UNIT 3 SEX DETERMINATION

Structure

3.1 INTRODUCTION

This is the first of the three units dealing with various aspects of the genetics of sex. This unit deals with three main aspects – the importance of sexual reproduction, the evolution of mating types in various organisms and the basis of sex determination.

The unit begins by explaining the importance of sexual reproduction. It explains the necessity of evolution of mating types or 'sexcs' before describing sex determination in prokaryotes. This is followed by a subsection dealing with sex determination in eukaryotes, which involves both environmental and genetic factors. Next, you would study the genetic basis of sex determination, which is either of genic type or of chromosomal type.

The study of this unit requires prior knowledge of mitosis and meiosis. You may already be familiar with these processes from your Cell Biology course (LSE-01), but it will be desirable to brush up your memory with these portions before beginning the study of this unit. You should try to understand the terms and concepts without memorising all the examples given.

Objectives

After studying this unit you would be able to:

- explain the importance of sexual reproduction in evolution (Section 3.2);
- describe the different mating types or sexes in eukaryotes and prokaryotes (Subsections 3.2.1 and 3.2.2);

- give examples and explain the role of environment in sex determination (Subsection 3.2.3);
- distinguish between the genic and chromosomal type of sex determination (Section 3.3);
- describe the chromosomal sex determination mechanisms (Sections 3.4 and 3.5).

3.2 SEXUAL REPRODUCTION

You must be aware that reproduction is one of the distinguishing features of living beings. Reproduction is basically of two types: asexual and sexual. In asexual reproduction an organism propagates itself without the formation of sex cells or gametes. Sexual reproduction is more complex than the asexual type. It is based on the production of two kinds of gametes, the male and the female. The gametes are microscopic and in order that they fuse, certain specific conditions are required. This makes sexual reproduction so very specialised.

You may question why a complex and difficult mode of reproduction is found in nature when a simpler mode is available. It is because, an offspring that has been produced asexually has exactly the same genetic constitution Like that of its parents. *Asexual reproduction necessarily involves mitosis which is a conservative process maintaining the status quo ante of the genetic material.* On the other hand, *sexual reproduction causes genetic variability* in offspring. This is due to meiosis which is an essential component of sexual reproduction. *Meiosis generates enormous variation through independent assortment of homologous chromosomes and crossing-over.* In addition, random fusion of gametes at the time of fertilisation also contributes in generating variation.

You may recall that genetic variability is a precondition for biological evolution. You would study more about it in the course on Taxonomy and Evolution (LSE-07). A species that is unable to evolve would sooner or later become extinct. Sexual reproduction hence is seen in a majority of existing forms of life to bring about variability. To ensure a sexual mode of reproduction, most organisms have evolved different 'mating types' or 'sexes'.

In nature there is a vast array of diverse mechanisms of sex determination in different species. We shall discuss some of them under two heads as given in subsections 3.2.1 and 3.2.2 below.

3.2.1 In Prokaryotes

In lower forms of life – prokaryotes, i.e., those organisms without a true nucleus, reproduction is usually of asexual type but sexual reproduction is not totally absent.

In many bacteria, e.g., *Escherichia coli* sex is determined by the presence or absence of a fertility factor called an *'F-Factor'* or *plasmid.* The F-Factor may exist independently in cytoplasm or integrated with the genome of the bacteria. Mating occurs only between bacteria having the F-Factor (F-positive, F^+) and the ones without it (F-negative, F) . These two mating types are morphologically distinct. The F^+ bacteria have sex pilus or hair (*pl. pili*) on their surface. The F^+ (male) bacteria transfer the F-factor in a uni-directional manner into the F^- (female) bacteria (see Fig. 3.1a). Thus in $F^+ \times F^-$ mating, a 'female' bacterium (F) is transformed into 'male' bacterium (F^+). Bacteria which have the F-factor integrated with their genetic material are'known as Hfr (High frequency recombinant) type (Fig. 3.1b). In Hfr × F^- matings the F-factor is the last to enter into the F^- bacteria, other genes precede it (Fig. 3.1c). The result of this is a passage of genetic material from Hfr to the F^-.

While reading this subsection, several questions may be arising in your mind. Questions like how are Hfr formed? What is their significance? And many others. You would find their answers in Unit 12, on Genetics of Bacteria and Bacteriophage.

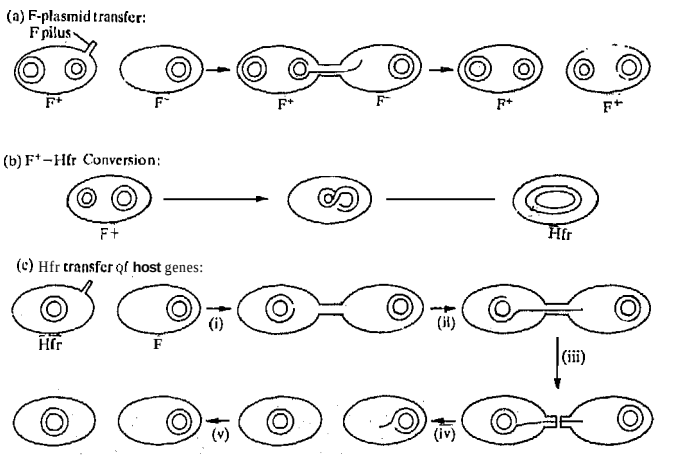

Fig. 3.1: Reproduction in bacteria. a) The F factor or **plasmid** passes from one cell to the other through F pilus, leaving a copy in the donor cell. **b)** F^+ to **Hfr** conversion. The F **plasmid combines** with the host chromosome. **c) Transfer** of **Hfr** genes into the recipient cell. i) First, the F **pilus** establishes a bridge between the conjugating cells. **ii)** Hfr chromosome begins replicating, with one daughter DNA molecule passing across the bridge to **the** recipient cell. iii) The bridge breaks during conjugation, leaving a piece **of** donor DNA in the recipient cell, iv) The donor DNA combines with the recipient **chromosome.** This may be a single-stranded event as shown here, or a double-stranded event. v) After **the** recipient cell replicates it contains a recombinant DNA, with part derived from the donor and **part** from the recipient.

