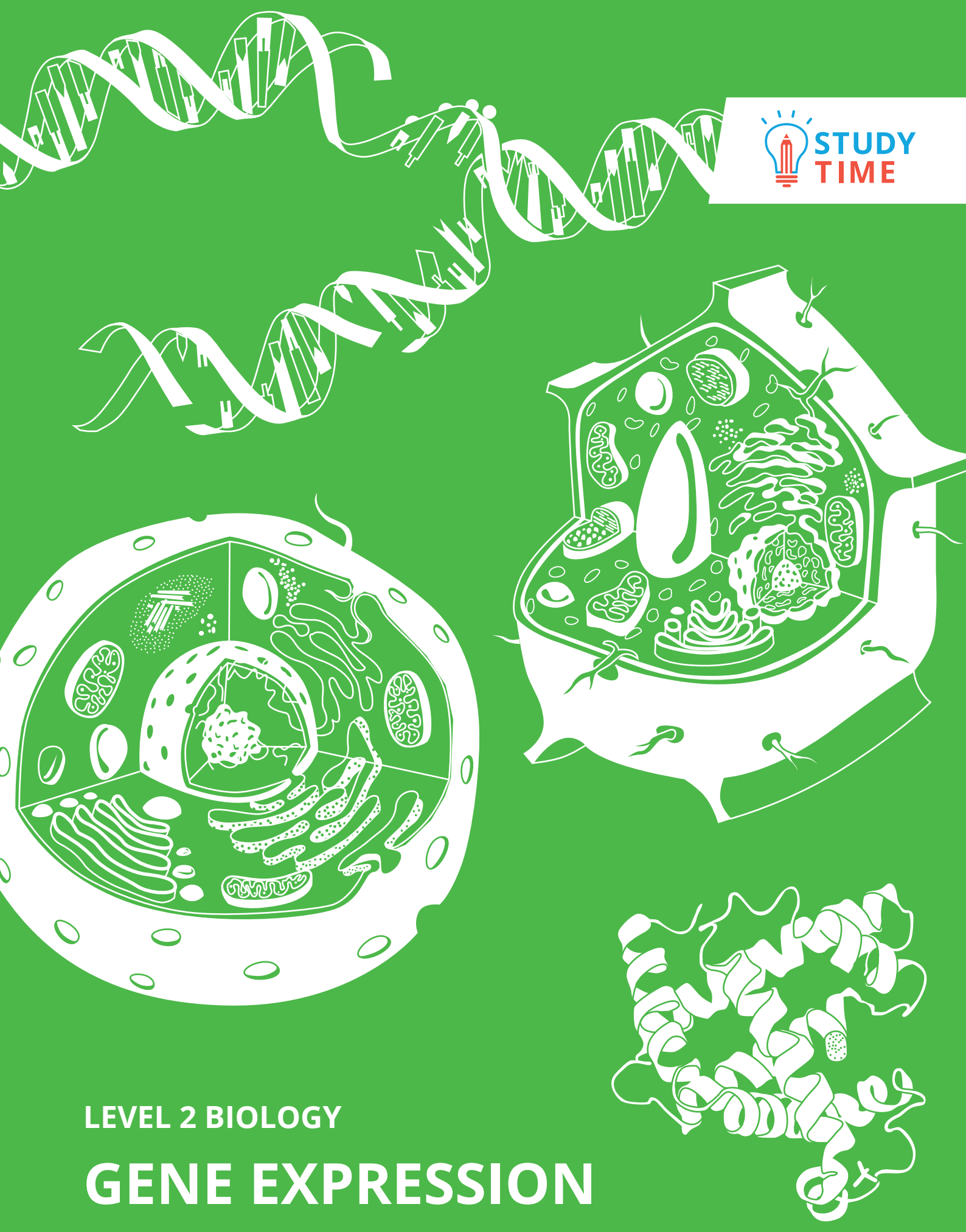


STUDY TIME

LEVEL 2 BIOLOGY

GENE EXPRESSION

NCEA Workbook Answers

Section One
The Foundations

1. DNA

a. The genetic code, which is the sequence of bases in the DNA.

b. A long molecule of DNA.

c. A length of DNA that codes for a particular trait (e.g. eye colour).

d. An alternative form of a gene (e.g. blue eyes or brown eyes).

e. The combination of alleles for a particular trait (one allele from each parent).

f. The physical expression of the genotype i.e. the trait shown.

g. A sugar, a phosphate and a base. A sugar, phosphate and a base bonded together, which form the building blocks of DNA.

