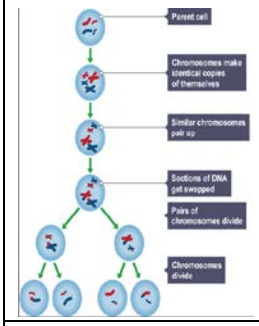
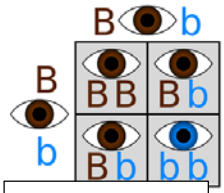
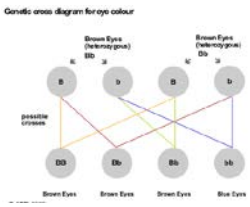
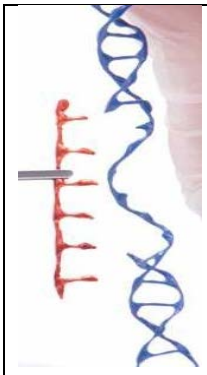
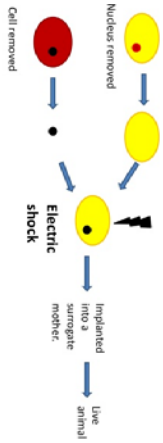
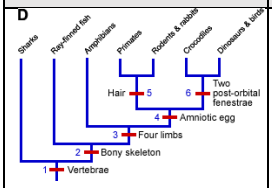
	4.6 Inheritance, variation and evolution
4.6.1	Sexual and asexual reproduction
4.6.1.1 sexual and asexual reproduction	**Sexual reproduction** involves the **joining** (fusion) of male and female **gametes:** • **sperm** and **egg cells** in animals • **pollen** and **egg cells** in flowering plants. In sexual reproduction there is **mixing of genetic information** which leads to variety in the offspring. The formation of gametes involves meiosis. **Asexual reproduction** involves only one parent and no fusion of gametes. There is **no mixing** of genetic information. This leads to genetically **identical offspring (clones**). Only mitosis is involved.
4.6.1.2 meiosis  	Cells in reproductive organs divide by **meiosis** to form gametes. When a cell divides to form gametes: • **copies** of the **genetic information** are made • the **cell divides twice** to form **four gametes**, each with a **single set** of **chromosomes** • all gametes are **genetically different** from each other. They have half the normal number of chromosomes (23 in humans) Gametes join at fertilisation to restore the normal number of chromosomes (46). The new cell divides by mitosis. The number of cells increases. As the embryo develops cells differentiate.
4.6.1.3 advantages and disadvantages of sexual and asexual reproduction (Biology only)	**Advantages** of **sexual reproduction**: • produces **variation** in the offspring • if the environment changes variation gives a **survival advantage** by natural selection • **natural selection** can be speeded up by humans in selective breeding to increase food production. **Advantages** of **asexual reproduction**: • only **one parent** needed • more **time and energy efficient** as do not need to find a mate • **faster** than sexual reproduction • many **identical offspring** can be produced when conditions are favourable. Some organisms reproduce by **both methods** depending on the circumstances. • **Malarial parasites** reproduce asexually in the human host, but sexually in the mosquito. • Many **fungi** reproduce asexually by spores but also reproduce sexually to give variation. • Many plants produce seeds sexually, but also reproduce asexually by runners such as strawberry plants, or bulb division such as daffodils.
4.6.1.4 DNA and the genome	The **genetic material** in the nucleus of a cell is composed of a chemical called **DNA**. DNA is a polymer made up of two strands forming a **double helix**. The DNA is contained in structures called **chromosomes**. A **gene** is a **small section of DNA** on a chromosome. Each gene c**odes** for a particular sequence of **amino acids**, to make a specific **protein**. The **genome** of an organism is the **entire genetic material** of that organism. The whole human genome has now been studied and this will have great importance for medicine in the future.

