

## 7. SEX DETERMINATION

Sex refers to the contrasting features of male and female individuals of the same species. Thus, sex is usually of two types *viz.*, male and female. Sex determination is a process of sex differentiation which utilizes various genetical concepts to decide whether a particular individual will develop into male or female. Plants also have sex as there are male and female parts in flowers. All organisms, however do not possess only two sexes. Some of the protozoa may have as many as eight sexes. In most higher organisms, the number of sexes has been reduced to just two. The sexes may reside in different individuals or within the same individual. An animal possessing both male and female reproductive organs is usually referred to as hermaphrodite. In plants where staminate and pistillate flowers occur in the same plant, the term of preference is monoecious Eg: maize, castor, coconut etc. However, most of the flowering plants have both male and female parts within the same flower (perfect flower). Relatively few angiosperms are dioecious i.e. having male and female elements in different individuals Eg:cucumber, papaya, asparagus, date palm, hemp and spinach. The sex cells and reproductive organs form the primary sexual characters of male and female sexes. Besides these primary sexual characters, the male and female sexes differ from each other in many somatic characters known as secondary sexual characters. Whether or not there are two or more sexes in the same or different individuals is relatively unimportant. The importance of sex itself is that it is a mechanism, which provides for the great amount of genetic variability characterizing most natural populations.

### **The various mechanisms of sex determination are:**

1. Chromosomal sex determination
2. Genic balance mechanism
3. Male haploidy or Haplodiploidy mechanism
4. Single gene effects (or) mono factorial mechanism of sex determination
5. Metabolically controlled mechanism
6. Hormonally controlled mechanism
7. Sex determination in *Coccinia indica* and *Melandrium album*,

## 8. Sex determination due to environmental factors

**I. Chromosomal sex determination:** The chromosomes, which have no relation with sex and contain genes, which determine the somatic characters of an individual are known as autosomes. These chromosomes do not differ in morphology and number in male and female sex. Those chromosomes, which differ in morphology and number in male and female sex and contain genes responsible for the determination of sex are known as allosomes or sex chromosomes.

### Differences between Autosomes and Allosomes

Autosomes	Allosomes or Sex chromosomes
1. Refer to other than sex chromosomes	1. These are sex chromosomes.
2. Morphology is similar in male and female sex.	2. Morphology is different in male and female sex.
3. The number is same in both the sexes.	3. The number is sometimes different in male and female sex.
4. Generally, control traits other than sex	4. Usually determine sex of an individual.
5. Number of autosomes differs from species to species.	5. Each diploid organism usually has two allosomes
6. Do not exhibit sex linkage.	6. Exhibit sex linkage.

The chromosomal influence on sex, in certain insects, has been shown for the first time by McClung in 1902 to be associated with a special sex determining 'X' chromosome. McClung proposed that a male had one 'X' chromosome per cell (XO) and a female has two 'X' chromosomes (XX). Later Stevens and Wilson (1905) found same number of chromosomes in both sexes of milk weed bug. In females, all chromosomes were paired and the homologues were equal in size (homomorphic). In the male, all the chromosomes were paired, but the chromosome identified as homologous to the "X" Chromosome was distinctly smaller and was called the "Y" Chromosome (Heteromorphic).

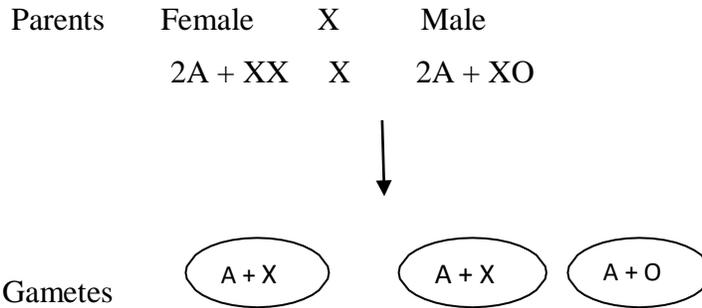
Thus, allosomes are generally of X and Y types, but in birds they are of Z and W types. Sex with similar type of sex chromosomes (XX or ZZ) is known as homogametic sex and with dissimilar type of sex chromosomes (XY or ZW) as heterogametic sex. These are two types:

- a) Heterogametic male and
- b) Heterogametic female

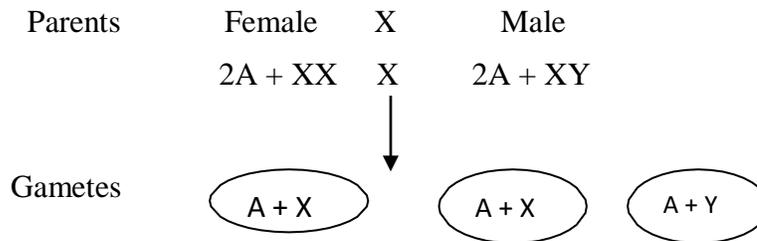
**a) Heterogametic male:** In this mechanism, the female sex has two 'X' chromosomes, while the male sex has only a single 'X' chromosome. As the male lacks a 'X' chromosome during meiosis, 50% of the gametes carry 'X' chromosome, while the rest do not have the 'X' chromosome. Such a mechanism, which produces two different types of gametes in terms of sex chromosome is called heterogametic sex. The female sex here is called homogametic sex because it produces similar type of gametes. The heterogametic male may be of the following two types.

- i)  $XX - XO$     ii)  $XX - XY$

*i) XX - XO:* In certain insects belonging to orders *Hemiptera* (true bugs), *Orthoptera* (grasshoppers) and *Dictyoptera* (cockroaches), female has two 'X' chromosomes (XX) and are, thus homogametic, while male has only single 'X' chromosome (XO). This mechanism was found by C.E. McClung in 1902. The presence of an unpaired X chromosome determines the masculine sex. The male being heterogametic sex produces two types of sperms, half with X chromosome and half without X chromosome in equal proportions. The sex of the offspring depends upon the sperm that fertilizes the egg, each of which carries a single X chromosome. Thus, fertilization between male and female gametes always produced zygotes with one 'X' Chromosome from the female, but only 50% of the zygotes have an additional X Chromosome from the male. In this way, 'XO' and 'XX' types would be formed in equal proportions, the former being males and the latter being females.



ii) **XX – XY:** In man, other mammals, certain insects including *Drosophila*, certain angiospermic plants including *Melandrium*, the females possess two X chromosomes (XX) and are thus homogametic and homomorphic, while the males possess one X and one Y chromosome (XY) and are hence heterogametic and heteromorphic. When an egg is fertilized by ‘Y’ bearing sperm, a male is produced.



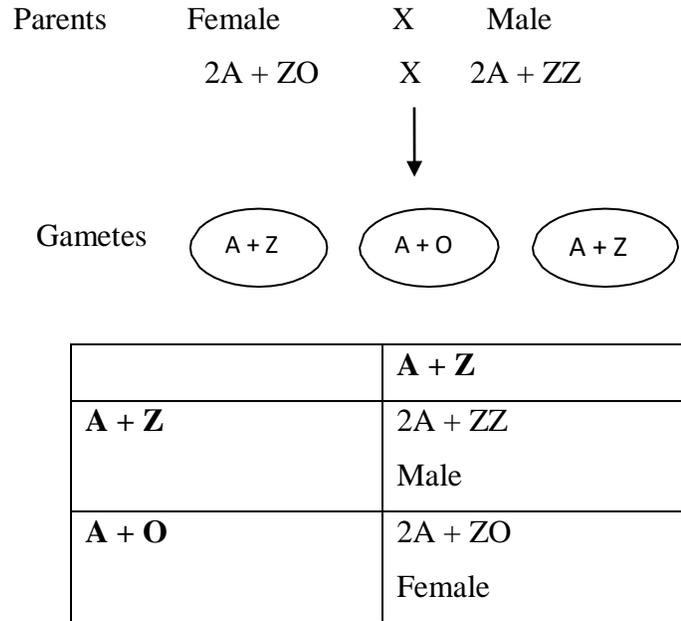
	<b>A + X</b>	<b>A + Y</b>
<b>A + X</b>	$2A + XX$ Female	$2A + XY$ Male

**b) Heterogametic female:** In this mechanism, the male possesses two homomorphic sex chromosomes and are thus homogametic, while the female possesses either a single ‘X’ chromosome or one ‘X’ and one ‘Y’ chromosome and are hence heterogametic. To avoid confusion with earlier types, instead of X and Y, the alphabets Z and W are used. This mechanism of sex determination is also known as “Abraxas mechanism of sex determination” (Kuspira and Walker, 1973). The heterogametic females may be of following two types.

