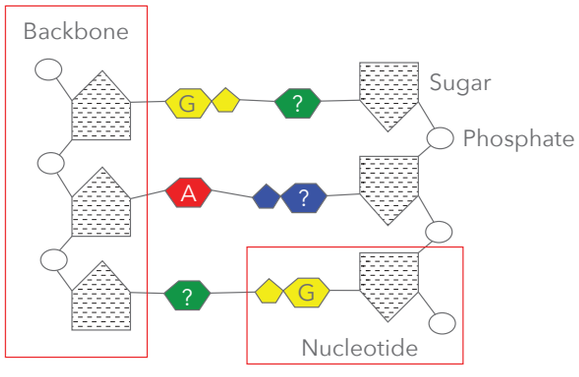
Workbook Answers
Level 1 Science
Genetics

Section One

1. Cells and DNA

1. DNA is found in the nucleus of cells for animals, plants and fungi.

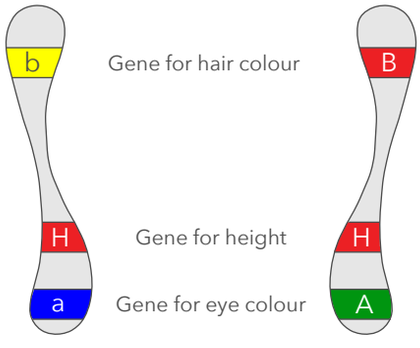
2.



3. DNA is a double-stranded molecule that is made up of sugar, phosphate, and four bases, A, T, G, and C. The sugar and phosphate make up the backbones of each strand, while the bases are found in the middle of the molecule. The base adenine (A) always pairs with thymine (T), while the base guanine (G) always pairs with cytosine (C). A nucleotide is a collection of one phosphate, one sugar, and one base. Nucleotides are the building blocks of the DNA molecule.

4. A chromosome is a long strand of tightly wound DNA found in the nucleus of the cell.

5. There is one DNA molecule per chromosome.



6. Homologous chromosomes are chromosomes which are very similar and pair during cell division.

   They have the same genes, in the same order, all the way down, but may have different alleles. For example, above, both chromosomes have the gene for hair colour at the top and gene for eye colour at the bottom. However, the one on the left has the recessive b allele for blonde hair and recessive a allele for blue eyes, while the one on the right has the dominant B allele for brown hair and A allele for brown eyes. Both chromosomes have the same allele for the height gene. Both chromosomes are also the same size. One of the chromosomes in the pair is inherited from the mother, and one from the father.

7. Most of a multicellular organism's body is made up of somatic cells (body cells). Body cells are the building blocks of your skin, muscles, heart etc. These make up the major tissue and organ systems of the body and help to keep the organism itself alive. Somatic cells are referred to as diploid, meaning there are pairs of chromosomes within the cell.
   Sex cells (gametes) are specific kinds of cell an organism produces in order to reproduce (make offspring). Gametes are usually produced in specific organs, such as the ovaries or testes of mammals, or in the flowers of plants. They are used to make the next generation of the organism. Gametic cells are also referred to as haploid, meaning there is only one copy of the genome.

8. A human somatic cell has 23 pairs of chromosomes; 46 total.

9. A human gamete has 23 chromosomes - half of the number in a somatic cell. A gamete only has one copy of each chromosome, instead of two like a somatic cell.

10. The sex chromosomes are the chromosomes that determine the biological sex of mammals at birth. Unlike the other 23 pairs of chromosomes, the sex chromosomes are not identical. One, called the X chromosome is much larger than the other, which is called the Y chromosome. The combination of X and Y determines whether an organism will be biologically male or female. XX gives a female, XY gives a male.

11. A gene is a section of DNA coding for a trait. For example, the gene for eye colour is a section of DNA which determines the eye colour of the organism. The sequence of bases in the gene give the instructions to produce the trait.

12. A gene carries the instructions for producing a particular trait. The sequence of bases in a gene is important because a different order of bases can result in a different trait. Think of this kind of like using a recipe to bake a cake - you have to mix together your dry ingredients with the wet, put it into the cake pan, and then put it into the oven. You need to follow the steps in the recipe in the right order, or you will get a different product - if you put the dry ingredients straight in the oven and then try adding the wet ingredients at the end, you certainly won't get a cake! A gene is similar - the order of the bases is important, but in the case of a gene, we are making a protein (not a cake). Different sequence of bases, different protein.

13. An allele is one version of a gene. For example, we may have a gene for eye colour. This gene gives the instructions to make coloured eyes. The gene can come in two or more different versions, called alleles. One allele might encode blue eyes, while another encodes brown eyes. In both cases, the gene still gives the instructions for eye colour, just different eye colours in each case.

14. A trait is a physical characteristic which can be observed, such as eye colour.

15. "Heritable" means a trait or mutation can be inherited. That is, passed down from parent to offspring.

16. A heritable trait can be inherited by the offspring. A non-heritable trait cannot be passed onto offspring.

17. Heritable traits: eye colour, earlobes attached (or loose), hair colour, ability to roll your tongue
Non-heritable traits: scars, tattoos, tanning, dyed hair colour. Heritable traits are traits you are born with, such as your eye colour, (natural) hair colour, and your ability to roll your tongue. Heritable traits can also be traits that you have the potential to achieve. For example, if both of your parents were very tall, you may have inherited the potential to grow tall yourself. However, you will only be able to achieve this genetic potential if you have adequate nutrition as a child, otherwise you will be shorter than you could have been. Non-heritable traits are traits you acquire after you were born, such as a tan, dyed hair, scars or tattoos.

18. The phenotype is the combination of physical traits that an organism has. For example, a person might have brown eyes and blonde hair. This would be their phenotype.

19. The genotype is the combination of alleles that an organism has. For example, a person might be BB for eye colour, and hh for hair colour. This would be their genotype.

2. Mutations and Cell Divisions

1. A mutation is any change to the sequence of bases. Mutations are important when they occur in genes, because changing the sequence of bases in a gene can change what it codes for.

2. A mutagen is a physical or chemical agent which causes mutations in DNA.

3. There are lots of different mutagens! Some common examples you might have come across include:
Physical mutagens: UV radiation in sunlight, gamma radiation, x-rays.
Chemical mutagens: Ethidium bromide, lead.

4. Cell division (i.e. mitosis) is the process whereby one cell splits into two (divides). The cell first makes a copy of its
DNA. It then grows larger, before splitting in half. This produces a new cell, so that there are now two. Each new cell gets its own set of DNA and organelles. The resulting cells are called daughter cells.

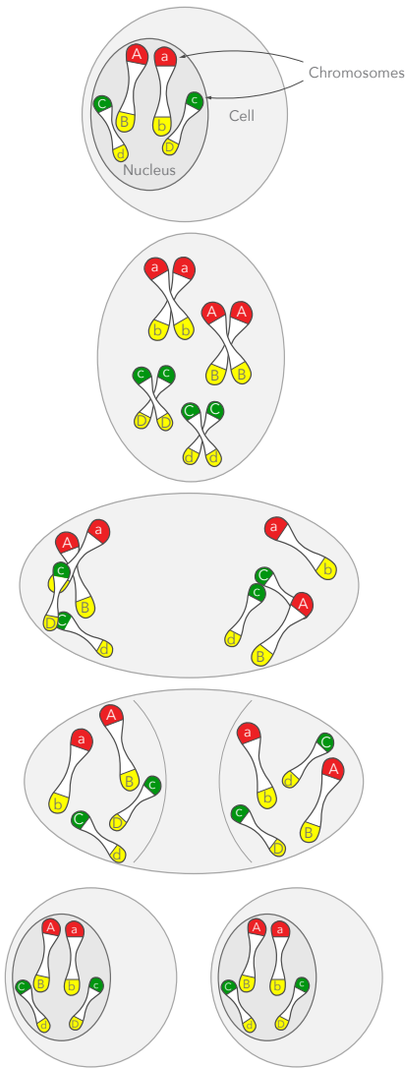
5. Four reasons why a cell might need to divide in a living organism:

   a. Repair: When you get an injury, such as a cut, some cells are killed. Living cells on either side of the wound divide to produce new cells, replacing those which were destroyed.
   b. Replacement: Cells don't live forever. Most cells in your body will only live for a short period of time before they become less able to do their jobs effectively. These cells will die and will be replaced by new cells. For example, your skin cells are continually dying and being replaced by a layer of new, fresh skin cells underneath.

c. Growth - in order to grow larger, a multicellular organism needs to produce more cells. You have more cells in your body now than you did when you were a baby.

d. Reproduction - organisms reproduce by producing new cells - either by producing gametes, for sexual reproduction, or by producing identical copies of their cells in asexual reproduction.

6. (See the diagram below). The first image shows a cell, with nucleus, and two pairs of homologous chromosomes (four in total). One chromosome holds the A (red coloured) and B (yellow coloured) genes. In this homologous pair, one chromosome has dominant alleles for both genes (i.e. A and B) and one has recessive alleles for both genes (i.e. a and b). The second set of chromosomes holds the C (green coloured) and D (also yellow coloured) genes. One chromosome in the pair has the dominant allele C, but recessive allele d. The other has two dominant alleles, D and C. Before cell division occurs, DNA replication takes place. Each chromosome is duplicated, forming an identical copy of itself. These copies are attached at the centromere, or thin centre part, of each chromosome. This is seen in the second picture. The membrane of the nucleus breaks down. Spindle fibres form and extend from the poles of the cells. These attach to the duplicated chromosomes at the centromere, and proceed to pull the duplicated chromosomes apart (image 3). One of each identical copy of each chromosome is pulled to each side of the cell. New nuclear membranes start to form around the chromosomes. Now the cell divides in half. Each of the new daughter cells is genetically identical to the parent cell, with exactly the same chromosomes and exactly the same alleles. No genetic variation is created.



