SURFING

NATIONAL BIOLOGY

Unit 3 Heredity and Continuity of Life

• Kerri Humphreys •

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Science Press

Science Press
Bag 7023 Marrickville NSW 1475 Australia
Tel: (02) 9516 1122 Fax: (02) 9550 1915
sales@sciencepress.com.au
www.sciencepress.com.au

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DNA, genes and the Continuity of Life

1 Assumed Knowledge

QUESTIONS

1. Define mitosis.
2. The diagram shows the last division of meiosis in the anther of a flower.

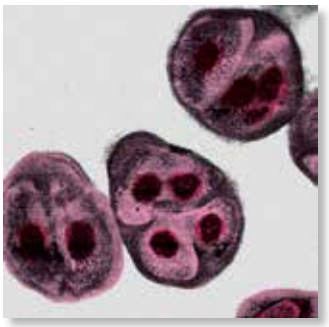
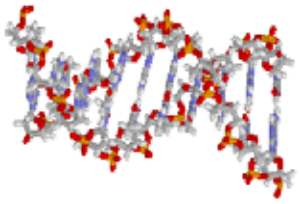


Figure 1.1 Meiosis in an anther.

   (a) What is meiosis?
   (b) What would be produced, according to this diagram?
3. How is information transferred when cells reproduce themselves?
4. What does DNA stand for?



`**Figure 1.2** DNA.

5. Name the basic unit of DNA.
6. Where is DNA located in cells?
7. Outline the structure of the DNA molecule.
8. What is the relationship between genes and DNA?
9. Explain the advantages of DNA replicating exactly.
10. What is a mutation?
11. Explain the advantages and disadvantages of DNA mutating.
12. What is a pedigree?
13. What is biotechnology? Give an example.
14. Describe some benefits of using biotechnology.
15. Describe some social and ethical issues of using biotechnology.
16. What is biodiversity?
17. Define evolution.
18. What is meant by the 'physical conditions' of the environment?
19. Many species compete for resources. What is meant by 'resources'?
20. Identify some areas of evidence for evolution.
21. Define palaeontology.
22. Define biochemistry.
23. Draw a flow chart to show the evolution of the vertebrates from the ancestral fish.
24. Why is Gregor Mendel often referred to as the 'father of genetics'?
25. Identify the factors that determine the features of an organism.
26. Use an example to show how environment influences the appearance of an organism.
27. Use an example to show how genes determine the features of an organism.
28. What is the 'Watson-Crick' model of DNA?
29. Define fertilisation.
30. Why is it important for gametes to have half the number of chromosomes of the species?
31. The diagram shows the structure of a buttercup.

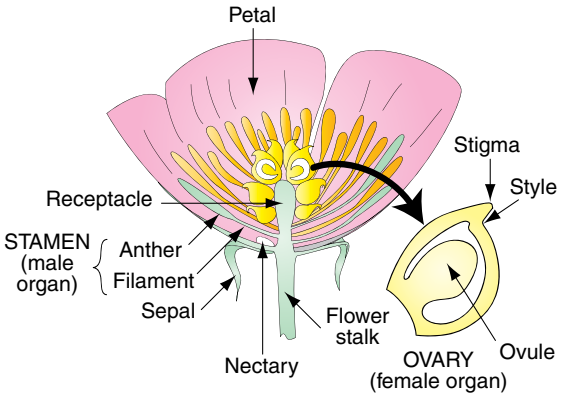


Figure 1.3 Half-flower of buttercup.

   (a) Identify the male part of the flower and the female part of the flower.
   (b) What is pollination?
   (c) Name some of the agents of pollination.
   (d) What is artificial pollination?
32. Gregor Mendel has often been called the 'Father of Genetics'. The following picture shows Gregor Mendel.

Figure 1.4 Gregor Mendel.

Describe Mendel's contribution to the study of genetics.

33. What is the Human Genome Project?
34. Define mutation.
35. Identify some causes of mutation.
36. Define hybrid.
37. What is a zygote.
38. What is a clone?