3.2.2 In Eukaryotes

In most eukaryotes, especially higher animals, individuals normally exhibit one or two sex phenotypes; **female** or **male.** In such species, females produce the **female gametes –.eggs, ovules** or **macrospores** and males produce the **male gametes – sperm, pollen** or **microsproes.** Species with separation of sexes in different individuals are called **dioecious** or **monosexual** organisms. All higher organisms and some higher plants are dioecious. Species in which both male and female gametes are produced by each individual are called **monoecious** or **bisexual** organisms. In lower animals, the production of both eggs and sperms by the same organisms is more commonly called **hermaphroditism,** and individual organisms producing both the types of gametes are termed **hermaphrodites.**

Although the two sex phenotypes are usually quite easily distinguished in humans and fruit flies, it is not universally the case. In lower or the 'primitive' eukaryotes, the two sexes are phenotypically indistinguishable except for their reproductive organs. Indeed, in lower eukaryotes the two genetically distinct types of gametes are sometimes morphologically indistinguishable. This is called **isogamy (iso** meaning 'same'). Isogamy occurs in several simple eukaryotes, such as the green alga *Chlamydomonas*, fungi-*Neurospora* and protozoa-Paramecium. They may however, be identified by their sexual reproduction pattern (see Figs. **3.2** and 3.3).

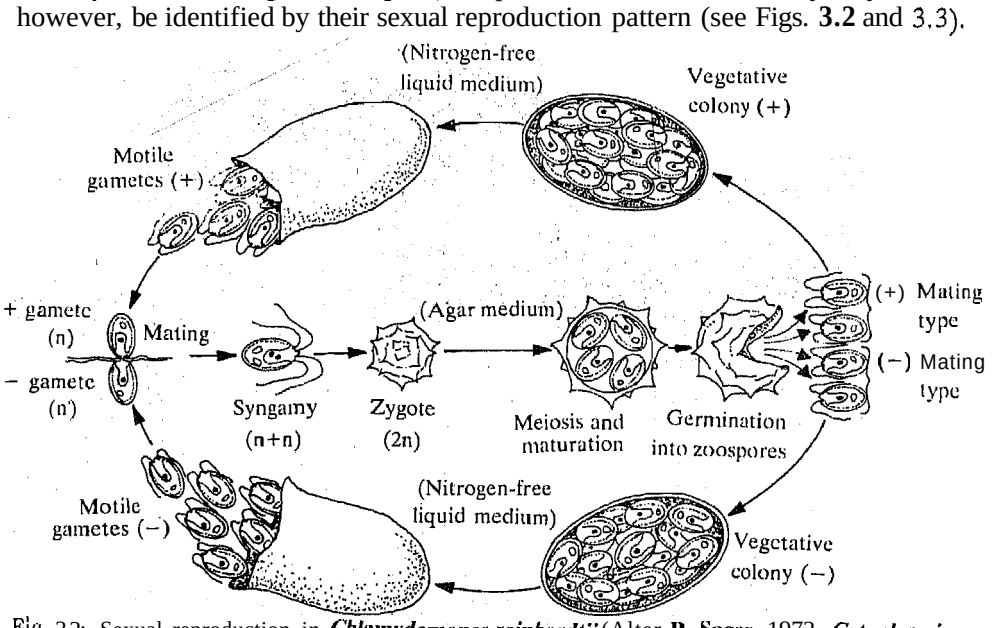

Fig. 3.2: Sexual reproduction in ***Chlamydomonas reinhardtii*** (Alter **R. Sagar,** 1972. ***Cytoplasmic Genes' and Organelles,*** Academic Press, New **Delhi**).

An individual belonging to one mating type exchanges genetic material by fusing only with an individual of another mating type but never with its own mating type (see Fig. **3.4).** Therefore, the similar looking male and female gametes, or isogametes are actually physiologically different, as is evident by their mode of reproduction.

Sexual differences between individuals probably originated first in their gametes. Most of the plants are hermaphrodite, producing both types of gametes, but have various adaptations to promote cross fertilisation. One such adaptation is the phenomenon of self-sterility. Its examples are cherry and tobacco plant. *Due to self sterility the plants have to undergo cross fertilisation,* and the *result is* the *recombination of genetic material.*

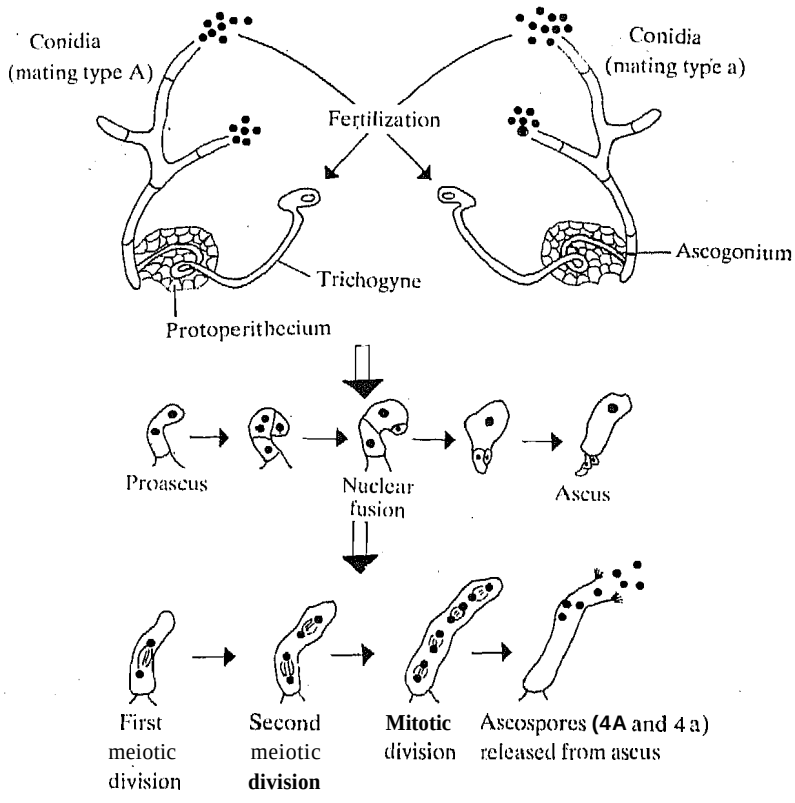

Fig. 3.3: Sexual reproduction in *Neurospora crassa* (Modified from Klug W.S. and Cummings, M.K. 1983. Concepts of Genetics, *C.E.* Merrill Publishing Co.