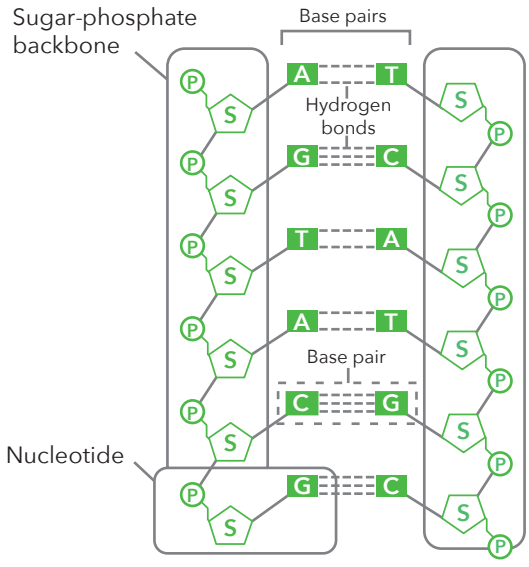
h. DNA is shaped like a ladder, twisted up into a double helix shape.

i. The 'sides' of the ladder are made of sugar and phosphate. The 'rungs' are made of base pairs.

i. The base pairing rule describes how bases bond together across each side of the double helix. A and T pair, while C and G pair. They are held together by hydrogen bonds.

j. Series of three bases in DNA. Each triplet codes for a specific amino acid.

k.



2. RNA

a. mRNA is a single-stranded copy of a gene which acts as a messenger. The purpose of mRNA is to carry genetic information from the nucleus to the ribosome, where it is translated into proteins.

b. Ribosomes are an organelle located inside the cell. The purpose of ribosomes is to facilitate translation of mRNA into proteins.

c. RNA has the base uracil (U) instead of the base thymine (T) found in DNA. Uracil's (U) complementary base pair is adenine (A).

d. RNA is a single strand of nucleotides, whereas DNA is a double strand of nucleotides. Instead of the thymine (T) base found in DNA, RNA has Uracil (U). DNA carries the genetic material needed for all proteins, whereas mRNA only carries information for a single gene, hence, mRNA is shorter than DNA. DNA is found in the nucleus, while RNA forms in the nucleus and then moves into the cytoplasm to the ribosomes.

e. No, mRNA is only made for genes that are turned on and are required to be expressed. One strand of mRNA will correspond to one gene of DNA.

f. The process where mRNA is made from the DNA template in the nucleus.

g. The process where proteins are made from mRNA in the ribosome.

h. mRNA is made through transcription in the nucleus. mRNA travels through the nuclear membrane, to the ribosomes, where it is translated. mRNA acts as a messenger to tell the ribosome which amino acids need to be linked together to make a functional protein.

3. Transcription

a. In the region of DNA to be transcribed, the enzyme helicase cleaves the hydrogen bonds between the DNA base pairs, splitting the DNA ladder in half.

i. This results in the DNA being open and accessible so that half of the DNA can be used as a template strand to make mRNA.

b. The strand of DNA in which complementary nucleotides are added, in order to make mRNA.

c. The strand of DNA which is not used as a template to create mRNA. Therefore, it is identical (not complementary) to the mRNA formed, with the expectation the mRNA having U bases not T.

d. An enzyme (RNA polymerase II) adds nucleotides to the template strand. The enzyme follows the base-pairing rule, adding complementary nucleotides, pairing C with G and A with U.

e. The mRNA is broken off from the template strand by another enzyme and DNA zips back up again. The mRNA leaves the nucleus through a special hole in the nuclear membrane called the 'nuclear pore' to travel to the ribosome where it is translated into a protein.