2 The Cell Cycle

The **cell cycle** is a series of events that occur in the life of eukaryotic cells. The cycle consists of mitosis, cytokinesis and the stages of interphase which are G_1 stage (growth stage 1), S stage (synthesis stage) and G_2 stage (growth stage 2). Mitosis is the shortest phase of the cell cycle taking less than 10% time and interphase taking 90% time of the cycle.

Mitosis is the division of the nucleus in cell division. **Cytokinesis** is the division of the cytoplasm and follows mitosis. In growing cells most of the time is interphase when DNA, other molecules and cell components are synthesised.

The timing of the cell cycle varies for different types of cells and for different times in the life of a particular species.

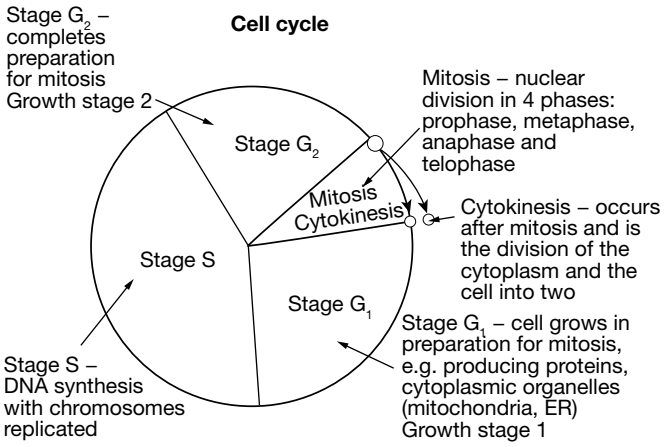


Figure 2.1 The cell cycle

M phase

The M phase is when mitosis occurs, followed by cytokinesis and the eukaryotic cell divides to form two identical daughter cells.

G1 phase

The G_1 phase is the 'first gap' when normal cellular activity resumes after the cell division and mitosis. The G_1 phase can be a long phase and is where cells that become differentiated leave the cell cycle and stop dividing. The cells grows by producing proteins and cytoplasmic organelles.

S phase

The S phase is a synthesis phase when DNA is replicated. The amount of DNA in the nucleus doubles in this phase. The chromosomes are not visible with a light microscope during this phase. The chromosomes exist as very long thin threads of **chromatin** which is a three-dimensional network of DNA and associated protein molecules. The associated proteins help keep the structure of the chromosome and help control the activity of the genes.

G2 phase

The G_1 phase is the 'second gap' when there is synthesis of other cellular molecules in preparation for cell division.

Checkpoint proteins

At certain times of the cell cycle there are checkpoint proteins that keep the steps of the cycle in order and keep the cycle operating normally, e.g. the S phase promoting factor (spf) and the mitosis promoting factor (mpf). These regulatory proteins are mainly **kinases** and **cyclins** and are part of the **cell cycle control system**.

In mammalian cells the G_1 checkpoint is a restriction point which determines if the rest of the cycle occurs or if the cell goes into a non-dividing state called the **G_0 phase**.

QUESTIONS

1. (a) What is the cell cycle?
   (b) What events make up the cell cycle?
   (c) What is the shortest phase of the cell cycle?
2. What proportion of the cell cycle is usually interphase?
3. What is mitosis?
4. What is cytokinesis?
5. Construct a table to summarise what happens during each of the phases of interphase.
6. If cells are given radioactively-labelled thymine the processes of the cell cycle can be investigated. Thymine is part of DNA but not part of RNA. Explain why the radioactive thymine is able to show the timing of the different phases of the cell cycle.
7. What is involved in the cell cycle control system?
8. Identify the regulatory proteins involved in the cell cycle control system.
9. What is the G_0 phase and when does it occur?
10. What is chromatin?
11. In active mammalian tissue the cell cycle can take 12-20 hours. The diagram shows the cell cycle for an active skin cell.

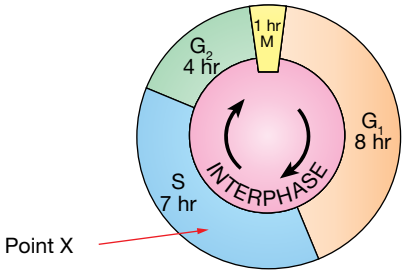


Figure 2.2 The cell cycle in an active mammalian tissue.