	Understanding the human genome helps us with: • search for genes linked to different types of disease • understanding and treatment of inherited disorders • use in tracing human migration patterns from the past.
4.6.1.5 DNA structure (biology only) 	**DNA is a polymer** made from **four different nucleotides**. Each nucleotide consists of a **common sugar** and **phosphate group** with one of **four different bases** attached to the sugar. DNA contains four bases, **A, C, G and T**. A sequence of **three bases** is the code for a **particular amino acid**. The order of bases controls the order in which amino acids are assembled to produce a particular protein. The long strands of DNA consist of alternating sugar and phosphate sections. Attached to each sugar is one of the four bases. The DNA polymer is made up of repeating nucleotide units. Genetic variants may influence phenotype: a) in coding DNA by altering the activity of a protein: and b) in non-coding DNA by altering how genes are expressed. (HT only) In the complementary strands a **C is always linked to a** G on the opposite strand and a **T to an A.** **A change in DNA structure** may result in a **change in the protein synthesised** by a gene. (HT only) **Proteins are synthesised on ribosomes**, according to a template. Carrier molecules bring specific amino acids to add to the growing protein chain in the correct order. (HT only) When the protein chain is complete it folds up to form a **unique shape**. This unique shape enables the proteins to do their **job** as **enzymes, hormones** or forming **structures** in the body such as collagen. (HT only) **Mutations** occur continuously. Most do not alter the protein, or only alter it slightly so that its appearance or function is not changed. (HT only) A few mutations code for an altered protein with a different shape. An enzyme may no longer fit the substrate binding site or a structural protein may lose its strength. (HT only) Not all parts of DNA code for proteins. Non-coding parts of DNA can switch genes on and off, so variations in these areas of DNA may affect how genes are expressed.
4.6.1.6. genetic inheritance  Punnett square	Some characteristics are controlled by a single **gene**, such as: fur colour in mice; and red-green colour blindness in humans. Each gene may have different forms called **alleles**. The alleles present, or **genotype**, operate at a molecular level to develop characteristics that can be expressed as a **phenotype**. A **dominant** allele is always expressed, even if only one copy is present. A **recessive** allele is only expressed if two copies are present (therefore no dominant allele present). If the **two alleles** present are the **same** the organism is **homozygous** for that trait, but if the alleles are **different** they are **heterozygous**. Most characteristics are a result of multiple genes interacting, rather than a single gene.  Genetic cross diagram
4.6.1.7 inherited disorders	Some disorders are inherited. These disorders are caused by the inheritance of certain alleles. • **Polydactyly** (having extra fingers or toes) is caused by a **dominant** allele. • **Cystic fibrosis** (a disorder of cell membranes) is caused by a **recessive** allele.
4.6.1.8 sex determination	Ordinary **human body cells** contain **23 pairs** of **chromosomes.** 22 pairs control characteristics only, but one of the pairs carries the genes that determine sex. • In **females** the sex chromosomes are the same **(XX).** • In **males** the chromosomes are different **(XY).**

4.6.2	Variation and evolution
4.6.2.1 variation	Differences in the characteristics of individuals in a population is called **variation** and may be due to **differences** in: • the **genes** they have inherited (genetic causes) • the **conditions** in which they have developed (environmental causes) • a **combination** of genes and the environment. There is usually extensive genetic variation within a population of a species • all variants arise from mutations and that: most have no effect on the phenotype; some influence phenotype; very few determine phenotype. **Mutations** occur continuously. Very rarely a mutation will lead to a new phenotype. If the new phenotype is suited to an environmental change it can lead to a relatively rapid **change in the species.**
4.6.2.2 evolution	**Evolution** is a **change** in the inherited characteristics of a population **over time** through a process of **natural selection** which may result in the formation of a new species. The theory of evolution by natural selection states that all species of living things have evolved from simple life forms that first developed more than three billion years ago. Evolution occurs through natural selection of variants that give rise to phenotypes **best suited** to their **environment.** If two populations of one **species** become so different in phenotype that they can no longer interbreed to **produce fertile offspring** they have formed two new species.
4.6.2.3 selective breeding	**Selective breeding (artificial selection)** is the process by which humans breed plants and animals for particular genetic characteristics. Humans have been doing this for thousands of years since they first bred food crops from wild plants and domesticated animals. Selective breeding involves **choosing parents** with the **desired characteristic** from a mixed population. They are bred together. From the offspring those with the desired characteristic are bred together. This continues over many generations until all the offspring show the desired characteristic. The characteristic can be chosen for usefulness or appearance: • Disease resistance in food crops. • **Animals** which produce **more meat or milk.** • **Domestic dogs** with a gentle nature. • Large or unusual flowers. Selective breeding can lead to 'inbreeding' where some breeds are particularly prone to disease or inherited defects.
4.6.2.4 genetic engineering	**Genetic engineering** is a process which involves **modifying the genome** of an organism by introducing a gene from another organism to **give a desired characteristic.** Plant crops have been genetically engineered to be resistant to diseases or to produce bigger better fruits. Bacterial cells have been genetically engineered to produce useful substances such as human insulin to treat diabetes. In genetic engineering, **genes** from the chromosomes of humans and other organisms can be **'cut out'** and **transferred to cells** of other organisms. (HT only) In genetic engineering: • **enzymes** are used to **isolate the required gene**; this gene is inserted into a vector, usually a bacterial plasmid or a virus • the vector is used to insert the gene into the required cells