f. A series of three bases in mRNA. Each codon eventually codes for an amino acid.

g. *i.* G-A-C-T-G-A-A-T-C-C-T-G

ii. C-T-G-A-C-T-T-A-G-G-A-C

h. *i.* T-C-G-T-A-C-T-G-A-T-G-G

ii. U-C-G-U-A-C-U-G-A-U-G-G

4. Translation

a. The building blocks of proteins, coded by triplets.

b. Coded for by triplets in DNA and subsequent codons in mRNA.

c. A chain of amino acids joined together by peptide bonds. This is the primary structure of a protein.

d. *i.* Met-Arg-Arg-Stop.

ii. This is because of redundancy due to degeneracy within the genetic code, amino acids may be coded for by several different codons.

iii. No, some codons code for 'stop'. This lets the ribosome know to stop as the translation process is complete.

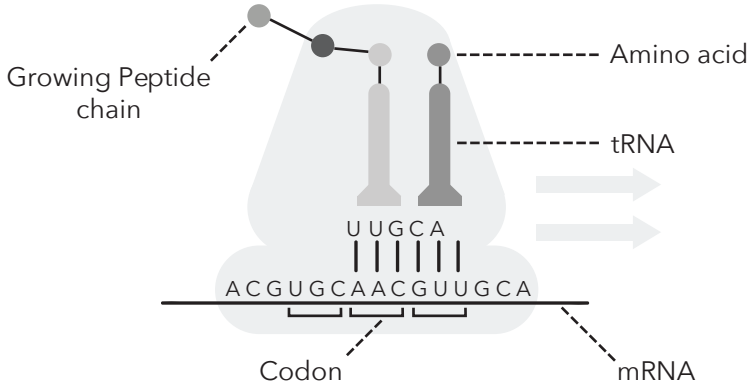
iv. AUG - Methionine.

v. So that ribosomes know when to start making the polypeptide chain and when to stop so that the appropriate protein is produced.

e. tRNA is a type of RNA with an anticodon on one end and a specific amino acid attached to the other end. tRNA carries amino acids to the site of translation.

f. A sequence of three bases on a tRNA molecule. Each anticodon is complementary to a particular mRNA codon.

g. The mRNA travels from the nucleus to the ribosome, where translation will happen. Before translation can begin, the ribosome must bind to the start codon of the mRNA. A tRNA molecule with the complementary anticodon (UAC) will come into the ribosome, bringing with it the methionine amino acid. The ribosome will then 'step' along to the mRNA to the next codon. The tRNA with the complementary anticodon and amino acid then comes into the ribosome. Every time tRNA brings in a new amino acid, the amino acid will form a peptide bond with the previous amino acid. Eventually, the ribosome will reach the stop codon of the mRNA. There will now be a chain of amino acids connected by peptide bonds, thus, a polypeptide chain forms.



h. The chain of amino acids (polypeptide chain) folds to form a functional protein.

5. Mutations

a. A mutation is a permanent change in the base sequence of DNA. Mutations can occur by accident when the cell is replicating its DNA or could occur from environmental factors such as radiation, chemicals or viruses.

b. An environmental factor that causes a mutation.

c. A substitution mutation occurs when one base is swapped for another which could result in a different amino acid being made.

d. A change in only one or a few bases on the DNA.

e. This is when all DNA bases occurring after the point of a mutation are shifted to the right (insertion mutation) or left (deletion mutation). This results in every codon downstream to be changed and therefore, the polypeptide chain will have a completely different sequence of amino acids.

f. An insertion mutation is when one or more bases are added to the base sequence. This causes a downstream shift of all DNA bases to the right, causing a reading frame-shift.

g. A deletion mutation is when one or more bases are removed from the base sequence. This causes a downstream shift of all DNA bases to the left, causing a reading frame-shift.

h. A mutation can cause a change in phenotype that could benefit the organism, depending on their environment. This could be through the mutated protein functioning better than the original protein, or a completely new protein being made that is beneficial.