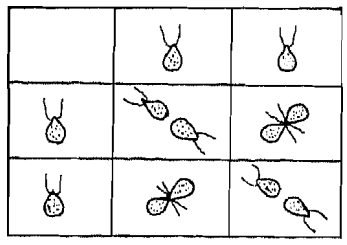

Fig. 3.4: Mating Types in *Chkmydomonas sp.*

3.2.3 Effect of Environmental Factors

In some lower organisms, though the genetic determiners of the sexes are present, the ambient environment plays a decisive role in the development of a particular sex type. And it appears that sex determination is non-genetic. The males and females have similar genotype, but stimuli from environmental factors initiate development towards one sex or the other. In *Equisetum* (horse tail) plant, for example, female characteristics develop when the plant is raised under favourable growth conditions, while in poor or unfavourable conditions males are formed.

Another salient example is of the marine worm *Bonellia* (see Fig. *3.5).* These worms are very small. The males remain in a highly reduced form in the reproductive tract of female (Fig. 3.5, arrow). The female is many times larger than the male (compare their size in the figure). Any young worm reared from a single isolated egg becomes a female. If the newly hatched worms are released into water containing mature females, some young worms are attracted to females and become attached to the female proboscis. These are then transformed into males and these migrate to the female reproductive tract, where they become parasitic. Experimental studies have shown that even the extracts made from the female proboscis influence young worms towards maleness.

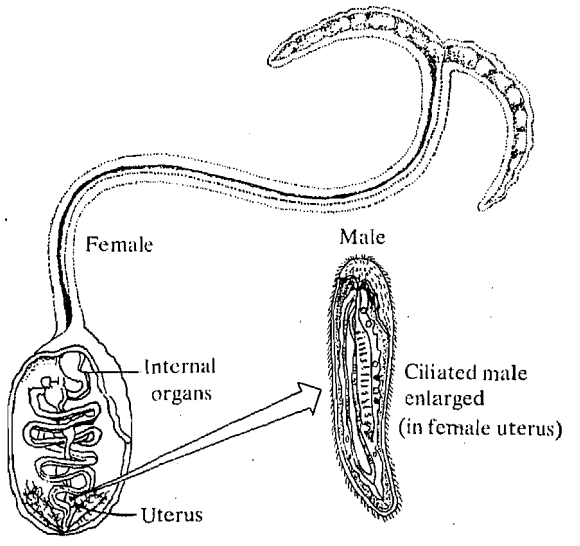

Fig. 3.5: The female nnd male of the marine worm *Bonellia viridis*. The male remains in highly reduced form in the uterus of the female (see arrow). Its enlarged version is drawn on the right (After Dobzhansky, T. 1955. *Evolution, Genetics and Man.*, John Wiley and Sons. Inc.)

In some reptiles, the temperature at which the fertilised eggs are incubated prior to hatching, plays a major role in determining the sex of the offspring. High temperatures during incubation have opposite effects on Sex determination in. different species. In the lizard Agama *agama,* some crocodiles and alligators, incubation at high temperature results in all male offspring while at low temperature it results in females. On the other hand, in the turtle, *Chrysema picta*, high egg incubation temperatures result in the production of mostly female progeny,

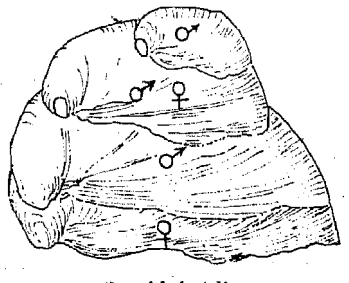

Fig. 3.6: *Crepidulu* (slipper shells), a cluster. The second organism from the top is in the process of changing from male to female. When it undergoes the chnnge and become ♀, it would be fertilised by the top organism which is n male.

An interesting example is of the slipper shell *Crepidula*, where individuals tend to live stacked up on one another (Fig. 3.6). Young *Crepidula* are always male. However, as an individual ages, the male reproductive system degenerates. The reproductive system can then re-form as a male or become female, depending on the sexes of the other organisms in the cluster. If the organism is attached to a female, the reproductive system will redevelop as male. Isolation or the presence of a large number of males will induce a male to become a female. Once a female, the individual will no longer change.

These examples clearly illustrate the diversity of sex determintion mechanisms that exist in nature. Although the segregation on specific sex-determining genes and chromosomes is responsible for sex phenotype, but in most species such as *Bonellia,* Chrysema picta and *Agama agama*, some specific factor in the environment triggers the expression of either the genes producing a male phenotype or the genes producing a female phenotype. This knowledge has a great potential use in agriculture and conservation method (see Box 3.1).

Box 3.1: Sex Determination and Conservation

The information obtained from temperature-dependent sex determination is being used to conserve some species of sea turtles. Sea turtles spend virtually all their lives at sea, except for one night each year when the females laboriously haul themselves onto a beach to dig nests and lay eggs, before returning to the sea. Because turtles arc so vulnerable at this time, many have been taken as food by humans at turtle nesting areas throughout the tropics and the turtle population has declined dramatically in the past century.

Conservationists began collecting eggs from sites, where endangered species nested. These eggs were incubated in captivity, but many of these early efforts were of limited success, because the eggs were incubated at only one temperature. All the artificially reared young were of one sex only.

Since the discovery of temperature-dependent sex determination, conservationists now incubate eggs at several temperatures or in thermally fluctuating environments that mimic the variations found at nesting sites in nature. Thus, young ones of both sexes are produced, and the future of these species is secure.

SAQ 1

Why is sexual reproduction favoured over asexual reproduction in nature?

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SAQ 2

It is not uncommon to encounter self-sterile plants. What is the importance of this phenomenon?

