Both spectra show a peak at wavenumber 1700 cm^{-1}. Identify the bond responsible for this peak. [1]

a.ii. Deduce which spectrum belongs to paracetamol, giving two reasons for your choice. Use section 26 of the data booklet. [2]

X or **Y**:

. . . . . .

Reason 1:

. . . . . .

. . . . . .

Reason 2:

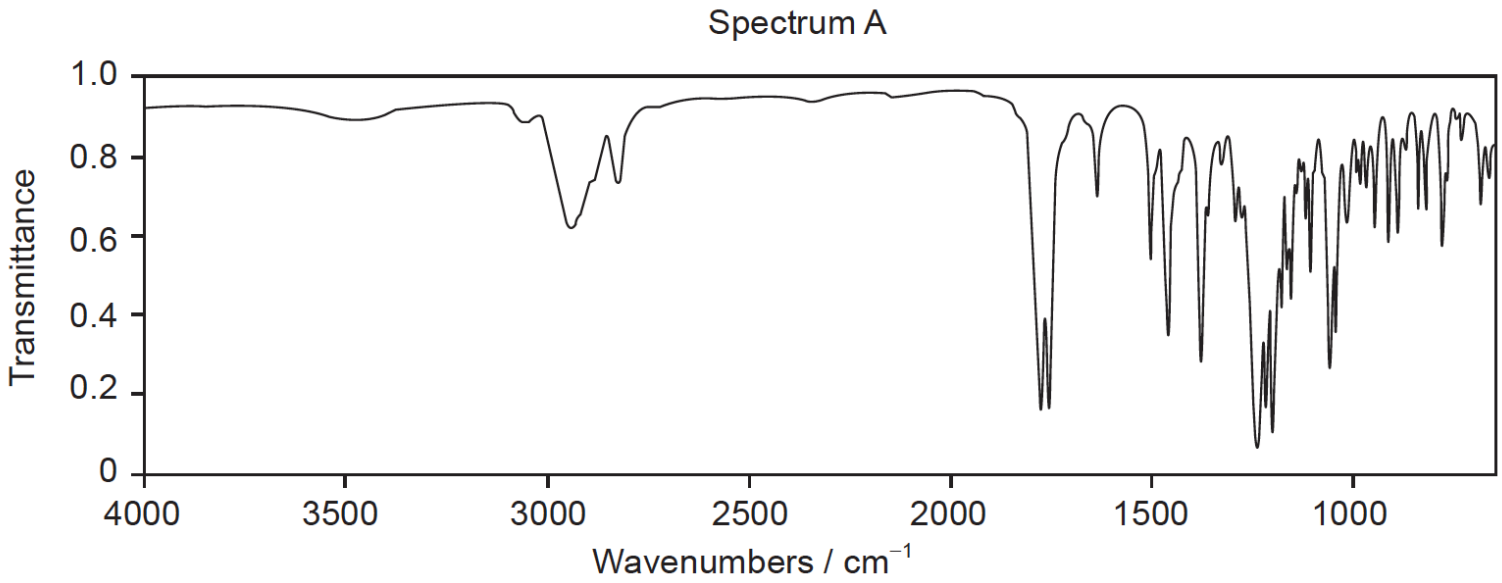
. . . . . .

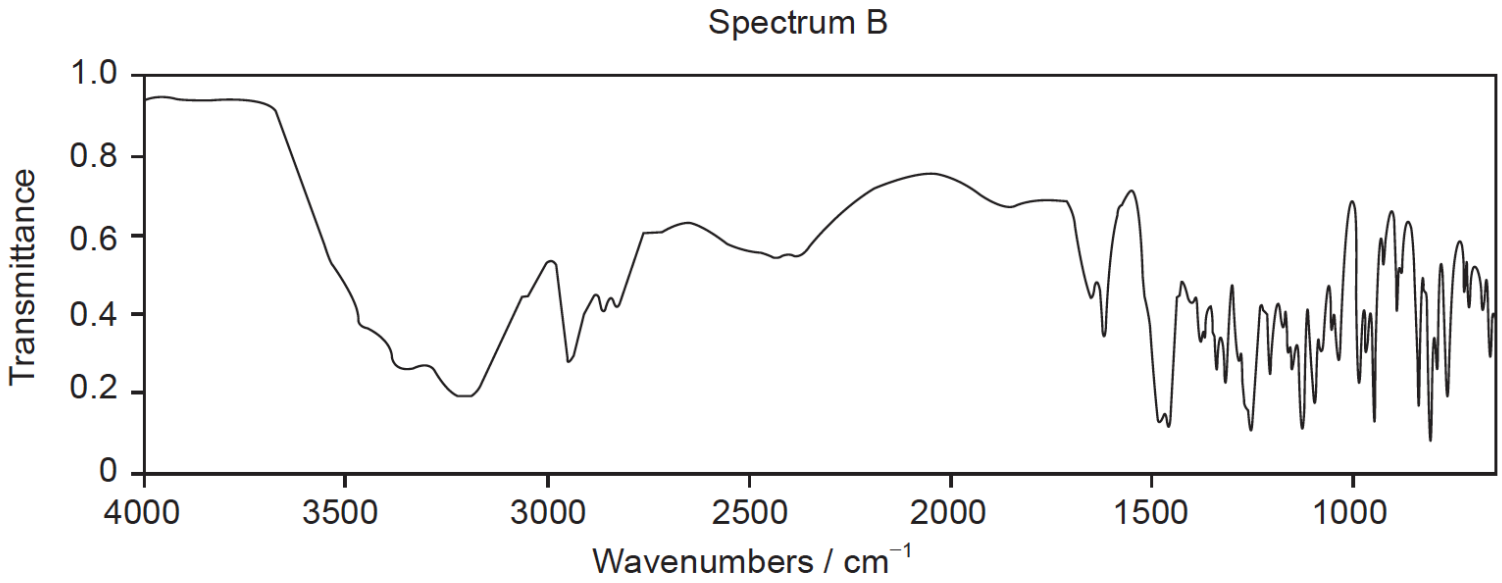
. . . . . .

b. Describe how mild analgesics function. [2]

Opiates have been used for thousands of years to alleviate pain. The structures of opiates are found in section 37 of the data booklet.

Using sections 26 and 37 of the data booklet, deduce, giving **two** reasons, which spectrum is that of morphine and which is diamorphine.





[Source: http://webbook.nist.gov]