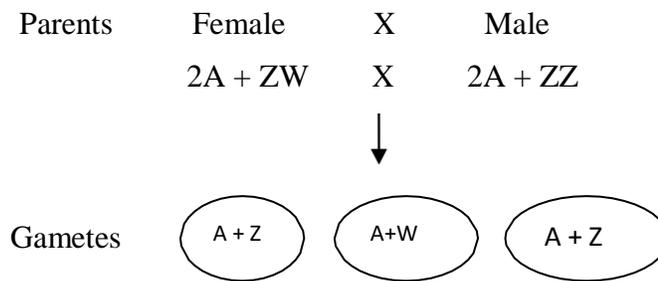
i) ZO – ZZ

ii) ZW – ZZ

i) **ZO – ZZ:** This mechanism is found in certain moths and butterflies. In this case, female possess one single 'Z' chromosome and hence is heterogametic. Male possesses two Z chromosomes and thus homogametic.



ii) **ZW – ZZ:** This system is found in certain insects (gypsy moth) and vertebrates such as fishes, reptiles and birds. In this system, the female is heterogametic and produces two types of gametes, one with 'Z' chromosome and the other with 'W' chromosome. On the other hand, male is homogametic and produces all sperms of same type carrying one 'Z' chromosome. The sex of the offspring depends on the kind of egg being fertilized. The 'Z' chromosome bearing eggs produce males, but the 'W' chromosome bearing eggs produce females.



	<b>A + Z</b>
<b>A + Z</b>	2A + ZZ Male
<b>A + W</b>	2A + ZW Female

**II) Genic balance mechanism:** By studying the sex chromosomal mechanism of sex determination, it may appear at first glance that some genes carried by sex chromosomes i.e. X and Y are entirely responsible for determining sex. But this may not always be true. Extensive experiments on different organisms by different workers have revealed the fact that most organisms generally have inherent potentialities for both sexes and each individual is found to be more or less intermediate between male and female. Hence may be referred to as intersex. There seems to exist a delicate balance of masculine and feminine tendency in the hereditary complement of an individual. Such a genic balance mechanism of determination of sex was first observed and studied by C.B. Bridges in 1921 while working with *Drosophila* for the inheritance of vermilion eye colour. According to this mechanism, the sex of an individual in *Drosophila melanogaster* is determined by a balance between the genes for femaleness located in the X-chromosome and those for maleness located in autosomes. Hence, the sex of an individual is determined by the ratio of number of its X chromosomes and that of its autosomal sets, the 'Y' chromosome being unimportant. The ratio is termed as sex index and is expressed as follows.

$$\text{Sex index} = \frac{\text{No. of X chromosomes}}{\text{No. of autosomal sets}} = \frac{X}{A}$$

**Different doses of X – Chromosomes and autosome sets and their effect on sex determination**

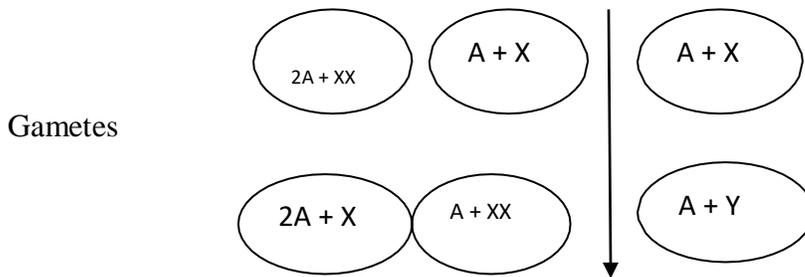
S.No.	Ploidy level	X-Chromosomes	Sets of autosomes	Sex index (X/A ratio)	Sex Expression
1.	Diploid	3(xxx)	2(AA)	1.50	Super female Or meta female
2.	Triploid	4(xxxx)	3(AAA)	1.33	
3.	Haploid	1(x)	1(A)	} 1.00	Female
4.	Diploid	2(xx)	2(AA)		
5.	Triploid	3(xxx)	3(AAA)		
6.	Tetraploid	4(xxxx)	4(AAAA)		
7.	Triploid	2(xxy)	3(AAA)	0.67	Inter sex
8.	Tetraploid	3(xxyy)	4(AAAA)	0.75	
9.	Diploid	1(xy)	2(AA)	} 0.5	Male
10.	Tetraploid	2(xxyy)	4(AAAA)		
11.	Triploid	1(xyy)	3(AAA)	0.33	Super male or meta male

Individuals with sex index of 0.5 develop into normal males and those with sex index of 1 into normal females. If the sex index is between 0.5 and 1, the resulting individuals will be neither a female nor a male, but have an intermediate sex expression and is called inter sex. Such individuals are sterile. Some flies have sex index of >1, such flies have more pronounced female characteristics than normal females and are called super females or metafemales. These are generally weak, sterile and non-viable.