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3.3 GENETIC BASIS OF SEX DETERMINATION

In most organisms, the sex determining mechanism is under genetic control, free of environmental factors. In the genome of higher organisms, there are certain genes or chromosomes which regulates-sex determination and thus sex is determined at the time of fertilisation.

3.3,1 Genic Type

In some organisms, certain **independent genes located on different chromosomes** are responsible for sex determination. Most species of fish illustrate this mode. The male may be represented as AA^1 for the sex determining genes, and the female as AA (Fig. **3.7).** According to this assumption, maleness is determined by the gene A^1 which is dominant over A.

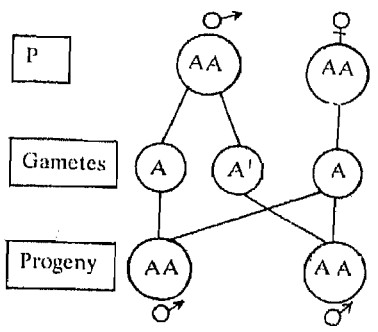


Fig. 3.7: Sex determination in fish at genic level.

In a parasitic wasp, called *Habrobracon,* genes are responsible for sex determination in **a** different way. The sex determining gene has multiple alleles (X^u, X^b, X^c,.X^d). When two alleles in a zygote are different or hcterozygous (X^aX^b, X^aX^c, $X^"X^c$, etc.) a normal, fertile female is formed. If the alleles in the zygote are in homozygous (X^aX^a, X^bX^b, etc.) or hemizygous (X^a,X^b, etc.) condition males arc formed.

3.3.2 Chromosomal Type

It refers to the condition where the genes involved in sex determination arc located on specific chromosomes known as the sex chromosomes.

First, we shall see how the genic type of sex determination evolved into a chromosomal type of sex determination mechanism. In the primitive forms, the only difference between the two sexes was in their gametes. Later in evolution, morphological or phenotypic difference developed in the two sexes of a species.

In primitive forms, sex determination was due to genes on autosomes (the genic type). In the process of evolution, gradually, the genes responsible for sex determination got localised on specific chromosomes – the *sex chromosomes.* These chromosomes were designated as 'X' and 'Y' or 'Z' and 'W', and they can usually bc distinguished morphologically from each other. The remaining chromosomes of the complement are known as. *'autosomes'* and are designated 'A'.

The X and Y chromosomes differ from each other in many respects. This is because, there is accumulation of sex determining genes on the respective sex chromosomes. Also, there is negligible crossing-over between the X and Y chromosomes. This helps to preserve gene combinations favouring distinct sexual differences. The consequence is that the Y chromosome bears mostly the genes essential for the male determination while all the other genes become inert. These regions got reduced in size in some species and are completely lost in others. This was how the heteromorphic sex chromosome evolved.

3.4 CHROMOSOMAL SEX DETERMINATION MECHANISMS

In most of the higher plants and animals, the chromosomal sex determination mechanisms are prevalent. Basically, five types of chromosomal mechanisms exist. These are XX-XY, ZZ-ZW, XX-XO, ploidy level, and compound chromosome system.

3.4.1 The XX-XY System

This is a common mode of sex determination in animals including man and some plants like the angiosperm genus *Lychnis* (see details in subsection 3.5.1). Both the sexes have equal number of chromosomes, of which one pair is of sex chromosomes. In females, the two sex chromosomes are similar and are called the X-chromosomes. Thus, the female is the **homogametic** sex ('homo' meaning same). Males in contrast usually possess an X chromosome, and one chromosome is dissimilar in morphology from all others and is known as the Y chromosome. Because the male sex chromosomes are different, the male is called the **heterogametic** sex ('hetero' meaning different).

In humans, the characteristic diploid chromosome number is 46 (Fig. 3.8). The females have 22 pairs of autosomes **(AA)** and a pair of X chromosomes (AA + XX). The males have 22 pairs of autosomes **(AA)** alongwith an XY pair (AA + XY). The sperms formed are either X-bearing or Y-bearing (Figs 3.8 and 3.9). This sex is

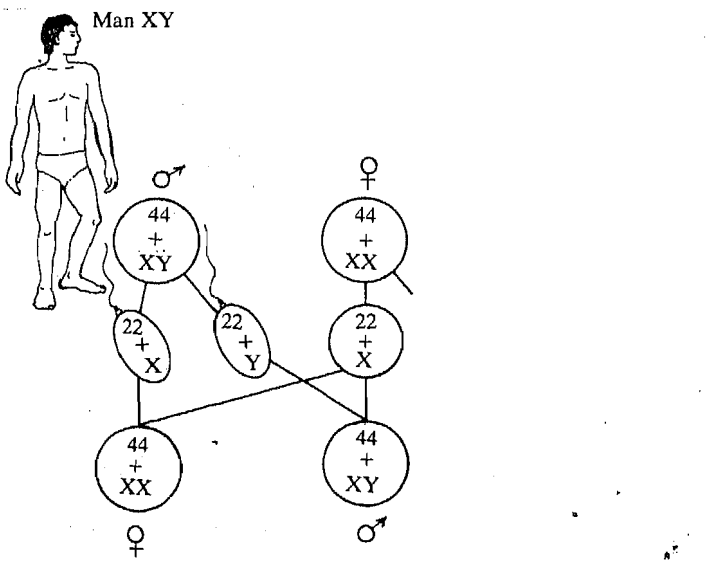


Fig. 3.8 : The XX-XY system of sex determination in man.

determined by the sperm because all eggs are similar and X-bearing. Studies on sex chromosomal abnormalities in man, helped in understanding the crucial role of Y-chromosome in determining maleness. It has been observed that a single Y chromosome, irrespective of the number of X-chromosomes present in the zygote, causes an individual to develop into a phenotypic male. And in the absence of a Y-chromosome, the zygote leads to femaleness. Genes on the Y chromosome direct

Fig. 3.9: Transmission of the sex chromosomes from parents to children.

differentiation of the embryonic gonad to a testis, whose hormonal products then induce a male phenotype. Genes on the Y chromosome also control spermatogenesis. Thus, the presence of the Y chromosome determines maleness, and without a Y chromosome, the female phenotype develops.