(a) How long is the cell cycle for this cell?
(b) What is the longest phase of this cycle?
(c) What would be happening in the cell at Point X of the cell cycle?

3 Binary Fission

Prokaryotes do not have membrane-bound organelles, e.g. nucleus and include the bacteria and archaea. **Eukaryotes** have membrane-bound organelles, e.g. nucleus and mitochondria and include plants, animals and fungi. Unicellular organisms use binary fission as a means of reproduction, e.g. the prokaryotes and the unicellular eukaryotes, e.g. Protista such as the protozoans.

In most bacteria the genetic information is on a single bacterial chromosome that is a circular DNA molecule with associated proteins. The prokaryotic chromosome is in the **nucleoid region** of the bacterial cell. Most bacteria also have **plasmids** which are small rings of DNA that only contain a few genes. Plasmids give the bacteria additional capabilities, e.g. the plasmids of some bacteria give them resistance to antibiotics.

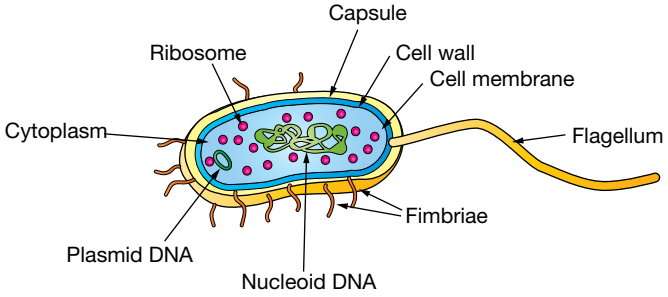


Figure 3.1 Typical bacterial cell.

Replication process in prokaryotes

Prokaryotes reproduce by binary fission when one cell splits into two. In bacteria the replication process starts at the **origin of replication** which is a specific part of the bacterial chromosome. This section is replicated and one copy of the origin moves to the other end of the cell. The nuclear material replicates and the cell elongates.

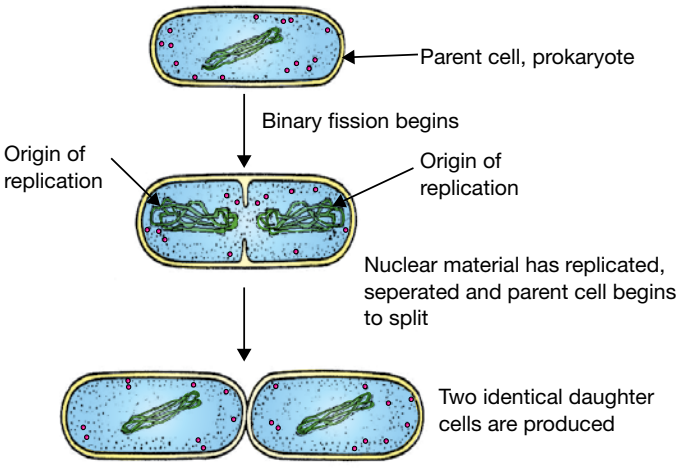


Figure 3.2 Typical bacterial cell.

When replication of the nuclear material has finished the cell membrane grows inward to split the long cell into two identical daughter cells.

The plasmids replicate independently of the main chromosome.

Binary fission in eukaryotes

In eukaryotes such as the protozoans which have a heterotrophic nutrition. The organism will have a period of growth, increasing in size until the cell undergoes nuclear division and fission splits the cell into two. Amoebas rely on binary fission for reproduction.

Evolutionary significance

Binary fission is a form of asexual reproduction as one parent gives rise to two or more individuals. Binary fission is energy efficient as the bacteria do not have to use energy or time to find a mate and they can quickly produce many numbers at an exponential rate if conditions are favourable. Since the Prokaryotes preceded the eukaryotes the process of binary fission gave rise to mitosis in evolutionary history.

As binary fission produces identical offspring with no mixing of genetic information variation, in offspring relies on the process of mutation. Survival ability can be threatened if there is a small gene pool and the environment rapidly changes.

Conjugation

Conjugation is a process in prokaryotes when there is direct transfer of DNA between two cells that are temporarily joined. The fimbria form a bridge between the two cells to allow the exchange of genetic material. In some bacteria, e.g. ciliates conjugation is a sexual process with the two cells exchanging haploid micronuclei.