Super male flies have a sex index value of <0.5 and are also weak, sterile and non-viable. Bridges drew the observation by crossing triploid females (3A + XXX) with normal diploid males (2A + XY). From such a cross, he obtained normal diploid females, males, triploid females, intersexes, super males and super females. The occurrence of triploid intersexes from such a cross clearly established that autosomes also carry genes for sex determination. Triploid individuals, which had two 'X' Chromosomes as in the case of normal female, here were inter sexes as they had an extra set of autosomes indicating that the autosomes play a definite role in the determination of sex.

**Results obtained from a cross of a triploid (3A+XXX) female fly with a diploid (2A+XY) male fly in *Drosophila***

Parents	Female	X	Male
Phenotype	Triploid	X	Diploid
Genotype	3A + XXX	X	2A + XY



	A + X	A + Y
2A + XX	3A + XXX Triploid female	3A + XXY Triploid inter sex
A + X	2A + XX Diploid female	2A + XY Diploid male
2A + X	3A + XX Triploid inter sex	3A + XY Super male
A + XX	2A + XXX Super female	2A + XXY Diploid female

**III. Male haploidy or haplodiploid mechanism or arrhenotokous**

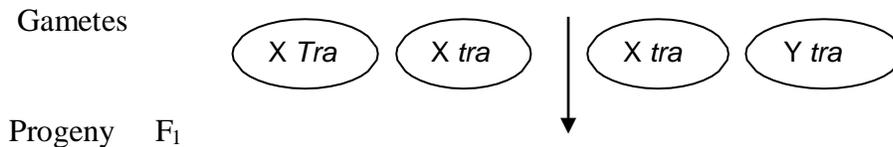
**parthenogenesis:** It is common in hymenopterans insects (ants, bees, wasps). In honey bees, queens usually mates only once during its life time and the sex ratio of offspring is under the control of queen. Fertilized eggs develop into diploid female and those eggs which the queen chooses not to be fertilized develop parthenogenetically into haploid but fertile males (drones). This phenomenon is

known as arrhenotoky and is a form of reproduction as well as a means of sex determination. Meiosis is normal during oogenesis in case of females and produces all haploid eggs. But crossing over and reduction division fails to occur during spermatogenesis in males due to their haploid nature. Thus, arrhenotokous parthenogenesis determines the sex in hymenopterans and sex chromosomes have no identity here (unlike *Drosophila*). It seems that heterozygosity for specific genes induces femaleness. The haploid can never be heterozygous. Most of the eggs laid in the hive will be fertilized and developed into worker females. Further during investigation, it has been found that the quantity and quality of food available to the diploid larvae determines whether that female will become a sterile worker or a fertile queen. The diploid larva, which feed on royal jelly, develop into fertile female called queen and the remaining larvae give rise to workers, which are sterile females. Thus, environment here determines sterility or fertility but does not alter the genetically determined sex.

**IV. Single gene effect or monofactorial mechanism of sex determination:** In *Neurospora*, *Asparagas*, *Drosophila*, maize and *Asparagus*, sex determination is influenced by the differential action of a single autosomal gene, which over rules the effect of sex chromosomes present in the individual.

Autosomal recessive transformer (*tra*) gene of *Drosophila*; when it is present in the homozygous recessive state, it transforms the female (XX) zygote to develop into males which are sterile. The gene *tra* is recessive and hence does not have any effect in heterozygous condition (*Tratra*) on either sex i.e male or female. In homozygous condition, (*tratra*), this gene has no effect in male. When a heterozygous (XX *Tratra*) female is mated with a homozygous recessive male (XY *tratra*), only 25% of the progeny are females (heterozygous) while remaining 75% are males. Among the males, 1/3 are sterile (XX individual's homozygous recessive for *tra* gene) as they are transformed to maleness by the *tra*.