3.4.2 A Variation : The ZZ-ZW System

Under this system, the *male is the homogametic sex* and the *female is heterogametic*. In order not to confuse this type of sex determination with the XX-XY mechanisms, the male chromosomes are labelled ZZ, the female ZW. In this system the ovum determines the sex of the resultant offspring, because all sperms carry similar chromosomes. Other than the reversal of homo-, and hetcrogametic sexes, the ZZ-ZW system functions similar to the XX-XY system. This mode of sex determination has been observed in birds including domestic fowl (see Fig. 3.10), butterflies and moths, some fishes, reptiles and amphibians, and in a plant species *Frageria orientalis*.

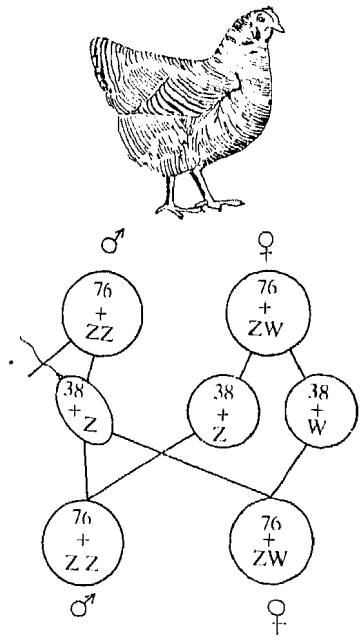


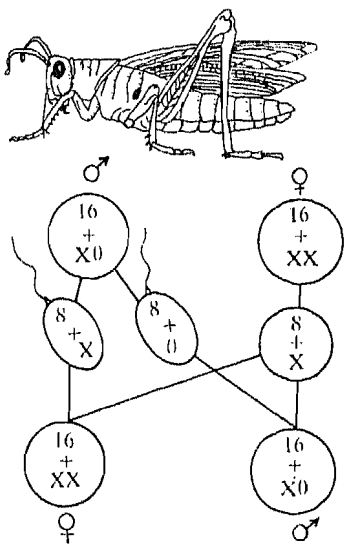
Fig. 3.10: The ZZ-ZW system of sex determination in domestic fowl.

3.4.3 The XX-XO System

In some species, the two sexes have different numbers of chromosomes. The difference often involves the sex determination mechanism. This phenomenon is called the XX—XO system (O indicates the absence of one sex chromosome). The female has two sex chromosomes just as in the XX—XY system, but the male has only one and is thus designated XO. In the species exhibiting this system, the diploid number of the chromosomes in male is one less than that of the female as a result of the absence of one sex chromosome. Consequently, the number of chromosomes is odd in males and even in females. The grasshopper (Fig. 3.11) is a good example of this mode of sex determination. The cricket and the beetle also exhibit a similar chromosomal basis of sex determination.'

3.4.4 Sex Determination by Ploidy Level

In many species of hymenoptera (bees and wasps) and some mites and ticks, sex is determined by the number of sets of chromosomes or ploidy of the individual. Females are diploid, producing haploid gametes via meiosis. Most eggs are fertilised by haploid sperm from males, but a few arc not. The fertilised eggs become females that show biparental inheritance. While the unfcrrilised eggs develop into haploid males (by parthenogenesis) that inherit their genes exclusively from their mother (Fig. 3.12). Haploid individuals, of course, cannot undergo normal meiosis, so males produce gametes via mitosis.



Pig. 3.11: The XX-XO system of sex determination in grasshopper.

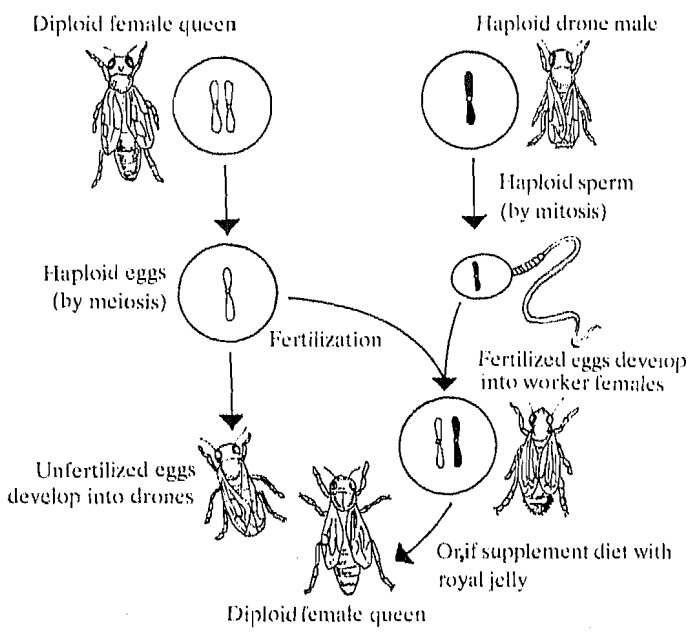


Fig. 3.12: Sex determination by ploidy level in honeybee.

Because males do not undergo meiosis for gamete production, all the sperm from one individual are genetically identical to each other and to the male parent. This has the interesting consequence of increasing the gametic relatedness of a male's

daughters. Remember in this system, a male produces no sons – only daughters. On an average, all daughters of one mated pair of bees share 75% of their genes, rather than the normal *50%* relatedness of offspring of most species. The daughters are identical for all the 50% of the genes received from their father, plus one-half of the 50% of the genes from their mother, this makes a total of 75% genetic relatedness.

In some vertebrates also unusual degrees of ploidy are associated with a particular sex. Some species of lizards consist of mostly triploid (3N) females and few males. In fact, males are superfluous, because the females develop *parthenogenetically*. A triploid female produces a triploid egg through mitosis, which undergoes complete development without being fertilised. Haploid males too develop parthenogenetically in the similar manner.