7. Meiosis (diagrams on the next pages)

The cell in the diagram has two pairs of homologous chromosomes. One pair has the genes A (coloured red) and B (coloured yellow). In this pair, one chromosome has the dominant allele A and dominant allele for B. The other chromosome is recessive for both genes (i.e. a b). The other homologous pair has the genes C (green coloured) and D (yellow coloured). In this pair, both chromosomes have the dominant allele for the C gene, while one has the recessive allele d, and the other, the dominant allele D. The genotype of the parent cell, before cell division, is therefore Aa Bb CC Dd.

Meiosis begins like mitosis. First, the DNA replicates, which causes each chromosome to be duplicated. At first, the identical chromosome copies are joined together at their centromere, the centre part of the chromosome. In the second image in the diagram, the chromosomes have already been duplicated.

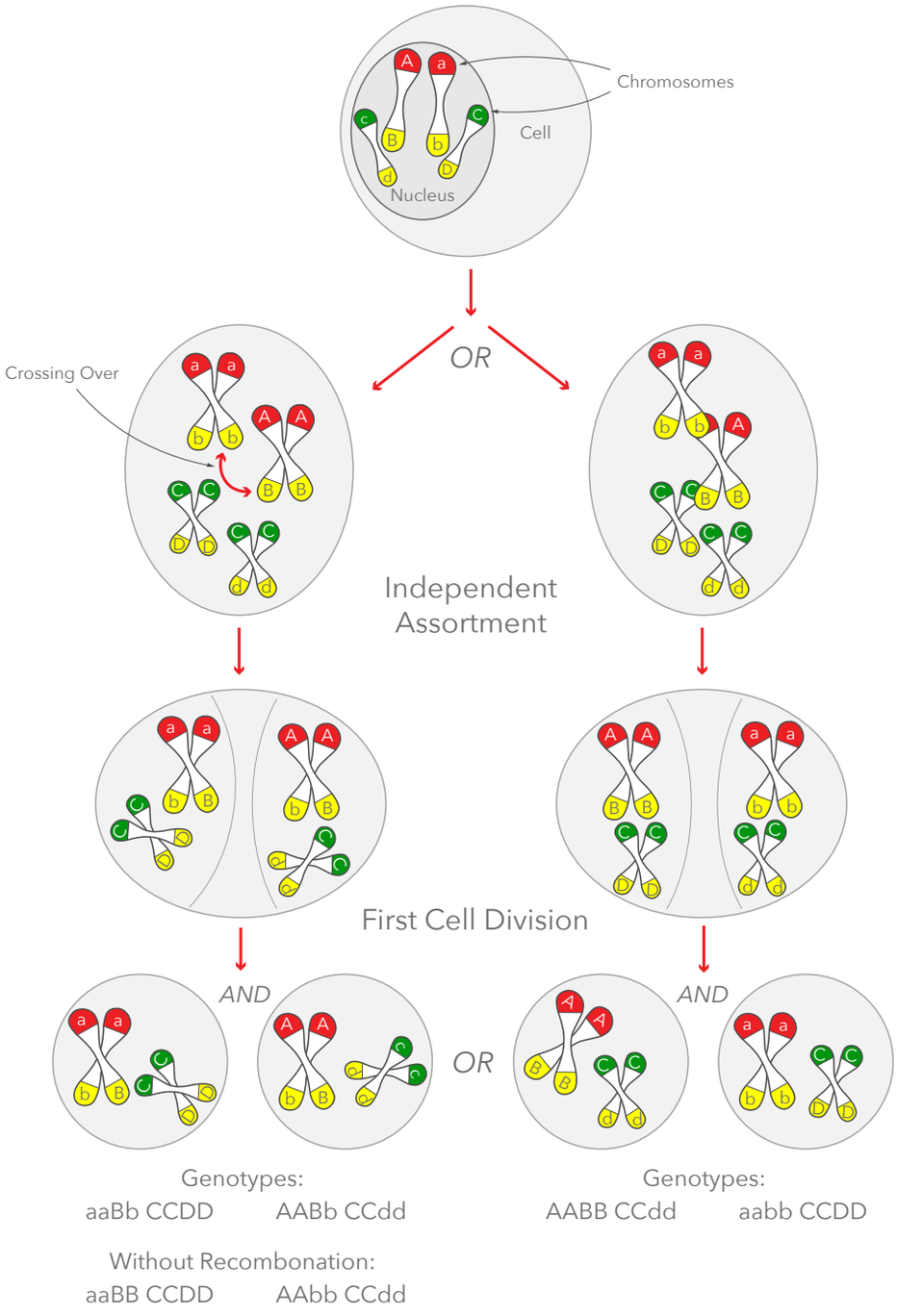
After duplication, the pairs of chromosomes line up in the centre of the cell. How the different pairs of chromosomes line up with respect to the other pairs is random. For example, in the first diagram, the duplicated aabb chromosomes are on the same side of the cell as the CCDD chromosomes, while the AABB chromosomes are on the same side as the CCdd chromosomes. The spindle fibres will pull the copies of the homologous pairs apart before the cell divides, so that aabb and CCDD will end up in the same daughter cell and the AABB and CCdd will end up in the other daughter cell. HOWEVER, when the pairs initially lined up, they could have lined up differently, with aabb and CCdd chromosomes on the same side (this is shown in the "OR" cell on the right hand side of the diagram.) If the chromosomes lined up this way instead, the daughter cells would have different genotypes. This is called independent assortment, and creates genetic variation.

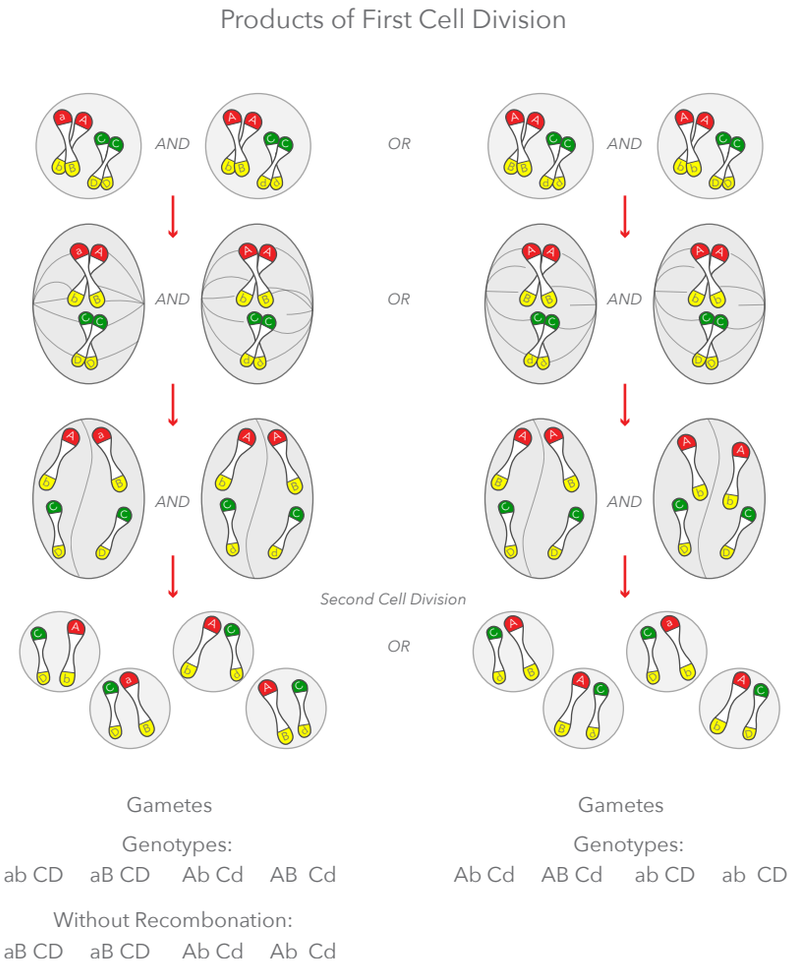
Before the spindle fibres pull the chromosomes apart, crossing over, also known as recombination, can occur. Crossing over happens while the duplicated homologous chromosomes are lined up in the centre of the cell. The two innermost chromosomes can swap bits of DNA - this is the "crossing over". In the diagrams below, an AB chromosome and an ab chromosome undergo crossing over, swapping their alleles for the B gene. This causes one chromosome to become Ab and the other aB. This creates genetic variation, because now there are different combinations of alleles on the chromosomes. This can lead to different combinations of traits in the phenotype. For example, if the A gene is for eye colour, with A encoding brown and a encoding blue, while the B gene encodes hair colour, B for brown and b for blonde, the parent cell has one chromosome with an AB genotype, and the other with ab genotype. Since we inherit a copy of each chromosome from each parent, this means that, without crossing over, the parent could pass on the AB chromosome to its offspring, allowing them to have brown hair and brown eyes OR it could pass on the ab chromosome, giving blonde hair and blue eyes. HOWEVER, after crossing over, two new combinations are created - an Ab chromosome, which could create offspring with brown eyes and blonde hair, and aB, which could create offspring with blue eyes and brown hair.

The spindle fibres pull apart the duplicated pairs of homologous chromosomes and the parent cell divides into two daughter cells. Each of these daughter cells is going to divide again. This creates four daughter cells, each with just one copy of each chromosome. These daughter cells have half the number of chromosomes of the parent cell, and are genetically different. These daughter cells are the sex cells, or gametes.

Meiosis produces gametes, which have half the number of chromosomes as the mother cell and are not genetically identical. Crossing over, A.K.A recombination, is involved in the production of gametes during meiosis and is one of the reasons why the gametes are genetically different to the mother cell.