i. This is most common with substitution mutations. If the substituted base still results in the codon producing the same amino acid, then no change would be observed. For example, both UCG and UCA code for the amino acid serine (Ser). So if the 3rd base of UUG was changed to A, then the same amino acid (Ser) will be produced thus no change is observed.

j. A non-functional protein is most likely to be produced through an insertion or deletion mutation as they result in a reading frame-shift. For example, if you have a gene encoding a protein that is 9 base sequences long and then a base/s is removed or added to this gene, every base and therefore triplet downstream will be changed. Hence, a completely different sequence of amino acids will be produced, which could result in a non-functional protein.

k.

Mutation #1

Original	A-U-G-A-A-U-G-C-U-U-A-U-A-G-C-U-C-U
Mutated	A-U-G-A-A-U-G-C-**C**-U-A-U-A-G-C-U-C-U
Type of mutation	Substitution
Original AA sequence	Met-Asn-Ala-Tyr-Ser-Ser
Mutated AA sequence	Met-Asn-Ala-Tyr-Ser-Ser
Effect/no effect	No effect

Mutation #2

Original	A-U-G-G-U-U-C-G-G-A-U-U-C-U-U-C-A-U
Mutated	A-U-G-G-U-U-**A**-C-G-G-A-U-U-C-U-U-C-A-U
Type of mutation	Insertion (frameshift)
Original AA sequence	Met-Val-Asp-Arg-Leu-His
Mutated AA sequence	Met-Val-Arg-Asp-Ser-Ser
Effect/no effect	Effect

Mutation #3

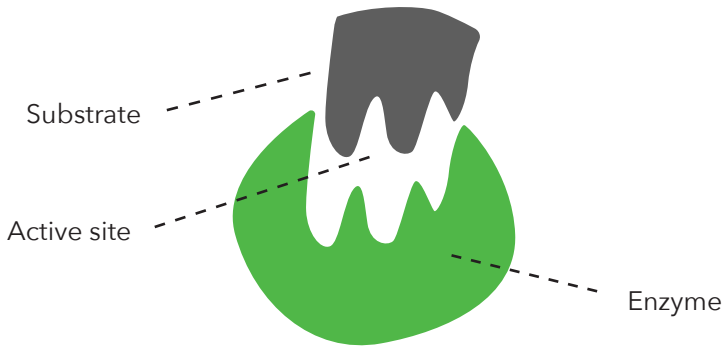
Original	A-U-G-A-U-U-U-G-C-A-C-C-A-G-A-G-C-G
Mutated	A-U-G-A-U-U-U-**G-A**-C-C-A-G-A-G-C-G
Type of mutation	Deletion (frameshift)
Original AA sequence	Met-Ile-Cys-Thr-Arg-Ala
Mutated AA sequence	Met-Ile-Stop
Effect/no effect	Effect

6. Enzymes and Metabolic Pathways

a. A type of protein that functions as a biological catalyst to speed up reactions inside living things without being used up itself.

b. A substance that is catalysed by an enzyme into a product.

c.



d. An enzyme is a protein which catalyses the conversion of substrates into products. Enzymes bind substrates via their active site, which is structurally specific to the substrate that it catalyses. Once bound, the enzyme is able to catalyse the substrate into a product.

e. A series of enzyme-catalysed reactions in which the product of each reaction is the reactant for the next reaction until the final product is made.