3.4.5 The Compound Chromosome System

Although the X is most commonly found as a single chromosome or single homologous pair or chromosomes, some species have another variation – compound chromosomes. These are named so because a group of chromosomes (e.g. 8X, 12X, 6Y etc.), at the time of meiosis unite end to end and behave as single unit. In such specics, there are large differences in the number of chromosomes in males and females. For example, in the nematode *Ascaris incurva* there arc 8X chromosomes and 1Y. This species has 26 autosomes. The diploid number of chromosomes in males is 35 (i.e., 26A + 8X + Y), and in females is 42 (or 26A + 16X).

In the above example, X chromosomes exist as a compound chromosome. There are instances where both, the Y chromosomes and the X chromosomes form compound groups., One such example is of *Blaps polychresta*, where the male has 12X's and 6Y's in addition to 18 autosomes.

3.4.6 The Transfer Gene

One additional complicating factor in sex determination in *Drosophila* is worth examining briefly. This shows that the sex chromosomes (X and Y, Z and W) are not the only ones involved in sex determination, but in addition numerous autosomal genes also come into play. In *Drosophila* a recessive allele, *tra,* on the third chromosome (an autosomc), when homozygous, "transforms" normal diploid females (AAXX) into stcrilc males. The *tra* gene has no effect in heterozygous condition. The XX *tra tra* flies have many sex characters of males (external genitalia, sex combs (see Fig. 3.13), and male type abdomen), but arc sterile. So are XXY *tra tra* flies. The XY *tra tra* males, however, are normal and fertile.

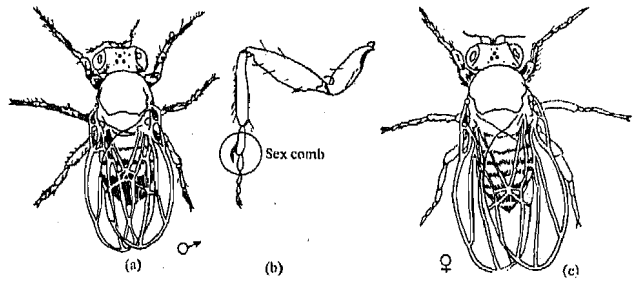


Fig. 3.13: ***Drosophila melanogaster*, (a) male, (b) female. Two distinguishing features are: the merging of the posterior bands in the male versns their distinct separation in the female, and Ihc longer more tapering abdomen of the female. (c) shows details of a male leg with sex comb (arrow).**

3.5 SEX DETERMINATION : AN EXTENSION

This section pertains to some extensions of the XX-XY system discussed in the previous section. We shall discuss them with the help of two representative organisms: *Melandrium* and *Drosophila*.

3.5.1 *Melandrium*

Sex determination in a following plant named *Lychnis dioica* (formerly the genus *Melandrium*) of pink family (Caryopyllaceae) has been extensively investigated. This plant illustrates a *variation of* XX-XY *system*. The chromosome composition varies

between male and female plants of this species. This plant usually has four autosomal pairs of chromosomes and a pair of sex chromosomes. The male contains four pairs of autosomes plus an **X** and a **Y** chromosome. Female plants contain the same number of autosomes as the male but have two **X** chromosomes. In this plant abnormal chromosome composition is often seen. A correlation of abnormal chromosome composition in plants with the sex of the individual is depicted in Table 3.1.

Table 3.1: A comparison of chromosome and sex in *Melandrium*. (From: Klug W.S. and Cummings, M.R. 1983)

Chromosome Composition		Sex
Number of Sets of Autosomes (A)	Sex Chromosomes	
2A	XX	**Normal** Female
2A	XY	**Normal** male
2A	XXX	Female
3A	XX	**Female**
4A	XXXX	Female
2A	XYY	Male
2A	XXY	Male
3A	XY	Male
3A	XXXY	Male
4A	XXXY	Male

The Y chromosome has a strong masculinising influence, because when it is present, a male plant is always produced. The **X** chromosome has a feminising influence, but its influence is masked by the action of Y chromosomes. The **XXY** and XXXY plants are malc (see Table 3.1) despite the presence of two and more **X** chromosomes.

Cytological studies have shown that the Y chromosomes is larger than the X chromosome, and any of the autosomes. Compare the X and Y chromosome in Fig. 3.14. Only a small portion of the **X** chromosome is homologous with a similar small bit of the Y chromosome, i.e., region IV. Regions I and IV of the Y chromosome suppress female developmenl, counteracting the influence of region V of the X which promotes female development. If either region I or IV is missing, bisexual development occurs. Region II promotes the male development, and if male tissue develops, region III is essential for male fertility. In the absence of region III, malc tissue develops, but the plant is sterile. A region of the X chromosome is also designated IV because it has been identified as the only part of the chromosomc which synapses with the **Y** chromosomc during meiosis.

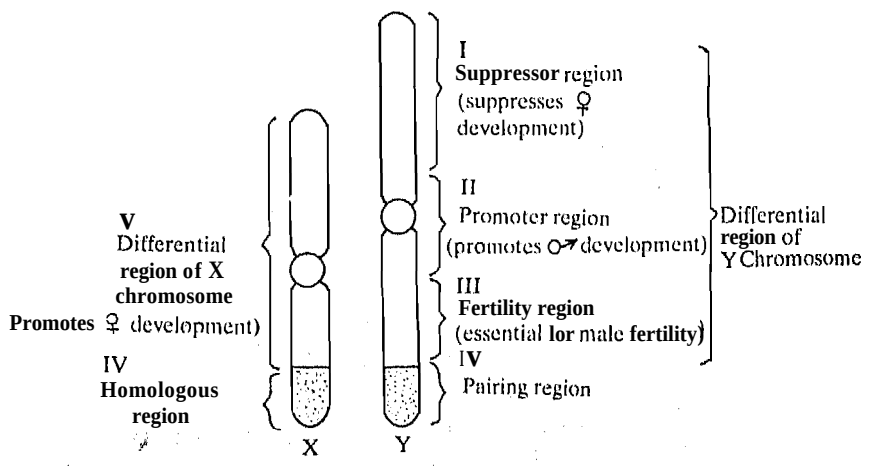


Fig. 3.14: X and Y chromosomes of *Lychnis*. Regions I, II and III bear holandric genes; and region V. X-linked genes. Genes in region IV nre termed incompletely sex-linked. Note, the Y chromosome is larger than the X chroniosome,

3.5.2 *Drosophila*

A special mention of *Drosophila* is necessary because it has played a key role in the study of inheritance. Let us now have a look at its sex determining mechanisms.