8. Mitosis is the type of cell division used to produce new body cells. These new body cells have the same number of chromosomes as the original cell and are genetically identical to it.
   Mitosis occurs in body cells, such as the skin and muscle. In contrast, meiosis only occurs in specific types of cells in the reproductive organs, such as the testes and ovaries in mammals, or in the flower for flowering plants.





9. A zygote is a special type of cell formed when two gametes, such as a sperm and an egg, fuse together. The zygote is the very first living cell of the offspring.

10. Each gamete has half the number of chromosomes of a body cell for the species. When the gametes fuse, the zygote produced has the normal number of chromosomes for a body cell.

11. Asexual reproduction only involves a single organism. The organism produces offspring using mitosis. Each daughter cell produced in this way will go onto become its own organism. Each will be genetically identical to the parent (clones of the parents). No genetic variation is produced. Sexual reproduction involves two organisms of the same species. Each organism produces gametes using meiosis. The gametes are sex cells with half the number of chromosomes found in the body cells of the parent. The gametes are not genetically identical to each other or to the parent. During sexual reproduction, two gametes fuse. This is called fertilization and results in a zygote, which is a single cell with a full set of chromosomes, the same number as in the body cells of the parents. Half of its chromosomes have come from its mother; half from its father. The zygote is the first cell of the offspring. Since it is produced from gametes which are not genetically identical to either parent, the offspring is also genetically different to the parents, so sexual reproduction creates genetic variation.

12. In many multicellular organisms like humans, chromosomes come in homologous pairs. In any given homologous pair, one chromosome came from the mother and one from the father.

3. Determining Genotypes and Phenotypes

1. "Homo" means "the same". The word homozygous means the two alleles the organism has for a given gene are the same. For example, if we think about the eye colour gene, there might be two alleles, b for blue eyes and B for brown eyes. An organism homozygous for that gene has two alleles which are the same, e.g. they have two B alleles or two b alleles, making their genotype BB or bb.

2. "Hetero" means "different". The word heterozygous means the two alleles an organism has for a particular gene are different. For example, if we think about the eye colour gene, there might be two alleles, b for blue eyes and B for brown eyes. An organism which is heterozygous for that gene has two different alleles, e.g. they have one B allele and also a b allele, making their genotype Bb.

3. Humans (as well as other animals and most plants) have two copies of every chromosome and therefore, two alleles for each gene (one on each of the chromosomes). The trait encoded by a dominant allele will be visible in the phenotype as long as there is at least one copy present. However, for a recessive allele, the trait encoded by the allele will only be present if there are two copies present - if both of the alleles the organism has are the recessive allele. Recessive alleles can be 'masked' or hidden by dominant alleles.
   If we think about eye colour, with the b allele giving blue eyes and B giving brown eyes, the genotype BB gives brown eyes, but so does the genotype Bb. As long as there is at least one copy of the dominant allele, B, present, the organism will have brown eyes. However, the allele for blue eyes is recessive. To have blue eyes, the person must have two copies of the recessive allele, i.e. be bb. As long as a person has at least one brown eye allele, they will have brown eyes, regardless of what their other allele is for the eye colour gene.

4.
   AA: Homozygous dominant
   Bb: Heterozygous
   bb: Homozygous recessive

5. A true-breeding organism always passes down a particular trait, producing offspring with the same phenotype as itself. For example, if a black coloured rat is "true-breeding" or "pure-breeding" for coat colour, it will only ever produce black coloured offspring. The offspring might differ from their parents in other ways, but for this particular trait, they are the same.

6. A test-cross is a way to investigate the phenotype of an organism. In a test cross, a breeder takes an organism whose genotype they want to investigate and crosses them with a homozygous recessive individual. They then examine the ratio of phenotypes in the offspring to determine the genotype of the individual they are interested in. For example, imagine our organism of interest is a plant with red flowers. We know the red flower gene comes in two forms, dominant allele R for red flowers, and r, a recessive form giving white flowers. Our organism of interest, with red flowers, could have a genotype of Rr or RR. We can determine which it is by conducting a test cross.
   We cross the individual with one homozygous recessive for the same gene (e.g. rr). If the individual

we are interested in has an Rr genotype, we would expect the following:

	R	r
r	Rr	rr
r	Rr	rr

Half the offspring are homozygous recessive. This tells us the genotype of the individual is Rr. If the genotype of the organism we were interested in was in fact RR, we would expect the following:

	R	R
r	Rr	Rr
r	Rr	Rr

None of the offspring have the homozygous recessive phenotype of white flowers, they are all red flowered.

If we cross the organism we are interested in with a white individual (rr) and **any** offspring have white flowers, the organism we are interested in must have a heterozygous genotype (Rr), and is not true breeding. If only red offspring are produced, it is still possible the organism is Rr. Even though there is only a 50% probability of producing red flowered offspring, every offspring is an independent event, similar to flipping a coin. Over time, you expect about 50% heads and about 50% tails, but it wouldn't be too strange to get 10 heads in a row, and it would even be possible (though unlikely) to get 50 in a row. This is the same with offspring. If we only look at 10 offspring and all are red, it is possible that the parent is still Rr and the offspring are all just red by chance. However, the more offspring we look at, the more sure we can be. With a large sample size of 30 or more and all are red, it is probable the organism is RR for genotype.

7. 50% chance of a boy, and 50% chance of a girl. Even if the mother already has four sons, there is still a 50% chance that her next child will also be a son. This is because the biological sex of each child is independent. This is kind of like flipping a coin. Over time, you expect 50% heads and 50% tails. However, just because you got heads last time, does not mean you will definitely get tails on the next flip!

8.

	A	a
A	AA	Aa
a	Aa	aa

Genotype Ratio: 1AA:2Aa:1aa
Phenotype Ratio: 3 golden: 1 white
Percentages: 100% golden: 25% white

	A	A
A	AA	AA
a	Aa	Aa

Genotype Ratio: 2AA:2Aa
Phenotype Ratio: All golden
Percentages: 100% golden

9. Yellow pod color is dominant to green pod colour. A pea plant pure-breeding for yellow pods is homozygous dominant for the yellow pod colour. This means it will always pass on the dominant yellow pod allele to its offspring; this is the only allele for this gene it has to give. Since the yellow pod allele is dominant, any offspring that receive even a single copy will have the trait, so all of the offspring will have yellow pods. In contrast, the green pod allele is recessive, meaning the offspring would need two copies to have green pods.

	Y	Y
y	Yy	Yy
y	Yy	Yy

We'll say that Y is the letter for dominant and y for recessive. The pure-breeding yellow-pod pea plant is homozygous for Y. The green pod pea plant must also be homozygous to produce green pods. All offspring will have yellow pods. However, none of them will be pure-breeding as none of them will be homozygous for Y. This means they will not always pass the yellow pod trait onto their own offspring, like a pure-breeding individual must do. If we crossed one of the offspring with a yy green-pod plant, some offspring would have green-pods, so therefore they are not pure-breeding.

10. If the red flowering rose is RR:

	r	r
R	Rr	Rr
R	Rr	Rr

Genotype ratios: 100% Rr
Phenotype ratios: All red flowering

If the red flowering rose is Rr:

	r	r
R	Rr	Rr
r	rr	rr

Genotype ratios: 1Rr:1rr
Phenotype ratios: 1 red: 1 white

11.

	X	X
X	XX	XX
Y	XY	XY

50% male (XY) 50% female (XX).

12.

a. Individuals 1 and 2 belong to generation I; individuals 9, 10, 11 and 12 belong to generation III.
b. Individuals 7 and 8 are married/together/have children; they are the parents of individual 12
c. Individuals 4 and 5 are sisters.
d. Individual 3 is the father of individual 9.
e. Individual 1 is the grandfather of individuals 10 and 11.
f. Individuals 1, 3, 6, 7, 10, and 11 have albinism.
g. Individuals 7 and 10 are females with albinism.
h. Individuals 8 and 12 are males without albinism.
i. Individual 7 is the daughter of individual 1, who has albinism, and individual 2, who doesn't. Individual 7 probably inherited their albinism from their father, individual 1.
j. Individual 6 is not the son of individuals 1 and 2, but has married/had a child with their daughter. Since individual 6 is not related to individuals 1 and 2, they cannot have inherited their albinism from individual 1 and 2.

4. Variation

1. Something which is variable is something that can come in different forms. For example, hair can come in a range of different colours, lengths, and textures, so we could say that hair colour is variable, hair length is variable, and hair texture is variable, because all three of these traits can have different forms. If everybody has exactly the same for that trait, then the trait is not variable, and we say there is no variation. For example, if a bunch of clones of a plant all make exactly the same colour flower, then we can say that there is no variation for flower colour for that particular group of plants.

2. A population is all of the individual organisms of a particular species in a particular area. For example, if we think about human beings, we could count all of the people who live in a city like Auckland, and this would be the population of humans in Auckland.

3. Genetic variation is the range of genotypes for a particular gene which are found in the population. If there are multiple genotypes for a particular gene found in the population, then the population has genetic variation.
   For example, let's think about flower colour where the dominant allele, R, gives red flowers and the recessive allele, r, gives white flowers. Remember, each individual in the population has two alleles for the gene, so the possible genotypes could be RR, Rr, or rr for this gene. If every individual in the population has an RR genotype for this gene, there is no genetic variation in the population for this gene. However, if some members of the population have RR and others rr, then there is genetic variation in this population.

4. Phenotypic variation refers to the range of phenotypes for a particular trait that are found in the population. If there are multiple different phenotypes for a particular trait in the population, then the population has phenotypic variation.
   For example, let's think about flower colour. A particular species of plant might be able to have red flowers or white flowers. If all of the individuals in a particular population have red flowers, then there is no phenotypic variation for flower colour in the population. However, if some have red flowers and some have white, there is phenotypic variation for flower colour in the population.