QUESTIONS

1. What are prokaryotes?
2. What are eukaryotes?
3. Which organisms reproduce by binary fission?
4. Where is the genetic material in prokaryotes?
5. Outline the process of binary fission in prokaryotes.
6. What is the believed origin of mitosis?
7. In organisms that rely on binary fission, how does variation occur?
8. Why are plasmids an important feature for some bacteria?
9. Which of the following organisms would *not* rely on binary fission for reproduction?
   (A) *Amoeba* (B) *Paramecium*
   (C) *Escherichia* (D) *Hydra*

4 Mitosis and Cytokinesis

Mitosis is a process during cell division in which the cell nucleus divides into two. Mitosis is needed to create new cells for growth, repair and reproduction. Since all organisms begin life as one cell, a fertilised egg, mitosis is essential to become a multicellular organism.

Mitosis increases the number of cells. Even when the organism has ceased 'growing', mitosis is still needed. Older cells need replacement as they are damaged or worn out and some parts, even in adults, are continually growing, e.g. hair and fingernails in humans and root tips and shoot tips in plants.

Genetic information is transferred to new cells as DNA and DNA is present in nuclei, mitochondria and chloroplasts. Each new daughter cell is identical to the parent cell and has a full set of chromosomes.

Interphase

Interphase is often called the 'resting' stage but it is actually a time of high activity between cell divisions, when the DNA is replicating and when other organic molecules and cell components are being synthesised. The nucleus appears as a dark-staining material called chromatin and the nucleolus is visible. Chromosomes are NOT visible. The cell cycle consists of mitosis and interphase.

The stages of mitosis

Mitosis is a continuous process that can take from fifteen minutes to several hours to complete. In mitosis a cell splits into two with each new daughter cell having the same genetic information as the parent. For convenience, mitosis has been divided into stages:

Prophase. The chromosomes become visible as long, thin threads which shorten and thicken. The nucleolus and then the nuclear membrane disappear. The chromosomes appear as two chromatids joined together by a centromere. In animal cells the centriole divides into two and each moves to opposite ends of the cell. Plant cells do not have centrioles.

Metaphase. The chromatids line up along the central plane of the cell and the spindle forms. Each pair of chromatids are attached to the spindle at the centromere. At this time the chromosomes have maximum shortening and thickening with individual chromatids and the centromere clearly visible.

Anaphase. Is the shortest stage in mitosis. The centromere divides and the pair of chromatids separate as each one is pulled to opposite ends of the cell by the spindle fibres as the fibres shorten.

Telophase. The spindle disappears, the sets of chromosomes at the poles condense, the nucleoli reform, and a nucleus forms around each group. At this time cytokinesis occurs and the cells split into two distinct groups. Two new cells are formed.