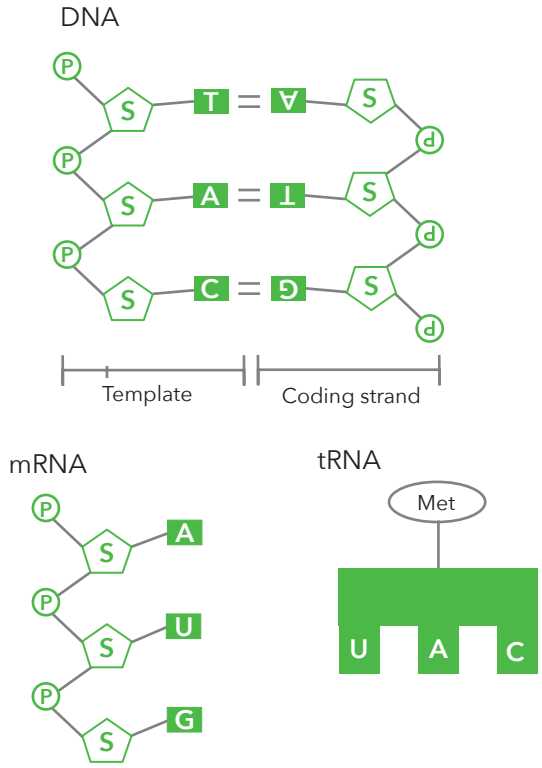
f. *i.* The product of the first enzyme becomes the substrate for the second enzyme and the product of the second enzyme becomes the substrate for the third enzyme. This goes on until the final product is made.

ii. Substrate three would not be made. Therefore, enzyme three could not catalyse the reaction of substrate three and as a result, no final product would be formed. Additionally, enzyme one is still catalysing the reaction of substrate one to substrate two so substrate two would build up in the body.

iii. No final product being produced could mean the body is missing out on a vital substance, which could result in disease. Additionally, substrate 2 is building up in large amounts, which could be harmful and also result in disease.

7. Developing Skills

a.



b. Both processes use mRNA, however, transcription makes mRNA while translation reads mRNA. Both processes have a template, but, transcription uses DNA as a template while translation uses mRNA as a template. Both processes use complementary base pairing. Transcription base pairing occurs between DNA and free RNA nucleotides, whereas translation involves pairing bases of tRNA and codon mRNA. Both processes have a start and stop sequence, are controlled by enzymes and read in sets of three bases. However, the processes occur in different locations, with transcription occurring in the nucleus and requiring DNA while translation occurs in the cytoplasm and requires ribosomes, tRNA and amino acids.

c. A same-sense mutation is a type of substitution mutation in which there is no change in the amino acid sequence as the same amino acid has been coded for. This is due to the redundancy of the genetic code. A missense mutation is where the substitution mutation has caused a change in the amino acid, but this does not affect the protein. This may occur due to the new amino acid having similar properties to the original amino acid. Lastly, a nonsense mutation is when there is a change in the amino acid which results in a faulty, non-functioning protein, likely caused by an early stop codon.

d. This is an example of a substitution mutation as the T base has been swapped for the A base. This is also an example of a point mutation, as only one base on the DNA has changed. Additionally, this could be considered a nonsense mutation as there has been a change in the amino acid, which has resulted in a faulty, non-functioning protein.

e. *i.* T-A-T-G-T-C-C-A-C

ii. U-A-U-G-U-C-C-A-C

iii. A-U-A-C-A-G-G-U-G

iv. Tyr-Val-His

v. This would change the codon from G-U-C which encodes the amino acid Val to the codon G-U-G which also encodes the amino acid Val. Therefore this is a same-sense mutation, or, a silent mutation which will have no effect on the organism.

f. An organisms phenotype can change due to interactions with the environment. These can be due to lifestyle choices, diet, and exposure to certain factors (e.g. radiation) and change the way the organism looks without changing the genetic code.

i. The genotype of the queen bee is considered fully expressed because it has optimal conditions, with access to the correct amount of nutrients. The worker bee does not have access to the correct amount of nutrients, therefore it's genotype is not fully expressed, resulting in phenotypic differences between the queen bee and worker bees.

Section Two
Exam Skills & Mixed Practice

Question One

A protein is a large molecule composed of one or more chains of amino acids. These amino acid chains are referred to as polypeptide chains and are determined by the base sequence of DNA. Proteins are essential for the structure, function and regulation of an organism's cells, tissues and organs. An example of an important protein is haemoglobin, which functions to carry oxygen to the tissues and organs of the body. Protein synthesis is the process by which cells generate new proteins through transcription and translation.