5. Genetic variation does not always result in phenotypic variation. For example, imagine a population of ten organisms, five with the genotype AA and five with the genotype Aa, where A gives black fur and a gives white. There is genetic variation in the population, because the individuals do not all have the same genotype. However, all of the individuals have black fur, so there is no phenotypic variation.

6.

	H	H
H	HH	HH
h	Hh	Hh

The parents are HH - tall, and Hh - tall. The offspring may be HH or Hh, and all will be tall.

	H	H
h	Hh	Hh
h	Hh	Hh

The parents have an HH genotype with tall phenotype and hh genotype with shorter height. The offspring will all have Hh genotype and all will be tall.

5. Developing Skills

1. A gene is a section of DNA that codes for a trait. This means the gene gives the instructions for the organism to make that trait. For example, the gene for hair colour tells an organism how to make hair that is coloured. Alleles are different versions of a gene that code for different versions of the trait. For example, a gene for hair colour might have two alleles, one that gives brown hair, and one that gives blonde hair. The sequence of bases in a gene is important because a different order of bases can result in a different trait. If the sequence is only a little different, you get a different allele that produces a different version of the same trait. However, different genes (coding for different traits) have very different base sequences to each other.
   Think about base sequences as being like using a recipe to bake a cake - you have to mix together your dry ingredients with the wet, put it into the cake pan, and then put it into the oven. You need to follow the steps of the recipe in the right order, or you will get a different product. If you put the dry ingredients straight in the oven and add wet ingredients at the end, you certainly won't get a cake! A gene is similar - the order of the bases is important, but in the case of a gene, we are making a protein (not a cake). Different sequence of bases, different protein.
   However, if we only modify the recipe slightly (change a few bases in the sequence), we get a similar product. Alleles are like recipes coding for slightly different cake varieties like a recipe for chocolate cake versus one for banana. Both give you a cake at the end, but the cakes produced are a little bit different because the recipes were a little bit different.
   Completely different genes have very different base sequences. For example, the gene for eye colour has a very different sequence of bases to the gene for hair colour. This is similar to how the recipe to make minestrone soup is quite different to the recipe to make a tasty cake!

2. Different alleles for the same gene have a very similar sequence of bases, with just one or a few differences.

3. A mutation is any change to the sequence of bases. Changing the sequence of bases can change the trait that the gene codes for (see the explanation for the question above), so a mutation can change what a gene codes for, and creates a new allele. This is where all new alleles come from.

4. a. Different genes have different sequences of bases so they give instructions for making different traits.
   b. A gene will be at the same loci (location) on the chromosome. An allele refers to a different base sequence within that gene.

5. DNA is a molecule made up of sugar, phosphate, and four different bases - A, T, G, and C. The DNA molecule has a double-helix shape and encodes the genetic information, which means it is responsible for the different traits of the organism. A chromosome is one long DNA molecule, which can have several genes on it. A gene is a section of DNA coding for a trait. This means the gene provides the instructions for the organism to make that trait. Alleles are different versions of the gene and they code for different versions of the trait. For example, a gene for hair colour might have two alleles, one that gives brown hair, and one that gives blonde hair.

6. The genotype is the combination of alleles an organism has for each gene. The genotype is responsible for the phenotype of the organism. This is because each gene encodes a trait, giving

the instructions for the organism's body to produce the trait. Alleles are different versions of the gene which code for slightly different versions of the trait, such as brown hair versus black hair. If the genotype of the organism is different, this means it has a different combination of alleles. This may mean that it has a different phenotype, since it has a different set of instructions to produce its traits. For example, if B is the allele for brown eyes and b for blue eyes, an organism with genotype BB has brown eyes but an organism with genotype bb has blue eyes. Alleles can be dominant or recessive. The trait that a dominant allele codes for will always show up in the phenotype. The trait that a recessive allele codes for will only show up in the phenotype if the genotype is homozygous. The environment that an organism lives in also influences the phenotype, and some traits in the phenotype such as scars or missing limbs are not encoded in the genes. The genotype is not directly responsible for these traits.

6. Challenging Questions

1. All of the somatic cells (body cells) in your body have the same DNA, or at least very, very similar DNA. This is because you started out as a single-celled zygote, formed by the fusion of a sperm and an egg. This zygote had all of the DNA that would be yours, half of which came from your mother and half from your father. This zygote divided by mitosis to produce daughter cells, which also divided by mitosis, and so on, and this produced all of your other body cells. Since mitosis produces daughter cells that are genetically identical to the parent cell, this means that all of your body cells had the same DNA as the zygote. However, it is likely that some of your body cells have accumulated mutations since then. Mutations frequently occur during DNA replication (when a cell divides) and particularly in response to mutagens such as UV and x-ray radiation. Everyone is exposed to some mutagens during their lifetime, and DNA also sometimes mutates randomly, so it is likely that you have acquired several mutations to the DNA in some of your cells since birth. This means that the DNA in your cells is probably not all exactly identical anymore, just very similar.
   By contrast, your gametes do not have the exact same DNA as your body cells, because they were produced by meiosis. Since meiosis involves recombination and independent assortment, your gametes are genetically different to the rest of your body cells. So, not all of your cells have identical DNA, but most have very, very similar DNA.

2. A mutation is any change to the base sequence of DNA. If a mutation occurs in a gene, it can change the trait that the gene codes for. This is because the sequence of bases in a gene is important in giving the instructions for the organism to make the trait, and if the base sequence changes, so can what the gene codes for. This can change the phenotype. The change to the trait can be minor (e.g. the gene now codes for hazel eyes instead of brown eyes) or major (e.g. the organism will now be an albino and cannot produce any pigment at all). Sometimes, a mutation has no effect on the trait. This means a mutation that occurs in a gene can have any effect on the phenotype ranging from no effect right through to drastically changing the trait. A mutation that does not occur in a gene probably won't have any effect on the phenotype at all, since DNA that is not part of a gene does not code for a trait.

3. Examples of heritable traits: eye colour, ability to roll the tongue, presence of a widow's peak or not, (natural) hair colour, coat colour, hitch-hiker's thumb.
   In plants: flower colour, maximum leaf size, pea pod colour. Examples of non-heritable traits: scars, tattoos, tans, piercings, dyed hair colours, in plants, bonsai form for trees, red colouration on leaves (caused by exposure to more sunlight), leaf size variation in shade versus sunlight.
   A heritable trait can be passed down to the offspring. It is encoded genetically. When you inherit DNA from your parents, you inherit the genes and alleles for this trait. This is a trait you were born

with, or born with the potential to have. You would be able to pass on such traits to your own children. Examples are your eye-colour and natural hair colour, as well as the maximum height you could grow to, whether you are able to roll your tongue, and whether your earlobes are attached or free. For animals, coat colour is a heritable trait. For plants, fruit and flower colour, maximum possible fruit and leaf size, and hairiness of the leaves are all heritable traits.

A non-heritable trait cannot be passed down to the offspring. This is a trait acquired by the organism after its birth and which does not affect the genetic information in the gametes. These traits are a result of the environment interacting with the somatic cells. For example, you were not born with scars, piercings, dyed hair or tattoos - if you have any of these, these are non-heritable traits. They affect only your body, and could not be passed onto your children. This is because they do not change the DNA in your gametes, which are the cells that go on to make the next generation. For animals, amputations and scars are non-heritable. For plants, traits such as stunted growth (as in bonsai trees, which are smaller versions of larger trees), red leaf colouration, and leaf size can all be non-heritable.

4. Genetic variation in a population means that the individuals in the population do not all have the same alleles for each of their genes. This is important because having different alleles, and in different combinations, may mean that these individuals also have different traits in their phenotype, and different combinations of traits. This is important because in new or different environments, these different traits and combinations of traits may be at an advantage and make these individuals more likely to survive and continue the species. For example, if all of the individuals in the population had exactly the same genes and alleles and a disease came along that they were susceptible to, every member of the population would contract it. But, if there is genetic variation in the population, some individuals may be more resistant to the disease and more likely to survive, so that the population won't be wiped out by the disease.

5. Independent assortment occurs during meiosis, when the duplicated pairs of homologous chromosomes line up in the centre of the cell. Independent assortment means that each pair of duplicated homologous chromosomes lines up randomly with respect to the other pairs of chromosomes. Since the different chromosomes in a homologous pair can have different alleles for their genes, this means that different combinations of alleles can end up in the daughter cells. For example, if we have a homologous pair which has the gene A on it and one chromosome has A and one a, and a second homologous pair which has the gene B on it, one with B and one with b, when the chromosomes line up and separate into daughter cells, there are two options for the daughter cells: AB and ab, or Ab and aB. Since there are different options for the daughter cells, genetic variation is created.

6. Crossing over, A.K.A recombination, occurs during meiosis, while the duplicated pairs of homologous chromosomes are lined up in the centre of the cell. The two innermost chromosomes of the four chromosomes in the duplicated homologous pair, can exchange DNA with each other, swapping alleles. This is called crossing over. For example, if we have a pair of homologous chromosomes which have the C and D genes on them, and one chromosome in the pair is CD while the other is cd, during crossing over, they can swap alleles. For example, swapping the D gene allele. This would mean one chromosome is now Cd and the other cD. The two chromosomes involved in crossing over now have a different combination of alleles to the original chromosomes in the homologous pair, so genetic variation has been created.

7. Asexual reproduction is a type of reproduction where a single organism produces clones of itself. That is, offspring which are genetically identical to itself. This type of reproduction involves mitosis.

Since the offspring are genetically identical to their parent, the same combination of alleles for each gene, they will have the same or very similar phenotypes as well. Asexual reproduction produces no genetic variation, and therefore no phenotypic variation.