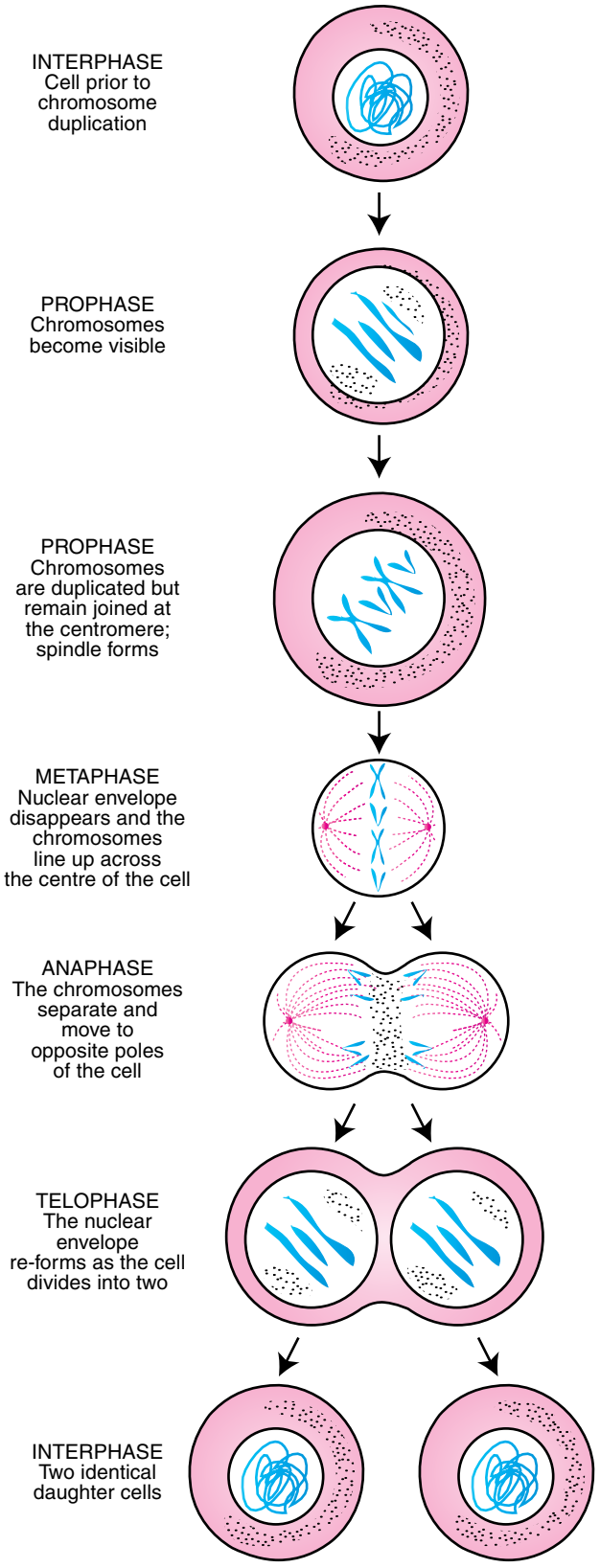


Figure 4.1 Stages of mitosis.

Cytokinesis in plant and animal cells

Cytokinesis is the division of the cell's cytoplasm following the division of the nucleus. Cytokinesis is important because it stabilises the internal concentration of materials in the two new cells.

The cell organelles are evenly divided and distributed between the two daughter cells. Each new cell needs sufficient organelles such as mitochondria, ribosomes and endoplasmic reticulum so that it can grow and carry out the processes of living.

In **animal cells** a cleavage furrow begins at the centre of the cell. The cell membrane constricts with the help of a contractile ring of microtubules and microfilaments which appear near the cell surface and contract. Cleavage continues as the cell membrane continues to be pinched in until they are separated into two segments. Plants cannot do this as they have rigid cell walls.

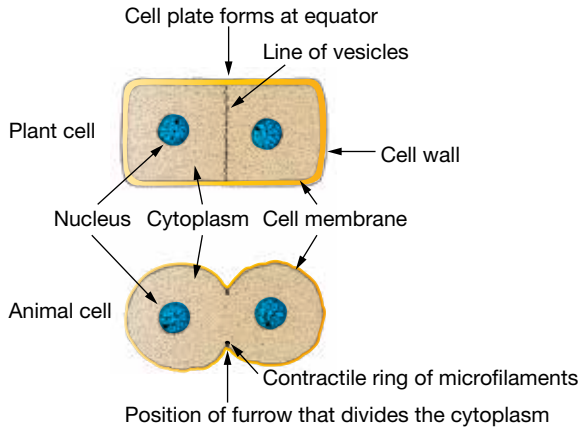


Figure 4.2 Cytokinesis.

In **plant cells**, a cell plate forms during telophase across the mid-line of the parent cell. The cell plates forms by the coalescence of tiny vesicles. These vesicles were made by Golgi bodies and contain the components of the cell wall and the cell membrane. The vesicles fuse and the plate grows outward from the centre of the cell, forming two membranes that become the two new cell membranes. The new cell walls form between these membranes.