Pig. 3.15: Calvin B. Bridges (1884-1938). American geneticist who pioneered in research on chromosomes of *Drosophila melanogaster.*

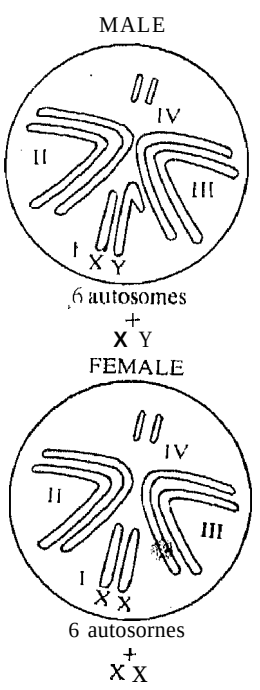


Fig. 3.16: The chromosomal composition of male and female *Drosophila melanogaster.*

The preliminary findings showed that a XX-XY system is operative in the determination of sex in *Drosophila.* It means that male *Drosophila* is heterogametic (XY). One might have assumed that the Y chromosome determines maleness in this species were it not for the investigations of Calvin B. Bridges (Fig. 3.15) in 1916. His investigations showed that the female determiners were located on the X chromosomes and male determiners were on the autosornes. No specific loci were identified at the time, but more recent evidence has demonstrated that many chromosome segments are involved. Specifically, *female-determining genes were shown to be carried on the X chromosomes, and male determining genes were* shown to be located *on the three autosomal chromosomes.*

It is apparent that Y chromosome is not needed at all for the life or even for maleness, as a fly can be male without a Y or can be female with one Y. Nevertheless, Y is essential for fertility, and is thus critical to the survival of the species and is not required for the determination of any sex.

The genic balance theory of sex determination was devised to explain the mechanism of sex determination in *D. melanogaster.* Bridges experimentally produced various combinations of X chromosomes and autosomes in this organism and deduced from comparisons that on X chromosome and two sets of autosomes (A) produced a normal male. The normal males had a ratio of X chromosomes to sets of autosomcs of 0.5. Note that a set of autosomes consists of chroinosomcs II, III and IV (set: Fig. 3.16). The combination of one X and two A's resulted in a normal diploid male; the combination of two X chromosomes and two sets of autosomes (2X + 2A, ratio of 2:2=1) produced a normal diploid female (see Table **3.2).**

To sum up, if the X/A ratio is 0.5 then the sex is male, and when 1.0 it is female. Any ratio between 0.5 and 1.0 results in intersexes. And those above 1.00 result in metafemale or superfemale, whereas those below 0.5 result in metamale (see Table 3.2).

Table 3.2: Ratio of X chromosomes to autosomes and corresponding sex types in *Drosophila melanogaster.* (After Bridges 1925, *American Naturalist, volume 59, pp 127-137.)*

X Chromosomes (X) and Sets of Autosomes (A)	Ratio X/A	Sex
1X 2A	0.5	Male
2X 2A	1.0	Female
3X 2A	1.5	Metafemale
4X 3A	1.33	Metafemale
4X 4A	1.0	Tetraploid female
3X 3A	1.0	Triploid female
3X 4A	0.75	Intersex
2X 3A	0.67	Intersex
2X 4A	0.5	Tetraploid male
1X 3A	0.33	Metamale

The first irregular chromosome arrangement from Bridges experiments resulted from nondisjunction—the failure of paired chromosome to disjoin or separate at anaphase. The X chromosomes, which ordinarily come together in pairs during the meiotic prophase of oogenesis and separate to. opposite poles during anaphase remained together and migrated to the same pole. As a result some female gametes received two X chromosomes and some received no X chromosome (Fig. 3.17).

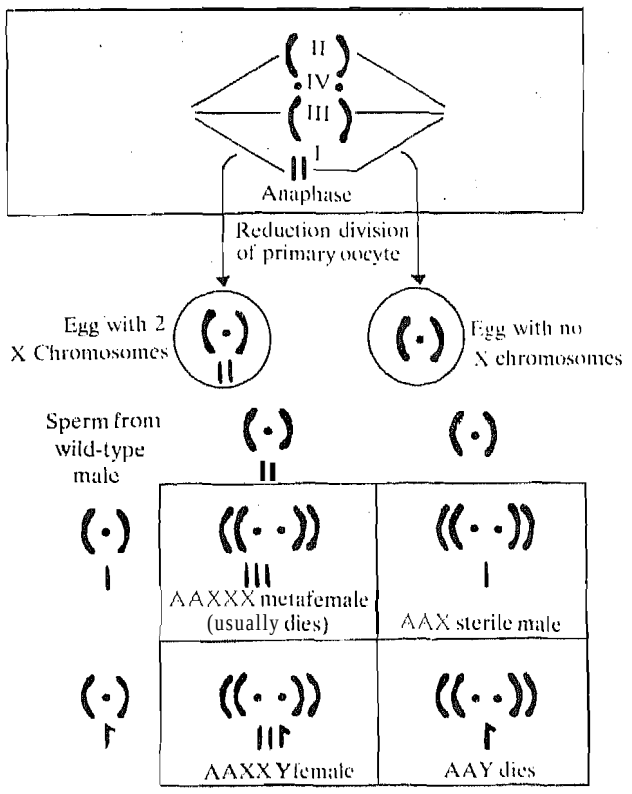


Fig. 3.17: **Nondisjunction** in *Drosophila*, and **the** zygotes that **result from fertilisation** by wild-type **males (AAXY). The AAXXY females** nnd the AAX **males were** exceptionrl flies in Bridge's experiment. In **the** primary **oocycte, autosomes** II and III nre represented by pairs of bent rods: **autosomes** IV, which are small and **take** their plnce in **the** centre of **the** equatorial plate, are represented **by** n pair of dots. The **X chromosomes** (I) nre **symbolised as short** rods; the **Y chromosome** introduced by the sperm is illustrnted **by** an inverted 'J' **shaped** symbol.