Transcription is the process in which a DNA strand is used as a template to create an RNA molecule that is the exact copy of the coding strand. Transcription occurs in the nucleus. DNA is transcribed by an enzyme called RNA polymerase. A specific nucleotide sequence, called the promoter, on the DNA molecule causes RNA polymerase to attach to the DNA in front of the gene. The DNA strand unwinds and RNA polymerase transcribes a single strand of DNA (the template strand) into a single-stranded RNA polymer called messenger RNA (mRNA). Like DNA, RNA is composed of nucleotides which are attached to each other based on the RNA base-pairing rules. RNA polymerase moves along the DNA until it reaches a terminator sequence. At this point, RNA polymerase releases the mRNA polymer and detaches from the DNA. The mRNA strand then leaves the nucleus via pores in the nuclear membrane and travels to a ribosome.

Translation is the process in which the genetic code carried by mRNA is decoded to produce the specific sequence of amino acids in a polypeptide chain, i.e. a protein. Translation occurs in the ribosomes. Once the mRNA has left the nucleus it attaches to a ribosome. A ribosome is an organelle that 'reads' mRNA bases in a sequence of three bases at a time. This is known as a codon. A start codon on the mRNA initiates the translation. Another type of RNA molecule, called transfer RNA (tRNA), attaches to amino acids found in the cytoplasm based on the three bases on the end of the tRNA. The bases on the tRNA are called anticodons. Anticodons on the tRNA are complementary to a codon on the mRNA. Codon-anticodon 'matches' combine according to the base-pairing rules and bring the correct amino acid to the next part of the sequence. In the ribosome, amino acids bond to other amino acids with peptide bonds and form a polypeptide chain. A stop codon then ends translation. The polypeptide chain is then released from the ribosomes and folds into a three-dimensional structure and becomes a functional protein.

Proteins are coded for by sections of DNA called genes. Each gene codes for a protein that expresses different traits and alleles within an organism, therefore, proteins and gene expression are directly linked.

Question Two

A mutation is a permanent change in the base sequence of DNA. Specifically, this base sequence change occurs in an allele of a gene, causing the allele to produce a different protein/enzyme.

A deletion mutation is when one or more DNA bases are removed from the DNA base sequence. Amino acids are coded for by three bases, therefore, when one amino acid is absent, it indicates that three bases have been deleted from the base sequence. An absent amino acid can have a detrimental effect on the folding of the protein. As folding of the protein depends on the interactions and bonds between amino acids, such as hydrogen bonds and disulfide bridges, a missing amino acid can

change these interactions, and therefore, significantly changes the shape that the protein folds into.

A substitution mutation is when one or more bases in the DNA sequence are swapped for another base. This changes the DNA and mRNA sequences, resulting in a change in the amino acid sequence. This will change the interactions between the amino acids in the final protein, altering the final shape of the protein.

While a substitution mutation results in a change in the shape of the final protein, if the substituted amino acid has a similar structure to the original amino acid, then there will be little difference in the folding of the protein. This means the cystic fibrosis disease may be less severe. The more different the amino acid is from the original, the more severe the cystic fibrosis disease is due to the increased difference in the folding of the protein. However, a deletion mutation will also result in a missing amino acid, therefore, the resulting protein will always fold in a very different way, reducing the protein's ability to function, causing severe cystic fibrosis. This explains why substitution mutations can lead to a milder form of cystic fibrosis, while a deletion mutation will result in a more severe cystic fibrosis disease.

Question Three

A metabolic pathway is a series of enzyme-controlled reactions in which converts compounds from one form to another. A principle chemical, known as the substrate, is modified by an enzyme-controlled reaction. The reaction modifies the substrate into a product that is then used as the substrate for another enzyme-controlled reaction. This process continues until the final product is produced. The correct function of each enzyme is crucial as all of the enzymes in the metabolic pathway are needed to produce the final product. If one enzyme in the metabolic pathway is non-functioning, there is a build-up of the substrate for that reaction, and the final product cannot be made.