QUESTIONS

1. (a) Define mitosis.
   (b) Explain why mitosis is vital for multicellular organisms.
2. (a) Define cytokinesis.
   (b) Explain why cytokinesis is important.
3. Outline the role of mitosis.
4. Which organelles contain DNA?
5. During the 'resting' phase of the cell cycle, is the cell really 'resting'?
6. Describe how cytokinesis is different in plants and animals.
7. How are the cell organelles divided between the two new daughter cells?
8. Describe the appearance of a cell at the beginning of mitosis.
9. Briefly outline the process of mitosis.
10. Describe spindle fibres and their function.
11. When will cells divide?
    (A) The surface area to volume ratio becomes too large.
    (B) Nutrients cannot efficiently reach all parts of the cell by diffusion.
    (C) Membrane surface area is too large to efficiently support cellular metabolism.
    (D) Wastes leave the cell too quickly.
12. A scientist was observing a cell undergoing mitosis. Which event would show it was a plant cell rather than an animal cell?
    (A) Formation of cell plate.
    (B) Cleavage of the cytoplasm.
    (C) Spindle fibres attach to centrioles.
    (D) Formation of chromatids.
13. A cell with 14 chromosomes undergoes mitosis. How many chromosomes will be in each daughter cell?
    (A) 7 (B) 14 (C) 21 (D) 28
14. The diagram shows mitosis and interphase.

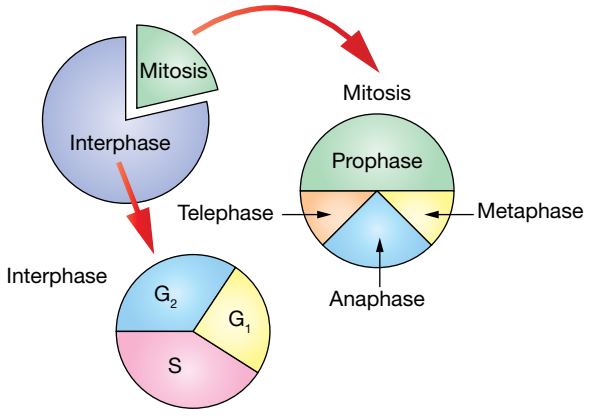


Figure 4.3 Interphase and mitosis.

From this diagram what is the longest phase of mitosis?
    (A) S phase.
    (B) Interphase.
    (C) Prophase.
    (D) Anaphase.
15. Which organelle produces the vesicles that contain the components of the cell wall and cell membrane for cytokinesis in plant cells?
    (A) Mitochondria.
    (B) Chloroplasts.
    (C) Nucleus.
    (D) Golgi bodies.