Sexual reproduction is a type of reproduction which produces offspring that are genetically different to the parents, which means genetic variation is created. This type of reproduction involves meiosis to produce gametes (reproductive or sex cells) that each have half the number of chromosomes as 'normal' body cell of the organism. Two of these gametes then fuse to produce the zygote, which goes onto become the offspring. This means that two different parent organisms can also contribute to the genetic content of the offspring, which also leads to increased genetic variation. The offspring do not have the same combination of alleles for each gene as their parents, which means that they may have a different phenotype as well.

Asexual reproduction tends to use less energy and resources than sexual reproduction. A population which is reproducing asexually could be entirely derived from a single organism and all members genetically identical. This can be an advantage as a single organism can colonise a new habitat rapidly by producing lots of clones of itself quickly and efficiently. A population which mostly reproduces asexually will have less genetic variation. Over time, a few genotypes (those of the most successful organisms, which survive to reproduce asexually) will become more and more common. This can be an advantage if the habitat of the organisms is unchanging. This is because the organisms which survive to reproduce will be those best suited to their environment, and when they reproduce asexually, they will produce offspring that are clones of themselves, sharing their genotype and phenotype, and are also, therefore, best suited to their environment.

However, if the conditions in the environment change, asexual reproduction is disadvantageous. This is because in a new environment, the phenotype, and therefore genotypes, of the parent organisms may no longer be the best suited to the new environment. If all of the offspring are clones, they will also be less suited to the new environment. However, if some of the offspring are genetically different and have different phenotypes, they might be better suited. Having genetic variation in the population therefore means that if the environment changes, it is more likely that at least some of the offspring will be well suited to the new conditions. Genetic variation also means that if an adverse environmental impact, like a drought, or biological impact, like a disease, strikes the population, some individuals may be better able to resist the disease or poor conditions. If all members of the population were genetically identical, they would all suffer equally and the population might be wiped out. However, sexual reproduction can also be wasteful in an unchanging environment because it generates offspring that are genetically different to the parents, even though the parents have a phenotype and genotype well suited to the current environment. This means some offspring will be less suited to the environment than their parents, so energy and resources have been wasted in creating them.

Section Two

1. Question One

Understanding the Question:

1. What do you need to find out, explain, or do for this question?

   a. **Highlight or list the key action words you can see in the question.**
   Discuss, explain.

   b. **Highlight or otherwise mark any bullet points at the bottom of the question which tell you what you should include in your answer.**
   Three bullet points.

   c. **Rephrase the sentences with the action words into questions that you can answer**.
   Discuss how information in DNA is responsible for the different pea pod colours in individual pea plants:

   "How can DNA cause the different pea plants to have different pea pod colours?"
   Explain the relationship between the molecule DNA, chromosomes, genes and alleles:

   1. How are DNA and genes related?
   2. How are genes and alleles related?
   3. How are DNA and alleles related?
   4. How are DNA and chromosomes related?
   5. How are chromosomes and genes/alleles related?

   Explain the relationship between genotype and phenotype.
   "How are genotype and phenotype related?"

   Explain how the base sequence on DNA determines a particular feature (e.g. pod colour).
   "How does the base sequence of DNA determine what trait an individual has?"

2. **What key information is given to you as context or background information?**
   a. Highlight or list the key information you are given by the question/already know.
   Genes determine the colour of a pea pod has, this means that the trait of pod colour is heritable.
   Yellow pea pods are less common; green are more common.
   Yellow pea pods are the result of a dominant allele, e.g. Y.
   Green pea pods are the result of a recessive allele, therefore peas with green pods must be yy.

3. **What key words, concepts, or skills are relevant to this question which they might want you to 'show you know'?**

   a. Brainstorm a list of key words and concepts that you have learned for this achievement standard that would be relevant to this question. These can be words in the question.

   DNA, chromosomes, genes, alleles, dominant, recessive, coding for, trait, genotype, phenotype, genetic code, population, heritable, non-heritable, bases, base sequence, base pairs, genetic variation.

b. From your brainstorm, choose those which you think are most relevant. Remember to define or show that you know what these mean when you write your answer.

Important words/ideas:

DNA, chromosomes, genes, alleles, genotype, phenotype → these are mentioned in the question itself, so we know they are important.

Coding for, genetic code, trait → the question asks how the base sequence of DNA is important for creating a trait. We will probably need to talk about the genetic code and how genes code for traits to answer this.

Dominant, recessive → the question asks about the relationship between genotype, and phenotype. For this, we will need to talk about dominant and recessive alleles.

Less important:

Population → the question says: "Discuss how information in DNA is responsible for the different pea pod colours in individual pea plants". The word population does not appear anywhere in the question. We are only dealing with individual pea plants here.

Heritable, non-heritable → the question explicitly says that pea pod colour is determined by genetics; the question starts off with the background information: "Genes determine many of the features of organisms, such as the colour of pea pods." There is no mention of environment, or how the environment affects phenotype. Therefore, this question is only interested in genetics, and in heritable traits, so we don't need to worry about the difference between heritable and non-heritable traits.

Answering the Question:

List of relevant key words: ***DNA, chromosomes, genes, alleles, genotype, phenotype, Coding for, genetic code, trait, Dominant, recessive***

1. How are DNA and genes related?

   DNA is a molecule found in the cells of living organisms. It carries the instructions to make the organism and its traits. It is a double-stranded helix made up of sugar, phosphate, and four bases (A, T, G, C). A gene is a sequence of bases on a DNA molecule which codes for a particular trait. This means that the gene gives the cell the instructions to make that particular trait. For example, the gene for pea pod colour allows the pea cells to make the pea pod colours, such as yellow or green. We can represent genes with letters, e.g. Y or y for the gene for pod colour.

2. How are genes and alleles related?

   Alleles are different versions of a gene. For example, the gene for pea pod colour has two alleles, one for yellow pods and one for green pods. We can represent different alleles of the same gene by using upper or lower case letters, e.g. Y for the allele for yellow, y for green allele.

3. How are DNA and alleles related?

   The different alleles of a gene have slightly different base sequences. For example, part of the yellow pod allele could be "ATGCA" and for the green pod allele could be "ATGGA". The sequence is very similar but a little different.

4. How are DNA and chromosomes related?

   A chromosome is one very long DNA molecule.

5. How are chromosomes and genes/alleles related?

   Each chromosome can carry many genes. Chromosomes come in pairs, one inherited from the mother and one from the father. These are called a homologous pair. The chromosomes in a homologous pair have the same genes (e.g. both have a gene for pea pod colour), but can have different alleles, (e.g. one has the allele for yellow pods and the other for green pods).

6. How are genotype and phenotype related?

   The genotype of an organism is its combination of alleles, e.g. YY or Yy or yy for pod colour. Individuals have two alleles for each gene because they have homologous chromosomes. The phenotype of an organism is its physical traits, such as yellow pod colour or green pod colour. Since the genes of an organism give the instructions for making the different traits, the genotype is responsible for phenotype. An organism with genotype YY only has the instructions for making yellow pods, so its phenotype will be yellow pods. A dominant allele, like Y for yellow, is one where the trait always shows up in the phenotype if the allele is present. A recessive allele, like y for green, only has the trait show up in the phenotype if it is the only type of allele present, e.g. yy. If the genotype is Yy, the pea will have a yellow pod phenotype because Y is the dominant allele so always shows up in phenotype. If the genotype is yy, the pea will have green pods; it cannot make yellow pods because it doesn't have the isntructions for making yellow pods.

7. How does the base sequence of DNA determine what trait an individual has?

   Genes code for traits; give the instructions to make a trait. Different alleles of a gene give different phenotypes, like Y giving yellow pods and y giving green pods. Different alleles are different because there base sequence is slightly different to each other, which means that they have slightly different instructions for the cell, giving rise to different traits/phenotype.

8. How does DNA cause different pea plants to have different pea pod colours?

   This has already been answered by answering all of the questions above!

If we put it all together:

DNA is a molecule found in the cells of living organisms. It carries the instructions to make the organism and its traits. It is a double-stranded helix made of sugar, phosphate, and four bases (A, T, G, C).

A gene is a sequence of bases on a DNA molecule which codes for a particular trait. This means the gene gives the cell the instructions to make a particular trait. For example, the gene for pea pod colour allows the pea cells to make pea pod colours like yellow or green. We represent genes with letters, e.g. Y or y for the gene for pod colour.

Alleles are different versions of a gene. For example, the gene for pea pod colour has two alleles, one for yellow pods and one for green. We show different alleles of the same gene with upper or lower case letters, e.g. Y for yellow alle, y for green allele. The different alleles have slightly different base sequences. For example, yellow pod allele could be "ATGCA" and green pod allele "ATGGA". The sequence is very similar but a little different.

A chromosome is one very long DNA molecule. Each chromosome carries many genes. Chromosomes come in pairs, one inherited from the mother and one from the father. These are called a homologous pair. The chromosomes in a homologous pair have the same genes (e.g. both have a gene for pea pod colour), but can have different alleles, (e.g. one has the allele for yellow and the other for green pods).

The genotype of an organism is its combination of alleles, e.g. YY or Yy or yy. Individuals have two alleles for each gene because they have homologous chromosomes. The phenotype of an organism is its physical traits, such as yellow pods. Since the genes of an organism give the instructions for making the different traits, the genotype is responsible for phenotype. An organism with genotype YY only has the instructions for making yellow pods, so its phenotype will be yellow pods. If the genotype is yy, the pea will have green pods; it cannot make yellow pods as it doesn't have instructions for making yellow pods. If the genotype is Yy, the pea will have yellow pods because Y is dominant. A dominant allele is one where the trait always shows up in the phenotype if the allele is present.

