Genetic diversity and adaptation

Specification reference

- *3.4.3*
- *3.4.4*

Learning objectives

After completing this worksheet you should be able to:

- understand how meiosis produces haploid gametes
- know how the process of meiosis and subsequent fertilisation gives rise to genetic variation
- understand how mutation can create new alleles or leave them unchanged
- understand how natural selection works to make species better suited to their environments.

Introduction

In this worksheet you will learn about how variation arises within species, and how natural selection works to make species more suited to their environments. The exam questions on this topic will mostly be set in context. You will be expected to apply your knowledge and understanding to a new situation rather than simply recalling facts. The questions at the end of this sheet are there to give you practice at this.

Background

Genetic variation within species is a good thing. Just think what would happen if every student in a school or college became ill from the same infection at once! The fact that this does not happen is partly due to genetic variation. In a wider context, a genetically varied species is more likely to survive changing conditions than a species where are the individuals are genetically identical. In animals and plants, sexual reproduction helps to ensure genetic variation. Organisms like bacteria that reproduce asexually rely on mutations and, sometimes, the ability to transfer plasmids, for their genetic variation.

Genetic variation and inheritance

You will remember that alleles are different versions of the same gene. For example, we all have genes that code for our hair colour, but there are different alleles for different hair colours. As each chromosome in our cells exists as a homologous pair, each of us can carry two alleles. If they are the same we are homozygous, if they are different we are heterozygous for that allele.

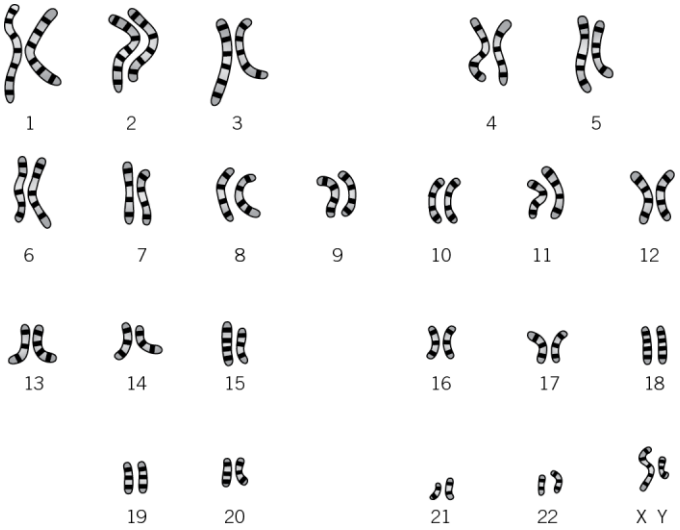

Figure 1 *The 46 human chromosomes in pairs 1 – 22 and the sex chromosome pair (in this case X and Y, male). This complete set of paired chromosomes is called diploid or 2n.*

Meiosis

Animals and plants that reproduce sexually produce special sex cells called gametes. In humans these are the egg or ovum (female) and the sperm or spermatozoa (male). The gametes are special because they are haploid, or n, meaning they only contain a half set of chromosomes. Meiosis is the type of cell division used to produce gametes.

Meiosis has similar stages to mitosis, so you may want to look over the support sheet on Cell Structure.

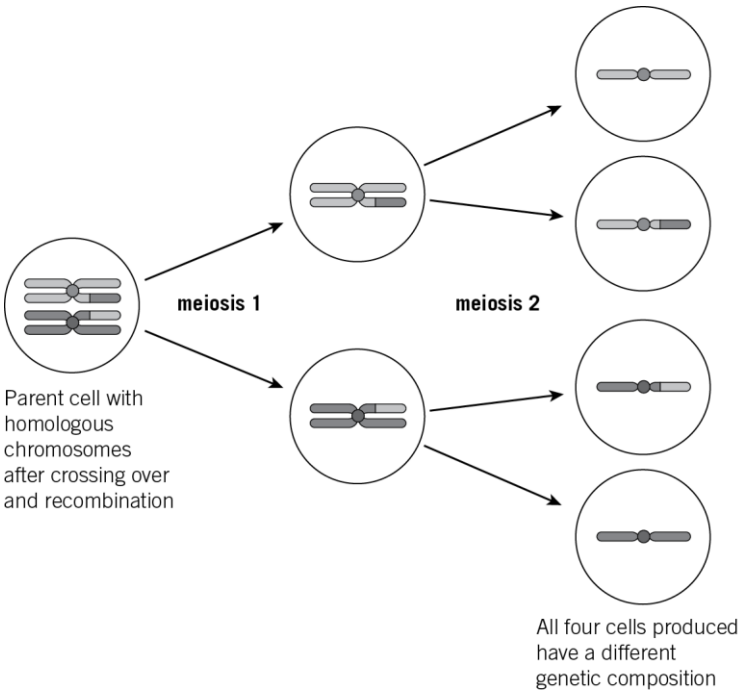

Figure 2 *The divisions of meiosis*

Key differences between meiosis and mitosis are:

- in meiosis, at prophase I, the chromosomes can cross over
- in meiosis, there is no DNA replication before prophase II
- meiosis produces genetically different daughter cells
- meiosis produces haploid daughter cells.

Crossing over

In prophase I of meiosis, the chromosomes can cross over, break and re-join as shown in Figure 3.