Following fertilisation by sperm from wild-type males (AAXY), all zygotes had 2n autosomcs (2A), but some received two X's from the mother and an X from the father (3X). The ratio of X chromosomes to sets of autosomcs of 3:2 rcsultcd in flies called **metafemales** that were inviable. The XXY flies (2X/2A) from the same mating were normal females in appearance. The XO (1X/2A) males arc sterile, and those with a Y chromosome but no X did not survive. These results clearly show that, the *Y chromosome is not involved in sex determination.* It is, however, *required for male fertility.*

The flies with 4X/3A were also metafemales. Those with 4X/4A and also those with 3X/3A, both with an X/A ratio = 1 were females. The combinations 3X/4A = 0.75 and 2X/3A = 0.67 wcrc intermediate in characteristics between males and females and were called "**intersexes**". Combination of 2X/4A = 0.5 were males and those of 1X/3A = 0.33 wcrc metamales.

No other species has been as thoroughly investigated as *D. melanogaster.* The knowledge thus obtained has been used to understand the sex determination mechanisms operating in many other organisms.

SAQ 3

The diploid chromosome number of honey bee is 32. How many chromosomes will be found in the somatic cells of a) males, b) females, and in c) the sperm, and d) egg?

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SAQ 4

What would be the phenotypic sex of following human beings having 22 autosomcs as a haploid set and rcprescnted by 'A'?

a) AAXXX, b) AAXXY, c) AAX

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SAQ 5

A mother claims that her son was the result of parthenogenesis. a) Do you think her claim is justified? If not, why? b) What would be the sex of such a child?

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SAQ 6

What is the sex of the following individuals of *Drosophila*?

a) AAAXXX, b) AAAAXX, c) AAX

.....

.....

SAQ 7

The cells of a grasshopper are analysed and found to contain 23 chromosomes. a) What is the sex of this individual? b) What is the haploid number of chromosomes in. the species?

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3.6 SUMMARY

In this unit you have learnt that:

- Sexual reproduction is responsible for genetic variability which is extremely important for biological evolution. To ensure genetic variability different mating types of sexes evolved.
- In some plants and in the majority of animals separate male and female sexes are present, a condition called dioecious (monosexual) in plants and bisexual in animals.
- Hermaphrodites possess sexual characteristics of both sexes.
- The mechanisms of sex determination may either involve environment, or genetic or both the factors.
- Genes located on specific chromosomes or all the chromosomes are responsible for genetic determination of sexes. The chromosomes having different forms in two sexes ate often involved in determining sex and are known as the sex chromosomes. The major chromosomal sex determination mechanisms are: XX-XY system; ZZ-ZW system; XX-XO system: ploidy level; and compound chromosome system.

3.7 TERMINAL QUESTIONS

1) In *Bonellia,* environment influences sex determination. Contrast this mode of sexual determination with that in turtles.

2) Contrast the mode of sex determination in *Drosophila* and man.

3) Match the following:

i) Honeybee	a) environmental type
ii) *Melandrium*	b) XX-XO system
iii) Grasshopper	c) X:A ratio in the XX-XY system
iv) *Drosophila*	d) masculinising influence of Y chromosome
v) *Bonellia*	e) ploidy level

4) What difference exists between male- and female-determining sperm in animals with heterogarnetic males?

5) In linc with the Bridge's Genic theory of sex determination, what is the expected sex of individual with each of thc following chromosome arrangements: a) 4X4A, b) 3X4A, c) 2X3A, d) 1X3A, *c)* 2X2A and f) 1X2A?

6) List the expcctcd results in terms of sex and intersex combinations from a cross bctwecn a triploid (3n) female fruit fly, with two X chromosomes'attached and one free, and a normal diploid male. (Assume that the cross is successful and the gametes of the female will carry one or two whole sets of autosomes).

7) In plants of the genus *Melandrium,* which sex will be determined by the following chromosome arrangements: a) XY, b) XX, c) XY with region I removed, and d) XY with region H removed?

ti) What sox is cxpcctcd for individuals of the following genotypes in *Habrobracon* : a) X^bX^b, b) X^aX^b, c) X^cX^c and d) X^bX^c?

3.8 ANSWERS

Sell-assessment Questions

1) Sexual reprocluction is favoured over asexual reproduction because it provides variability by genetic recombination.

2) Self-sterility in plants encourages cross-fcrtilisation. The resulting sexual reproduction allows genetic exchange.

3) a) 16 b) 32 c) 16 d)16

4) Phenotypc of AAXXX and AAX is female since there is no Y chromosome while that of AAXXY is male since a Y chromosome is present.

5) a) The claim is in all likelihood not justified since parthenogenesis has not been scientifically reported in man, and fertilisation of female gamete by a male gamete is essential to stimulate embryological dcvelopmcnt.

   b) Even if it is conceded that such an event of parthenogenesis has occurred, then the child will be a fernalc. This is because the dcvelopmcnt of the child has occurred from the ovum and there is no chance of a Y-chromosome being present in the mother.

6) Sex of the *Drosophila* is **a)** female b) male and c) male, based on the ratio of X chromosomes to the number of sets of autosomes.

7) a) The sex of the grasshopper with 23 chromosomes is male, as fcmales possess all paired chromosomes.

   b) The haploid number of the species is 12.

Terminal Questions

1) Refcr to Subsection 3.2.3.
2) See Sections 3.4, and 3.5

3) i) e
   ii) d
   iii) b
   iv) c
   v) a

4) Male Y and female X bearing sperm.

5) a) female (tetraploid)
   b) intersex
   c) intersex
   d) metamale
   e) female (diploid)
   f) male (sterile if no Y chromosome is present in *Drosophila*)

6) Female gametes would be (2X2A), (2XA), (X2A), and (XA). Zygotes and sex would be 3X3A female (triploid), 3X2A metafemale, 2X3A intersex, 2X2A female (diploid), 2XY3A intersex, 2XY2A female, XY3A metamale, XY2A male.

7) a) Male
   b) female
   c) bisexual
   d) female

8) a) male
   b) female
   c) male
   d) female