The base sequence of DNA determines what traits and individual has because genes, which are sequences of DNA, give the instructions for making the traits. Different alleles of a gene give different phenotypes and different alleles are different because their base sequence is slightly different to each other, which means that they have slightly different instructions for the cell, giving rise to different traits/ phenotype. This is how DNA causes different pea plants to have different coloured pods.

2. Question Two

Understanding the Question:

1. **What do you need to find out, explain, or do for this question?**

   a. Highlight or list the key action words you can see in the question

   State, use, work out, explain, draw.

   b. Highlight or otherwise mark any bullet points at the bottom of the question which tell you what you should include in your answer

   Question 2 has one bullet point, question 3 has two.

c. Rephrase the sentences with the action words into questions that you can answer. State the genotype of individual 2 in the pedigree chart → "What is the genotype of individual 2 in the pedigree chart?" Use the family tree above to work out the genotype of individual 4 → "What is the genotype of individual 4?" Explain how you worked this out → "How can you be sure what the genotype of individual 4 is; how do you know?" Use the family tree above to explain why individuals 5 and 6 must have the genotype Bb. → "Why do individuals 5 and 6 have to have the genotype Bb based on the pedigree chart?"

Draw Punnett squares.

Explain why the genotypes of individuals 5 and 6 cannot be BB or bb → "Why can't the genotypes of individuals 5 and 6 be BB or bb?"

2. What key information is given to you as context or background information?

a. Highlight or list the key information you are given by the question/already know

Blue eyes is recessive.

Brown eyes is dominant.

Female with blue eyes is shown by a grey circle.

Male with blue eyes is shown by a grey square.

Female with brown eyes is a white circle.

Male with brown eyes is a white square.

Brown is B and blue is b.

3. What key words, concepts, or skills are relevant to this question which they might want you to 'show you know'?

a. Brainstorm a list of key words and concepts that you have learned for this achievement standard that would be relevant to this question.

DNA, bases, base sequence, genes, alleles, phenotype, genotype, dominant, recessive, trait, chromosomes, inherit.

b. From your brainstorm, choose those which you think are most relevant. Remember to define or show that you know what these mean when you write your answer.

Important:

Dominant, recessive, gene, genotype → these are all mentioned in the question so must be important.

Alleles, phenotype → these are all closely related to the concepts of dominance, recessiveness, genes and genotype.

Inherit → we are dealing with a family tree and inheritance of traits.

Chromosomes → genes and alleles are carried on chromosomes, and chromosomes are what are passed down from parents to offspring during meiosis/gamete production and fertilisation.

Less important:

DNA, bases, base sequence → this question is more interested in the genotypes and inheritance of genes than what genes are made of!

Answering the Question:

List of relevant key words: *Dominant, recessive, gene, genotype, alleles, phenotype, inherit, chromosomes*

1. What is the genotype of individual 2 in the pedigree chart?

bb

Explanation: Individual 2 has a red circle. This means they are a female with blue eyes. We know that blue eyes is represented by b. We also know that blue eyes is coded for by a recessive allele. This means that a blue-eyed individual must be bb. Since brown eyes, B, is the dominant allele, and the trait coded for by dominant alleles always shows up in the phenotype if they are present, if the individual had even one B allele they would have brown eyes, not blue eyes. So they must be homozygous for b, bb.

2. What is the genotype of individual 4?

a. How can you be sure what the genotype of individual 4 is; how do you know?

Individual 4 is a male with brown eyes (we can tell because they are represented by a white square). Since the allele for brown eyes, B, is dominant over the allele for blue eyes, b, we know that individual 4 must have at least one B allele in their genotype.

Genes provide the instructions for making different traits (code for different traits), and different alleles (different versions of a gene) give instructions for making the different versions of the trait, e.g. brown eyes or blue eyes. Without a B allele, individual 4 would not have the instructions for making brown eyes so could not make brown eyes. However, B is a dominant allele, which means that the trait will show up in the phenotype even if only one copy is present. This means individual four could be homozygous dominant (BB) or heterozygous dominant (Bb) and still have brown eyes.

However, we know they have the Bb genotype because of their parents, individuals 1 and 2. Individual 2 is a blue-eyed female. Since blue eyes are recessive, she must be bb. This is because a recessive allele will only show up in the phenotype if the individual is homozygous recessive, so they have two copies of the recessive allele. Also, we inherit one copy of each allele from each parent. Since their mother is bb, individual 4 could only have inherited a b allele from them; she had no B alleles to give. However, individual four must have at least one B allele to have brown eyes. They must therefore have got their B allele from their father, so individual four is Bb.

3. Why do individuals 5 and 6 have to have the genotype Bb based on the pedigree chart?

Why can't the genotypes of individuals 5 and 6 be BB or bb?

The offspring of individuals 5 and 6 (individual 7) has blue eyes. We can tell because they are represented by a red square. However, both of their parents have brown eyes (we can tell because they are represented by a white square and a white circle). For individual 7 to have blue eyes, they must have two copies of the blue eye allele, b, so their genotype must be bb. This is because blue is a recessive allele, and its trait will only show up in the phenotype if the individual is homozygous recessive. If even one dominant brown allele was present, individual 7 would have brown eyes.

To have two copies of the recessive blue allele, individual 7 must have inherited one copy from

each parent. This is because we inherit one allele from our mother and one from our father for each gene. This means that both individual 5 and individual 6 must have at least one blue allele to pass onto their child. However, since both are themselves brown-eyed, they must each have at least one B brown eye allele as well. So both must be Bb heterozygous dominant.

Draw Punnett Squares

There are several possible Punnett squares we can draw showing what happens when we cross individual 5 and 6 to get their offspring, individual 7. The point of the Punnett square is to prove that our reasoning above is correct. We can draw one showing the case if both individual 5 and 6 were Bb (like the question says they are), one showing what would happen if one were Bb and the other BB, and one showing BB x BB. Here they are:

	B	B
B	BB	BB
B	BB	BB

All offspring have brown eyes. There is no way for an offspring to have blue eyes as there are no blue eye alleles to inherit. This means that the parents cannot both be BB.

	B	B
B	BB	BB
b	Bb	Bb

All offspring have brown eyes. There is a blue eye allele to inherit, but offspring can only ever have one copy of it which means the blue eyes won't show up in the phenotype. This means that the parents cannot be BB and Bb.

	B	b
B	BB	Bb
b	Bb	bb

One quarter of the offspring would be expected to have blue eyes. Blue-eyed offspring are possible with this combination only. Therefore, both parents must have Bb genotypes.

If we put it all together:

1. **State the genotype of individual 2 in the pedigree chart.**
   bb
2. **Use the family tree above to work out the genotype of individual 4.**
   a. Explain how you worked this out.

Individual 4 is a male with brown eyes. Since the allele for brown eyes, B, is dominant over the allele for blue eyes, b, we know individual 4 must have at least one B allele in their genotype. Genes provide the instructions for making different traits (code for different traits, e.g. eye colour), and different alleles (different versions of a gene) give instructions for making different versions of the trait, e.g. brown eyes or blue eyes. Without a B allele, individual 4 would not have the instructions for making brown eyes so could not make brown eyes. However, B is a dominant allele, which means that the trait will show up in the phenotype even if only one copy is present. This means individual four could be homozygous dominant (BB) or heterozygous dominant (Bb) and still have brown eyes.

However, we know they have the Bb genotype because of their parents, individuals 1 and 2. Individual 2 is a blue-eyed female. Since blue eyes are recessive, she must be bb. This is because a recessive allele will only show up in the phenotype if the individual is homozygous recessive, and has two copies of the recessive allele. Also, we inherit one copy of each allele from each parent. Since their mother is bb, individual 4 could only have inherited a b allele from them; she had no B alleles to give. However, individual four must have at least one B allele to have brown eyes. They must therefore have got their B allele from their father, so individual four is Bb.

3. **Use the family tree above to explain why individuals 5 and 6 must have the genotype Bb. In your answer, you should:**

a. Draw Punnett squares

b. Explain why the genotypes of individuals 5 and 6 cannot be BB or bb

The offspring of individuals 5 and 6 (individual 7) has blue eyes. However, both of their parents have brown eyes. For individual 7 to have blue eyes, they must have two copies of the blue eye allele, b, so their genotype must be bb. This is because blue is a recessive allele, and its trait will only show up in the phenotype if the individual is homozygous recessive. If even one dominant brown allele was present, individual 7 would have brown eyes.

To have two copies of the recessive blue allele, individual 7 must have inherited one copy from each parent. This is because we inherit one allele from our mother and one from our father for each gene. This means that both individual 5 and individual 6 must have at least one blue allele to pass onto their child. However, since both are themselves brown-eyed, they must each have at least one B brown eye allele as well. So both must be Bb heterozygous dominant.

	B	B
B	BB	BB
B	BB	BB

All offspring have brown eyes. There is no way for an offspring to have blue eyes as there are no blue eye alleles to inherit. This means that the parents cannot both be BB.

	B	B
B	BB	BB
b	Bb	Bb

All offspring have brown eyes. There is a blue eye allele to inherit, but offspring can only ever have one copy of it which means the blue eyes won't show up in the phenotype. This means that the parents cannot be BB and Bb.

	B	b
B	BB	Bb
b	Bb	bb

One quarter of the offspring would have blue eyes. Blue-eyed offspring are possible with this combination only. Therefore, both parents must have Bb genotypes.

3. Question Three

Understanding the Question:

1. What do you need to find out, explain, or do for this question?

a. Highlight or list the key action words you can see in the question.

Outline, discuss, compare, explain.

b. Highlight or otherwise mark any bullet points at the bottom of the question which tell you what you should include in your answer.

There are two bullet points for question 2.

c. Rephrase the sentences with the action words into questions that you can answer.

Outline the key differences between sexual and asexual reproduction → "What are the key differences between sexual and asexual reproduction?"