Siamese cats have a mutated gene that results in an enzyme that is affected by the environment. This mutated gene causes the production of the enzyme tyrosinase, which is sensitive to the temperature. The enzyme tyrosinase catalyses the production of melanin only in areas of the body that are cool enough for the enzyme to function, such as the feet, tail and ears of the cat. In these areas the enzyme is active, so the dark pigment melanin is produced and expressed in the coat colour of the cat. The area around the cat's chest is warmer, and therefore, the enzyme tyrosinase cannot function and produce melanin, resulting in the cat having an albino body.

Through protein synthesis, gene A causes the production of the enzyme tyrosinase, which changes the chemical tyrosine into melanin. Gene B causes the production of an enzyme for expression that causes the melanin produced to be expressed in the skin, hair and eyes. If a mutation in gene A caused a non-functioning tyrosinase enzyme to be produced, the pathway would not function as no tyrosine would be changed into melanin. Therefore, even if gene B is fully functioning, no melanin would be produced from which the darker colour could be expressed. This mutation in gene A would result in a fully albino cat. If gene A was normal and there was a mutation in gene B then melanin would be produced by the normally functioning tyrosinase enzyme from the normal gene A, but the melanin would not be expressed in the coat colour because of the non-functioning enzyme for expression produced by the mutated gene B. This would also result in an albino cat.

Section Three
Practice Exam

Question One

Enzymes are a type of protein that influences the metabolic pathways by acting as a biological catalyst speeding up the series of reactions through catalysing the conversion of substrates into products. A metabolic pathway is a series of enzyme-catalysed reactions in which the product of each reaction is the reactant for the next reaction until the final product is made. Each enzyme is specific to the reaction. For example, a specific enzyme such as tyrosine hydroxylase will convert tyrosine into the product DOPA. DOPA will act as a substrate for the next reaction where DOPA decarboxylase will convert DOPA into the final product dopamine.

A mutation in the tyrosine hydroxylase enzyme would mean there is no conversion of tyrosine to DOPA. This would have two major effects. Firstly, no conversion to DOPA would mean there can be no conversion to dopamine, hence no dopamine can be produced. Secondly, there would be a build of tyrosine. Having a buildup of tyrosine could be harmful to an individual, as tyrosine is involved in lots of processes in the body. An example of this is too much tyrosine would increase thyroid hormone which would increase heart rate and faster intestine movement, if this increased too much it could comprise the survival of an organism.

A mutation in the gene that encodes for the DOPA decarboxylase enzyme would mean there is no conversion of DOPA to dopamine. This would have one major effect; no dopamine is produced as there is no enzyme there to convert to DOPA to dopamine. This would lead to a build-up of DOPA. However, a large amount of DOPA is unlikely to be as harmful to an individual as tyrosine, as DOPA only has the one function to be a precursor to dopamine.

Question Two

The phenotype of an organism refers to the observable characteristics of the organism, whereas the genotype refers to the collection of genes and alleles that an organism has in its DNA.

A mutagen is an agent that causes genetic mutations. In the environment, a mutagen can cause mutations that influence the genotype and phenotype of an individual. However, not all environmental factors are mutagens as they do not affect the genotype of the organism.

There are a range of environmental factors, which can be internal or external factors, that influence the growth and development of organisms. For example, x-rays, water, nutrients and oxygen. Some of these environmental factors are mutagens, such as x-rays, as they can cause mutations in the base sequence of DNA, therefore, changing the genotype and potentially the phenotype. Other environmental factors, such as nutrient availability and wind, change the phenotype of the organism but do not change the genotype of the organism, and therefore, they are not mutagens. For example, a young animal that has limited availability of an important nutrient, will not grow as well as an animal that has a good supply of the same nutrient. The nutrient does not change the genotype of the individual, but the lack of it does change the phenotype of the individual compared with that of other individuals of the same species and age.

Quadruplet armadillo pups are ideal organisms to test the effect of environmental factors of phenotype as they all have the same genotype for all genes. Therefore, two of the armadillo pups could be kept as control organisms, while two could be exposed to different non-mutagenic environmental factors. After a length of time, the phenotypes of all four armadillos could be compared. Due to the genotypes of the controls and tested armadillo pups being identical, any changes in the phenotype would be caused by the environmental factor and not genetic factors.