	• genes are transferred to the cells of animals, plants or microorganisms at an **early stage in their development** so that they develop with desired characteristics. Crops that have had their **genes modified** in this way are called **genetically modified (GM) crops**. GM crops include ones that are resistant to insect attack or to herbicides. GM crops generally show increased yields. Concerns about GM crops include the effect on populations of wild flowers and insects. Some people feel the effects of eating GM crops on human health have not been fully explored. Modern medical research is exploring the possibility of genetic modification to overcome some inherited disorders.
4.6.2.5 Cloning (biology only) 	**Tissue culture**: using small groups of cells from part of a plant to grow identical new plants. This is important for preserving rare plant species or commercially in nurseries. **Cuttings**: an older, but simple, method used by gardeners to produce many identical new plants from a parent plant. Embryo transplants: splitting apart cells from a developing animal embryo before they become specialised, then transplanting the identical embryos into host mothers. **Adult cell cloning:** • The **nucleus is removed** from an unfertilised egg cell. • The nucleus from an adult body cell, such as a skin cell, **is inserted into the egg cell.** • An electric shock stimulates the **egg cell to divide** to form an embryo. • These embryo cells contain the **same genetic information** as the adult skin cell. • When the embryo has developed into a ball of cells, it is **inserted into the womb of an adult female** to continue its development.
4.6.3	The development of understanding of genetics and evolution
4.6.3.1 Theory of evolution (biology only)	**Charles Darwin,** as a result of observations on a round the world expedition, backed by years of experimentation and discussion and linked to developing knowledge of geology and fossils, proposed the theory of evolution by natural selection. • Individual organisms within a particular species show a **wide range of variation** for a characteristic. • Individuals with **characteristics most suited to the environment** are more likely to **survive to breed successfully.** • The characteristics that have enabled these individuals to survive are then **passed on to the next generation**. Darwin published his ideas in *On the Origin of Species* (1859). There was much controversy surrounding these revolutionary new ideas. The theory of evolution by natural selection was only gradually accepted because: • the **theory challenged the idea that God** made all the animals and plants that live on Earth • there was **insufficient evidence** at the time the theory was published to convince many scientists • the **mechanism of inheritance** (genes) and variation was not known until 50 years after the theory was published. Other theories, including that of Jean-Baptiste **Lamarck**, are based mainly on the idea that **changes that occur in an organism during its lifetime can be inherited.** We now know that in the vast majority of cases this type of inheritance cannot occur.

4.6.3.2. Speciation (biology only)	Alfred Russel **Wallace** independently proposed the theory of evolution by natural selection. He published **joint writings with Darwin** in 1858 which prompted Darwin to publish *On the Origin of Species* (1859) the following year. **Wallace** worked worldwide gathering evidence for evolutionary theory. He is best known for his work on warning colouration in animals and his theory of **speciation.** Alfred Wallace did much pioneering work on speciation but more evidence over time has led to our current understanding of the theory of **speciation.**
4.6.3.4 Evidence for evolution	Evidence for Darwin's theory is now available as it has been shown that characteristics are passed on to offspring in genes. There is further evidence in the **fossil record** and the knowledge of how **resistance to antibiotics evolves in bacteria**.
4.6.3.5. Fossils	**Fossils** are the '**remains' of organisms from millions of years ago**, which are found in rocks. Fossils may be formed: • from parts of organisms that have **not decayed** because one or more of the conditions needed for decay are absent • when **parts** of the organism are **replaced by minerals** as they decay • as preserved **traces** of organisms, such as **footprints,** burrows and rootlet traces. Many **early forms of life were soft-bodied**, which means that they have left few traces behind. What traces there were have been mainly **destroyed by geological activity**. This is why scientists cannot be certain about how life began on Earth. The **fossil record is incomplete** We can learn from fossils how much or how little different organisms have changed as life developed on Earth.
4.6.3.6 Extinction	**Extinctions** occur when there are no remaining individuals of a species still alive. They could be caused by **climate change, food shortages, disease, new predators, a catastrophic event.**
4.6.3.7. Resistant bacteria	**Bacteria** can **evolve rapidly** because they reproduce at a fast rate. **Mutations** of bacterial pathogens produce **new strains.** Some strains might be **resistant to antibiotics**, and so are not killed. They **survive and reproduce,** so the population of the resistant strain rises. The resistant strain will then spread because people are not immune to it and there is no effective treatment. **MRSA is resistant to antibiotics.** To reduce the rate of development of antibiotic resistant strains: • doctors should not prescribe antibiotics inappropriately, such as treating non-serious or viral infections • patients should complete their course of antibiotics so all bacteria are killed and none survive to mutate and form resistant strains • the agricultural use of antibiotics should be restricted. The development of new antibiotics is costly and slow. It is unlikely to keep up with the emergence of new resistant strains.
4.6.4	**Classification of living organisms**
	Traditionally living things have been classified into groups depending on their structure and characteristics in a system developed by **Carl Linnaeus.** Linnaeus classified living things into **kingdom, phylum, class, order, family, genus and species**. Organisms are named by the binomial system of **genus and species e.g. Homo sapien** This is the Linnaean system. As evidence of internal structures became more developed due to improvements in microscopes, and the understanding of biochemical processes progressed, new models of classification were proposed.

	Due to evidence available from chemical analysis there is now a '**threedomain system**' developed by Carl Woese. In this system organisms are divided into: • **archaea (primitive bacteria** usually living in extreme environments) • **bacteria** (true bacteria) • **eukaryota** (which includes protists, fungi, plants and animals). **Evolutionary trees** are a method used by scientists to show how they believe organisms are related. They use current classification data for living organisms and fossil data for extinct organisms.