Discuss the advantages and disadvantages of sexual and asexual reproduction for Daphnia. → "What are the advantages of sexual reproduction for Daphnia?"

"What are the disadvantages of sexual reproduction for Daphnia?"

"What are the advantages of asexual reproduction for Daphnia?"

"What are the disadvantages of asexual reproduction for Daphnia?"

Compare the amount of genetic variation each type of reproduction produces → "How much genetic variation does sexual reproduction produce versus asexual reproduction?"

Explain how this might affect the success of the population over time if there are changes in the environment, or if there are no changes in the environment → "How could the amount of genetic variation produced by sexual reproduction affect the success of a population in an unchanging environment?"

"How could the amount of genetic variation produced by sexual reproduction affect the success of a population in a changing environment?"

"How could the amount of genetic variation produced by asexual reproduction affect the success of a population in an unchanging environment?"

"How could the amount of genetic variation produced by asexual reproduction affect the success of a population in a changing environment?"

2. What key information is given to you as context or background information?

a. Highlight or list the key information you are given by the question/already know

Daphnia are a small species of crustacean.
They live in freshwater ponds and swamps.
They reproduce sexually and asexually.
They reproduce asexually during the growth season, when resources are plentiful.
They reproduce sexually at the end of the growth season, when resources are less plentiful.

3. **What key words, concepts, or skills are relevant to this question which they might want you to 'show you know'?**
   a. **Brainstorm a list of key words and concepts that you have learned for this achievement standard that would be relevant to this question.**
   Sexual reproduction, asexual reproduction, meiosis, mitosis, cell division, genetic variation, phenotype, genotype, population, gene pool, heritable, gene, DNA, alleles

   b. **From your brainstorm, choose those which you think are most relevant. Remember to define or show that you know what these mean when you write your answer.**
   Important:
   Sexual reproduction, asexual reproduction, genetic variation, population → These are all mentioned in the question, so we know they are important.
   Meiosis, mitosis, cell division → These relate to the differences between asexual and sexual reproduction.
   Phenotype, genotype, gene pool → These will be important when explaining the importance of genetic variation on the population and the population's success.

   Less Important:
   Gene, DNA, allele →This question is more interested in cell division and genetic variation in the population than the individual DNA, genes and alleles involved.
   Heritable → This question is concerned with heritable variation, rather than comparing and contrasting heritable and non-heritable, so this is not as relevant.

Answering the Question:

1. **What are the key differences between sexual and asexual reproduction?**
   Asexual reproduction is where an organism produces offspring that are genetically identical to itself, i.e. they have an identical genotype. This means that the offspring are clones of the parent and will also have a very similar phenotype. Only one organism is involved in asexual reproduction; the genetic information of the offspring is inherited from a single parent. The type of cell division involved is mitosis. In contrast, sexual reproduction involves two organisms. Each organism uses meiosis to produce gametes with half the amount of genetic information found in the parent. The gametes then fuse in a process called fertilisation, which produces a zygote that goes onto become the offspring. This means in sexual reproduction the offspring inherits half of its genetic information from each parent, instead of getting it all from one parent. The offspring also has a genotype different to both parents so its phenotype could also be more different. Asexual reproduction is faster than sexual reproduction and uses less resources and energy to produce offspring.

2. **How much genetic variation does sexual reproduction produce versus asexual reproduction?**
   Asexual reproduction produces no genetic variation because it involves mitosis which produces genetically identical daughter cells, and so the offspring are clones of the parent and have an identical genotype.

Sexual variation produces genetic variation because it involves meiosis, which produces gametes with half as much genetic information at the parent cell and a different combination of alleles. The offspring also contains genetic information from two parent organisms because it is the product of gametes from two different organisms fusing. This means the offspring has a different genotype.

3. **What are the advantages of sexual reproduction for Daphnia?**
   a. **How could the amount of genetic variation produced by sexual reproduction affect the success of a population in a changing environment?**
   Sexual reproduction produces genetic variation. This means the offspring are not all identical and do not have the same genotype as their parents or each other. Since the genotype is responsible for the phenotype, this means the offspring may also have different phenotypes. In any particular environment, some phenotypes will be better suited than the others. Some phenotypes will also be able to better deal with challenges such as diseases or drought e.g. some may be able to better cope. Some of the offspring may also be better suited to the environment. Producing genetic variation and new phenotypes means the population might produce novel phenotypes that are better. It also means that if a disease strikes the population, at least some members of the population will survive to keep the species alive. If all of the individuals were identical, they would all be equally affected by a disease and might all die out. Daphnia use sexual reproduction at the end of the growth season when the conditions are changing and resources are becoming more limited. This produces offspring with different phenotypes that might be better able to cope with the new environment and the changes occurring. Even though sexual reproduction takes more time and energy, it is an advantage in this case as it helps to ensure survival of the population into the future.

4. **What are the disadvantages of sexual reproduction for Daphnia?**
   a. **How could the amount of genetic variation produced by sexual reproduction affect the success of a population in an unchanging environment?**
   In order to reach reproductive age, an organism must have survived long enough in its environment to reproduce. This means it is likely to have a phenotype which is a good fit for its environment. Since genotype determines phenotype, such an organism has a good genotype for its environment. Sexual reproduction produces genetic variation, so the offspring do not have the same genotype or phenotype as the parents. Some, or many, of the new genotypes and phenotypes produced may be less well-suited to the environment, and the offspring less likely to survive and reproduce themselves. Sexual reproduction is therefore 'wasteful' since a lot of time and resources go into producing offspring that may be worse than the parents.

5. **What are the advantages of asexual reproduction for Daphnia?**
   a. **How could the amount of genetic variation produced by asexual reproduction affect the success of a population in an unchanging environment?**
   Asexual reproduction produces offspring identical to the parent organism. In an unchanging environment, this is an advantage because the parent organisms must have had phenotypes (and therefore genotypes) well-suited to the environment to survive to reproductive age. By producing offspring identical to themselves, they ensure this good genotype and phenotype is passed on and their offspring will also be well-suited to the environment. Daphnia use asexual reproduction during the growth season when the conditions are stable and resources are plentiful. This produces offspring with the same phenotype as the parents, which means they will be well-suited to thrive in these same conditions.

Asexual reproduction is also quick and does not need as many resources, so lots of offspring with good phenotypes can be produced quickly to take advantage of the plentiful resources and build population numbers.

6. **What are the disadvantages of asexual reproduction for Daphnia?**
   a. **How could the amount of genetic variation produced by asexual reproduction affect the success of a population in a changing environment?**
   If the environment changes, the phenotype of the parents will not necessarily be best suited to the new environment. This means the genotype of the parents might not be the best either. In this case, asexual reproduction is disadvantageous because it produces offspring with an identical genotype and phenotype to the parents.

If we put it all together:

1. **Outline the key differences between sexual and asexual reproduction**
   Asexual reproduction is where an organism produces offspring genetically identical to itself with identical genotype. This means offspring are clones of the parent and will have very similar phenotype. Only one organism is involved in asexual reproduction; the genetic information of the offspring is inherited from a single parent. The type of cell division involved is mitosis. In contrast, sexual reproduction involves two organisms. Each organism uses meiosis to produce gametes with half the amount of genetic information found in the parent. The gametes then fuse in a process called fertilisation, which produces a zygote that goes onto become the offspring. This means in sexual reproduction the offspring inherits half of its genetic information from each parent. The offspring also has a genotype different to both parents so its phenotype could also be different. Asexual reproduction is faster than sexual reproduction and uses less resources/energy to produce offspring.

2. **Discuss the advantages and disadvantages of sexual and asexual reproduction for Daphnia. In your answer you should:**
   a. **Compare the amount of genetic variation each type of reproduction produces.**
   b. **Explain how this might affect the success of the population over time if there are changes in the environment, or if there are no changes in the environment.**

   Asexual reproduction produces no genetic variation because it involves mitosis, which produces genetically identical daughter cells. The offspring are clones of the parent with identical genotypes. In an unchanging environment, this is an advantage because the parent organisms must have had phenotypes (and therefore genotypes) well-suited to the environment to survive to reproductive age. By producing offspring identical to themselves, they ensure this good genotype and phenotype is passed on and their offspring will also be well-suited to the environment. However, if the environment changes, the phenotype of the parents might not be best suited to the new environment. In this case, asexual reproduction is disadvantageous because offspring have identical genotype and phenotype to the parents. Daphnia use asexual reproduction during the growth season when the conditions are stable and resources are plentiful. This produces offspring with the same phenotype as the parents, therefore well-suited to thrive in these same conditions. Asexual reproduction is quick and does not need as many resources, so lots of offspring with good phenotypes can be produced quickly to take advantage of the plentiful resources and build population numbers.

Sexual variation produces genetic variation because it involves meiosis, which produces gametes with half as much genetic information at the parent cell and a different combination of alleles. The offspring contains genetic information from two parent organisms, as it is the product of gametes from two different organisms fusing (fertilisation). This means the offspring has a different genotype to both parents. Since genotype is responsible for the phenotype of the organism, the offspring may also have different phenotypes. In any particular environment, some phenotypes will be better suited than others. Some phenotypes will also be able to better deal with challenges such as diseases or drought e.g. some may be able to better cope. Producing genetic variation and new phenotypes means the population might produce some that are better. It also means if a disease strikes the population, at least some members of the population will survive to keep the species alive. If all of the individuals were identical, they would all be equally affected by a disease and might all die out.