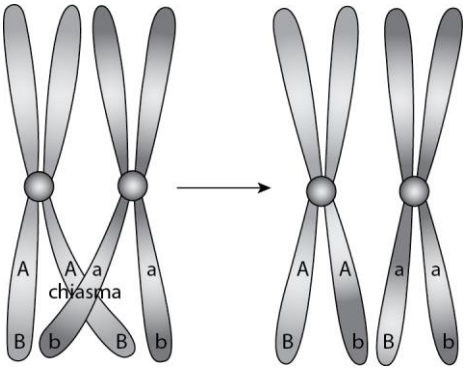

Figure 3 *Crossing over. In this case, one of the chromatids that had alleles A and B now has A and b. The chromatids held together by the centromere are no longer identical.*

The further apart to alleles are on a chromosome, the greater the probability that a crossing over event will happen between them. Crossover frequency can be used to map genes onto chromosomes.

Meiosis and genetic variation

Meiosis gives rise to genetic variation in two ways:

- crossing over – the alleles on a pair of chromatids held together by a centromere are no longer identical
- independent segregation – which chromatid from a pair that goes in each gamete is random.

The probability that an animal or plant will produce two gametes that are genetically identical will be very low. For example, in humans, the probability of this is 1 in 2^{46} even without taking crossing over into account! That's less than 1 in a thousand billion!

Random fertilisation

Genetic variation within a species is further increased by random fertilisation. This means that the one male and one female gamete that do eventually come together is random.

Worked example: using crossover frequency to map genes

The table gives crossover frequencies between four genes on one chromosome.

Use the frequencies to map the loci of the genes.

crossover between	crossover frequency / %
A and B	50
B and C	20
C and D	10
A and D	20
A and C	30
B and D	30

Method

- the highest frequency is between the genes that are farthest apart, A and B, so place these at either end of a line:

A _____ B

- then the next highest from A is C, so C must be further from A than D.
- C and D must be the closest, and the distance A to D must be the same as B to C, so the answer is:

A _____ D C _____ B

Natural selection

How do organisms become adapted to their environments? Any new allele which gives an advantage to an organism is more likely to be inherited, as that organism is more likely to survive long enough to mate. This will increase the frequency of that allele in the population, so in turn more organisms are likely to inherit it.

Mutations are changes in the nucleotide sequences of genes. Substitution mutations change one nucleotide for another, so could change an amino acid in a protein. This could change the protein's tertiary structure and therefore its function. Most mutations like this are harmful, but some, by chance, are beneficial.

Due to the redundancy of the genetic code, a substitution may not change an amino acid. For example, the four DNA codons starting with C G (i.e. C G A, C G C, etc.) all code for the amino acid alanine. Most commonly, it is a change in the third base of a codon that will not affect the amino acid. Mutations which do not affect the amino acid are called silent mutations.

Directional selection

This is a change over time to one particular phenotype (trait) which is at either extreme of the variation range. An example is antibiotic resistance in bacteria. A population of bacteria before the common use of antibiotics would have had only a few showing resistance. With the introduction of antibiotics, the resistant phenotype was favoured and so now there are more of them. In this case, the antibiotic is referred to as causing selection pressure. We also say that the antibiotic-sensitive bacteria were selected against.

Stabilising selection

In this case, the traits towards the middle of the variation range are selected for. A good example of this is human birth weights. Babies can be born with a range of weights, but mortality (death rate) is highest for those at the extremes of the range. These over- and underweight babies are selected against because they die before being able to pass on their alleles.

Questions

1 a The frog, *Rana esculenta*, has a diploid number of 26.

i Name the type of cell division used to produce gametes in *R. esculenta*. (*1 mark*)

ii State the number of chromosomes in *R. esculenta* gametes. (*1 mark*)

b Analysis of inheritance in *R. esculenta* showed that crossing over occurs between three genes, P, Q and R.

i Name the stage in cell division where crossing over occurs. (*1 mark*)

ii The crossover frequency between these genes was found to be:

P and Q 10%

Q and R 30%

P and R 20%

Use this information to determine the relative positions of these genes. Use a diagram for your answer. (*2 marks*)

iii Explain how crossing over contributes to genetic variation in gametes. (*2 marks*)

2 a Describe briefly how mutations contribute to natural selection. (*2 marks*)

b The European black bear, *Ursus minimus*, lived in Europe before and during the ice ages. Fossil records have shown that these bears gradually got smaller between the ice ages. Biologists believe that this was due to natural selection.

i Name this type of selection. (*1 mark*)

ii Fossil records also show that the bears gradually became larger again during an ice age. Suggest why larger bears were more suited to survive in an ice age. (*3 marks*)

iii Suggest why a trait such as body size in *U. minimus* is controlled by more than one gene. (*2 marks*)

3 a Copy and complete the table to show two differences between the daughter cells produced by mitosis and those produced by meiosis.

mitosis	meiosis

(*2 marks*)

b A species of insect is known to have three genes which are inherited on separate chromosomes. Each of these genes has two alleles.

How many genetically different gametes can be produced from an insect with genotype Ff Gg Hh?

Show your working. (*2 marks*)

c The sockeye salmon, *Oncorhynchus nerka*, is a fish that migrates every year from the ocean into rivers to breed. Over the years 1969 – 2003 the migration time of the salmon in Alaska was becoming earlier in the year. Biologists believe this to be a selection process caused by fishermen who catch the salmon later in the migration season.

i Name the type of selection which is changing the migration time. (*1 mark*)

ii Describe, in terms of genetics, how this selection works. (*3 marks*)