Question Three

A triplet is made of three bases in the DNA sequence, for example, CGT. A codon is made of three bases on the mRNA complementary to a triplet on the DNA. For example, if the triplet is CGT, the codon is GCA. An anticodon is three bases on a tRNA complementary to the codon on the mRNA. For example, if the codon is GCA, then the anticodon is CGU. Triplets, codons and anticodons are significant as they transfer information from the genetic code, allowing the correct amino acids to be coded for during translation in protein synthesis.

The start codon, AUG, on the mRNA strand codes for the amino acid methionine (Met), to be brought to the ribosome by a tRNA molecule, initiating the start of protein synthesis. Without the start codon, protein synthesis would not be initiated, and therefore, no proteins would be made. A stop codon, UAA, UAG or UGA, causes the ribosome to stop adding amino acids to the polypeptide chain, therefore, terminating the process of translation as they do not code for an amino acid. These stop codons are significant as their presence determines the location on the mRNA strand as to where translation will stop.

During transcription, triplets and codons interact. This occurs due to the DNA triplet bases being exposed when the DNA unwinds and the bonds between bases are broken. The interaction between the DNA bases and the mRNA bases follows the complementary base pairing, A to T and G to C, however, for RNA, the thymine (T) base is replaced by uracil (U). Therefore, if the base on DNA is A, the complementary base will be U. During transcription, each DNA triplet is 'read' so that a complementary codon is produced in the mRNA strand. For example:

DNA strand	TAC	GTA	ACG
mRNA strand	AUG	CAU	UGC

During translation, codons and anticodons interact with each other. The mRNA strand joins with a ribosome in the cytoplasm of the cell. The start codon AUG is available and a tRNA with the complementary anticodon UAC brings the amino acid Met to the ribosome. The codons and anticodons are held together by weak hydrogen bonds. Another tRNA with the complementary anticodon for the next codon also brings the next amino acid to the ribosome. For example:

Codon on mRNA	AUG	CAU	UGC
Complementary anticodon on tRNA	UAC	GUA	ACG
Amino acid carried by tRNA	Met	His	Cys

Peptide bonds form between neighbouring amino acids, and the weak hydrogen bonds between codons and anticodons break, releasing the tRNA from the ribosome. New tRNA molecules come to the ribosome to add amino acids to the growing polypeptide chain as the ribosome moves along the mRNA strand exposing more codons. This process continues until a stop codon is reached and protein synthesis stops. The polypeptide chain is released and goes on to fold into a functional protein.

Mutations in DNA can lead to a change in the triplet, and therefore, codon and anticodon. Substitution mutations which occur in the third position of a triplet, are less likely to cause a significant change in the formation of the protein as opposed to a substitution mutation which occurs in the first or second position. In your answer:

- Define a substitution mutation.
- Link the possible change in the protein caused by a substitution mutation, to the position of the mutation in the triplet and the redundancy of the genetic code.

A mutation is a permanent change in the base sequence of DNA. A substitution mutation is the replacement of one or more bases by others. The location of the base substitution on the triplet has an effect on whether the mutation will cause a change in the protein produced by that gene. Mutations can often cause a change in the functionality of the protein. If the substitution mutation occurs in the first or second positions of the triplet, it is likely that the triplet will code for a different amino acid, which may have an effect on the functionality of the protein. If the substitution mutation occurs in the third position of the triplet, the mutation is less likely to cause a change in the amino acid that is coded for by that triplet, and may not affect the functionality of the protein. This is due to the redundancy of the genetic code. This means that more than one codon can code for the same amino acid. For example, the amino acid leucine, Leu, can be coded for by the codons CUA, CUC, CUG, and CUU. Therefore, some codons are redundant and if the third base in the triplet is changed, the amino acid the new triplet codes for may still be the same, meaning the functionality of the protein is not affected.