However, in an unchanging environment, sexual reproduction is a disadvantage. The parents are likely to have a phenotype which is a good fit for its environment since they survived to reproductive age. With sexual reproduction the offspring do not have the same genotype or phenotype as the parents. Some, or many, of the new genotypes and phenotypes may be less well-suited to the environment and less likely to survive and reproduce themselves. Sexual reproduction is therefore 'wasteful' since a lot of time and resources go into producing offspring that may be worse than the parents. Daphnia use sexual reproduction at the end of the growth season when the conditions are changing and resources are becoming more limited. The offspring with a different phenotype might be better able to cope with the new environment and the changes occurring. Even though sexual reproduction takes more time and energy, it is an advantage in this case as it helps to ensure survival of the population into the future.

Section Three - Practice Exam

1. Question One

a. DNA is a molecule consisting of sugar, phosphate, and the bases A, T, G and C, and it is found in the cells of living organisms. DNA provides the instructions for producing the phenotype (physical traits) of the organism, such as flower colour. A gene is a section of DNA coding for a trait, i.e. it gives these instructions for a particular trait. For example, in hydrangea, there is a gene responsible for flower colour, that tells the plant how to make coloured (or non-coloured) flowers. Alleles are different versions of a gene which code for slightly different versions of the trait. For example, the flower colour gene in hydrangea has one allele that codes for coloured flowers and one that codes for white flowers. A mutation is any change to the sequence of bases in DNA. If the mutation is in a gene, it can change what the gene codes for. This can create new alleles. For example, a mutation in the gene for flower colour can change what the gene codes for from coloured flowers to white flowers. This is because the sequence of bases determines what trait the gene codes for, and if the sequence of base changes, the trait coded for may change too, which can change the phenotype. Since DNA is the molecule that is passed from parents to offspring, if the mutation is in a gamete, which is a reproductive cell used to form the offspring, then the offspring (seedlings) will inherit the mutation and might also have white flowers, so that their phenotypes are also affected.

b. Inheritable means that the trait, and the DNA coding for it, can be passed onto the offspring so that they also have this DNA (allele) and trait. A trait is only inheritable if it coded for by DNA, which is the genetic molecule passed onto the next generation. DNA is only inheritable if it is found in a gamete (sex cell) which is a reproductive cell used to form the next generation. New organisms (offspring) are formed from the gametes, so any DNA in the gametes becomes their own. Non-inheritable means that trait/DNA is not passed onto the offspring because it is not found in a gamete. The DNA found in most cells of an organism's body is not passed onto the offspring. That means if a mutation occurs in the DNA in these cells, it is not passed on (i.e. non-heritable) and will only affect the parent organism, and not any offspring.

   The environment can also affect phenotype. For example, hydrangea plants that produce coloured flowers can make flowers that are different colours depending on the pH of the soil, red in basic soil, and blue in acidic soil. This change to the phenotype of the plants is non-heritable because it is caused by the environment and not by a change to the DNA. We can tell this because the same plant (with the same DNA) produces red flowers in one type of soil and blue flowers in another type of soil. We can tell that the change in colour is not due to a mutation in the DNA because it goes back to making red flowers when the soil is changed again.

   However, the white-flowering plant produces the same colour flowers no matter what soil type it is in. White flowers must therefore be genetic, coded for on the DNA. White flower colour is therefore heritable. Since the white flowering plants never produce coloured flowers, but the coloured-flowering plants also never produce white flowers (only red or blue), the ability to make coloured flowers instead of white flowers must also be genetic and heritable, even though the specific colour of flower is determined by the environment. White vs. coloured is heritable, but red and blue flowers is not.

2. Question Two

a. A dominant allele always shows up in the phenotype (is expressed) if it is present in the genotype. White-flower colour is caused by a recessive allele, r. Since this is recessive, two copies are needed for the trait to show in the phenotype, so white-flowering plants must have a rr genotype (homozygous recessive). This is because if even a single dominant R allele was present, it would show up in the phenotype, so the offspring would be red-flowered. The seedlings receive one copy of each gene from their parents, so rr seedlings must have got a recessive r allele from each parent, so both parents must have at least one r. However, both parents are also red-flowered, so both parents must also have at least one dominant R allele to be red-flowered. Both parents must therefore be Rr heterozygous genotype, with the r allele hidden. Crossing two Rr heterozygous parents like this means that some seedlings will inherit two copies of the r allele and express the hidden allele.

	R	r
R	RR	Rr
r	Rr	rr

b. Pure-breeding means that all of the offspring will have that trait and inherit the allele causing that trait from the parent. This means that the parent must be homozygous for the allele causing the trait. A pure-breeding coloured-flowering hydrangea would be have an RR genotype, since the dominant R allele causes coloured flowers. A coloured-flowering hydrangea could be either Rr or RR. Since the R allele is dominant, only one copy is needed for the trait to be expressed in the phenotype.

To determine if the coloured-flowering hydrangea are Rr or RR and therefore pure-breeding, the breeder could conduct a test-cross where they cross each coloured-flowering parent with a white-flowering plant. If the coloured-flowering parent is Rr, when crossed with a white rr parent, half of the offspring will be white. This tells us it is not pure-breeding, because not all of the offspring inherited the coloured flower trait. However, if the coloured flower parent is RR, when crossed with a white rr plant, all offspring will be coloured flower and we can tell it is pure-breeding.

To test this, we need to generate a large sample size of offspring because even though 50% of the offspring should be white for an Rr x rr cross, it is still possible to get 100% coloured offspring if the sample size is small, (e.g. less than 30). This is because each offspring is an independent event. This is like flipping a coin, it's possible to get 10 heads in a row even though the probability is 50:50, but it is unlikely to get 50 heads in a row and no tails. So a large sample is needed, and if any of the offspring are white, this shows that the coloured parent had a recessive r allele and was no pure-breeding, but if all of the many offspring are coloured flowering, then the coloured-flowering parent is probably RR.

c.

	R	R
r	Rr	Rr
r	Rr	Rr

	R	r
r	Rr	rr
r	Rr	rr

i. Genotype of individual 2: rr

ii. Genotype of individual 1: Rr. They must be heterozygous because they have some offspring that are white-flowered, and therefore have the rr genotype. These offspring must have inherited a

recessive r allele from both parents since we get one copy of each gene from each parent. Therefore, individual 1 must also have a recessive r allele. However, individual 1 must also have at least one dominant R allele to have coloured-flowers, otherwise they too would have white flowers, so must be Rr

iii. Individuals 7 and 8 both have coloured flowers, but have produced a white-flowered offspring. Since a white-flowered offspring must be rr, this offspring must have inherited an r allele from each parent to get two copies, so both parents must be heterozygous, Rr. Since the parents are not-white, the white allele must be hidden, which means it is recessive. If white flowers was instead dominant, individual 12 would have to have this dominant allele to be white, and must have gotten it from a parent. However, this would mean that at least one parent would also have to be white to have the dominant allele to pass on. This is not the case, so the allele for white flowers must be recessive. Finally, individuals 10 and 11 can only have received a single coloured allele because one of their parents is white-flowering, and therefore only has white allele to pass on. They must have inherited this single coloured-allele from their parent, individual 6. However, both individuals 10 and 11 are coloured, so one coloured allele has been enough to give them this phenotype, so the coloured allele must be dominant.

3. Question Three

a. The genotype of an organism is the collection of alleles it has for each of its genes.

b. The phenotype of an organism is its physical characteristics; the collection of traits it has.

c. Sexual reproduction is a way of producing new organisms, or offspring. In sexual reproduction, the offspring is formed from the combination of two cells (gametes, or sex cells) which each contribute half of the DNA to the offspring. This allows for a mixing of DNA from two different individuals (parents) which creates genetic variation. The process where two gametes combine to form a zygote, which will go onto become the offspring, is called fertilisation.

Gametes are formed using the process of meiosis, a type of cell division. Some processes in meiosis also contribute to the genetic variation in the eventual offspring by ensuring that each gamete is genetically different to the cells of the parent. Two of these processes are independent assortment and crossing over (also known as recombination). [NOTE: the question only requires that you discuss one process; several are described here].

Independent assortment occurs during meiosis after the homologous pairs of chromosomes have been duplicated and are lined up in the middle of the cell. During cell division, half of the chromosomes will end up in one cell, and half in the other, with one duplicated chromosome from each homologous pair going into each daughter cell during the first division. However, which of the homologous pair goes into which daughter cell is random, and is independently random for each of the other chromosomes.
Since the different chromosomes in the homologous pair can have different alleles for the same gene, this means different combinations of alleles are possible. For example, two homologous chromosome pairs, one with A and a, and the second pair with B and b. We could end up with the chromosome

carrying A and the one carrying B in the same cell, OR the chromosome carrying A could end up in the same cell as the one carrying b.

Crossing over also occurs during meiosis when the duplicated chromosomes are lined up in the middle of the cell. The two innermost chromosomes in the homologous pairs can exchange DNA, meaning they can swap their alleles. This can create new combinations of alleles on the same chromosome, which are different to the combinations that the parent cell had. For example, if we have a chromosome with A and B alleles on it and its homologous partner has a and b, crossing over means we can end up with a chromosome that instead has A and b, which is a new combination of alleles and could be a new combination of traits.

Finally, each parent organism makes a lot of different gametes, however the gamete that eventually fuses with the gamete from the other parent is random. This random fertilisation also leads to genetic variation because each offspring is just one of several possible gamete combinations, and each new offspring will be made from new combinations of gametes.

Sexual reproduction creates genetic variation in a population by allowing offspring to be produced that have different genotypes to the parents. This can be advantageous if the environment changes or a new disease comes, because it is more likely that some of the population will be well suited to the new conditions or resistant, and therefore able to survive, if all of the individuals in the population are not identical. This means the population is more likely to survive changes in the environment. However, sexual reproduction is also wasteful because it produces offspring that are different to the parents. However, to reach reproductive age, the parents must have a phenotype, and genotype, well-suited to the current environment. This means that they produce some offspring that are not as well-suited to the environment as they are, which is wasteful.