Answers

1 Assumed Knowledge

1. Mitosis is a process during cell division in which the cell nucleus divides into two.
2. (a) Meiosis is cell division to produce haploid daughter cells.
   (b) Meiosis produces four daughter cells and in the anther will produce four pollen grains.
3. Information is transferred as DNA on chromosomes when cells reproduce themselves.
4. DNA stands for deoxyribose nucleic acid.
5. The basic unit of DNA is the nucleotide.
6. Most DNA is located in the nucleus. DNA is also found in mitochondria and in the chloroplasts of green plants.
7. The structure of the DNA molecule is a double helix.
8. A gene is a certain length of DNA that has the code for one characteristic.
9. DNA needs to be able to replicate itself exactly so that cell division can form identical new cells for growth, repair and maintenance of the body of a multicellular organism. Exact replication is also needed to maintain the genetic code for a species and hence keep its integrity as a distinct unit in nature.
10. A mutation is a change in the chemical structure of the DNA.
11. An advantage of DNA mutating is that it can lead to different phenotypes, and individuals with different forms of characteristics which can be beneficial in a changing environment for natural selection and the survival of the species. A disadvantage is that mutations are often harmful and reduce the normal lifespan of the individual, e.g. mutation causing cancer.
12. A pedigree is a graphical way of picturing the ancestry of living things. It shows genetic history.
13. Biotechnology is the use of biological processes by industry or agriculture to change organisms in order to produce useful products or provide services, e.g. to brew beer and breed cattle with specific characteristics.
14. Biotechnology has helped humans develop new food sources, e.g. baking bread, making cheese, brewing beer, breeding certain strains of cereal crops to get a higher yield. This has increased food supply and hence allowed population growth.
15. Social issues arising from the use of biotechnology can involve human safety and confidentiality. For example, the production of genetically modified food is a recent development in biotechnology. Some people call them 'frankenfoods' and are worried about the effect on human health if there is long-term consumption of these foods. Biotechnology has also developed new diagnostic tests using genetic engineering. A social issue arising from these diagnostic tests involves confidentiality of the results and whether insurance companies have the right to personal genetic information about an individual. Ethical issues involving biotechnology have arisen with the recent experiments with animal cloning and whether the creation of human clones should be allowed. Another ethical issue is animal welfare. Animals are involved in many ways in genetic research and although there are guidelines (minimum number of animals to be used, the experiments are to be carried out humanely) some activists would like to ban all animal experimentation.
16. Biodiversity refers to the genetic variety found in the different life forms on Earth.
17. Evolution is the change in a population over time.
18. Physical conditions of the environment refer to features such as temperature, rainfall, humidity, topography and wind speed and direction.
19. Resources refers to anything that is used by the organisms, e.g. nesting material, food supply, water source.
20. Areas of evidence that support the theory of evolution include – 1. Fossil evidence. 2. Comparative embryology. 3. Biogeography. 4. Comparative anatomy. 5. Biochemistry such as DNA sequencing and DNA-DNA hybridisation.
21. Palaeontology is the study of life from the past based on fossil remains.
22. Biochemistry is the study of molecules and how they react in organisms.
23. Fish → amphibian → reptile → bird / mammal
24. Gregor Mendel experimented with pea plants and worked out the basic laws of inheritance. His work led to the study of genetics and hence he is often referred to as the 'father of genetics'.
25. Both genes and environmental factors determine the features of an organism.
26. In plants, e.g. pea plants, the environment can have a great influence on the appearance of an organism. If the plant has the genetic code to be tall, but is grown in poor soil which has few nutrients, then the plant will not reach its full height potential and may appear to be a dwarf plant.
27. In pea plants there are two alleles for plant height – tall (T) and dwarf (t). Given that all other environmental factors are the same, a plant with the genetic code TT or Tt will be tall, while a plant with the code tt will be dwarf.
28. Watson and Crick discovered that DNA had a double helix structure.
29. Fertilisation is the union of two gametes.
30. Gametes fuse to form a zygote. It is essential that gametes contain only half the number of chromosomes to maintain the chromosome number of the species. Otherwise the number of chromosomes would double every generation.
31. (a) The male part of the flower is the stamen and it consists of the anther and the filament. The female part of the flower is the carpel and it consists of the ovary, with ovules, the style and the stigma.
    (b) Pollination is the transfer of pollen from the anthers to the stigma.
    (c) Agents of pollination include the wind, insects and birds.
    (d) Artificial pollination is when humans transfer the pollen from a plant with desired characteristics onto the stigma of another plant so they can breed plants with certain features.
32. Gregor Johann Mendel studied the inheritance of different characteristics in pea plants in 1856. He started with many strains and bred them for several years to find easily recognisable traits that bred true. Mendel crossed purebreeding round seeds with purebreeding wrinkled seeds and found that the first generation (F_1) were all round seeds. When he crossed two of the offspring he found that the ratio was 3 round : 1 wrinkled in the second generation (F_2). Mendel concluded that there were two factors for a character and one (e.g. round seed shape) was dominant over the other (e.g. wrinkled seed shape).
33. The Human Genome Project was a program which wanted to map all the genes in the human genome.
34. A mutation is a permanent change in the genetic information.
35. There are several causes of mutation, e.g. mistakes in DNA replication, DNA damage by chemical mutagens, radiation and incorrect repair and maintenance of cells.
36. A hybrid is heterozygous for a characteristic and can be produced by crossing two different purebreeding organisms.
37. A zygote is a fertilised egg.
38. A clone is an organism that has the identical genetic make-up to the parent cell.

2 The Cell Cycle

1. (a) The cell cycle is a series of events that occur in the life of eukaryotic cells.
   (b) The cycle consists of mitosis, cytokinesis and the stages of interphase which are G_1 stage (growth stage 1), S stage (synthesis stage) and G_2 stage (growth stage 2).
   (c) Mitosis is the shortest phase of the cell cycle.
2. Interphase usually lasts for around 90% cell cycle.
3. Mitosis is a process during cell division in which the cell nucleus divides into two.
4. Cytokinesis is the division of the cell's cytoplasm following the division of the nucleus.