Parents	Female	X	Male
Genotype	XX <i>Tratra</i>	X	XY <i>tratra</i>



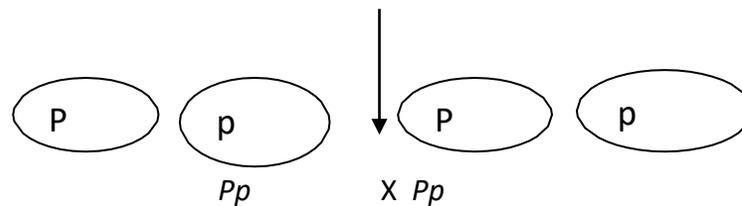
	<b>X tra</b>	<b>Y tra</b>
<b>X Tra</b>	XX <i>Tratra</i> Female fertile	XY <i>Tratra</i> Male fertile
<b>X tra</b>	XX <i>tratra</i> Male sterile (Transformed)	XY <i>tratra</i> Male fertile

**Ratio: 3 Males: 1 Female**

Monogenic control of sex has also been reported in some plants like *Asparagus*, maize, papaya, spinach, etc. *Asparagus* is a dioecious plant. However, rarely female flowers bear rudimentary anthers and male flowers bear rudimentary pistils. Occasionally, male flowers with poorly developed pistils set seed on selfing and segregate in 3: 1 ratio of male and female.

**Segregation of sex in seed obtained from a rare bisexual flower in *Asparagus* showing monogenic control**

Rare male plant when selfed



	P	p
P	<i>PP</i> Male	<i>Pp</i> Male
p	<i>Pp</i> Male	<i>Pp</i> Female

**Ratio: 3 Males: 1 Female**

Maize being a monoecious plant bears both female (silk) and male (tassel) inflorescences on the same plant. A recessive gene *ba* (barren cob) in homozygous condition (*baba*) makes the cobs barren or non-functional. Similarly, a recessive gene *ts* in homozygous condition (*tsts*) converts the male flowers of tassel into female flowers. Thus, homozygous state of gene *ba* (*baba*) converts the monoecious plant into male. Similarly, gene *ts* in homozygous condition (*tsts*) converts the monoecious plant into female. The plants with both dominant genes (*BaTs*\_ ) are monoecious, with *babaTs*\_ normal male, with *Ba\_tsts* female, and with *babatsts* rudimentary females.

In papaya, the sex is postulated to be governed by three alleles, viz., *m*, *M1* and *M2* of a single gene. Homozygous recessive (*mm*) produces female plants, heterozygous, viz., *M1m* and *M2m* produce male and hermaphrodite plants, respectively. However, combination of both dominant alleles (*M1* and *M2*) produces inviable plants both in homozygous (*M1M1* and *M2M2*) and heterozygous conditions (*M1M2*). Crosses between female (*mm*) and male (*M1m*) produce females (*mm*) and males (*M1m*) in 1: 1 ratio. Similarly, crosses between female (*mm*) and hermaphrodite (*M2m*) will produce females (*mm*) and hermaphrodite (*M2m*) in 1: 1 ratio. Selfing of hermaphrodite (*M2m*) plants produce hermaphrodite (*M2m*) and female (*mm*) progeny in 2: 1 ratio and about ¼ of the zygotes (*M2M2*) do not survive.

**V. Metabolically controlled mechanism:** Riddle found that metabolism has some definite role in the determination of sex in pigeon and dove because increased rate of metabolism lead to the development of maleness while decreased rate of metabolism caused femaleness.

**VI. Hormonally controlled mechanism:** Crew in 1923 reported a complete reversal of sex in hen. Female chicken that have laid eggs been known to undergo not only a reversal of the secondary sexual characteristics such as development of cock feathering, spurs and crewing, but also the development of testis and even the production of sperm cells (primary sexual characteristics). This might have occurred when a disease destroyed the ovarian tissue and in absence of female sex hormones, rudimentary testicular tissue present in center of ovary began to proliferate or multiply and secrete male hormones, which lead to the development of maleness.

Sexual differentiation in man is influenced by hormones. When the testis of the male is removed before puberty, female characteristics of body form, voice and hair pattern develop in the adult. Tumors of adrenals in women are associated with the development of masculine characters such as low-pitched voice and increased growth of hair.

**VII. Sex determination in *Coccinia indica* and *Melandrium album*:**

Ploidy level	Chromosome Constitution (Autosomes) + (Allosomes)	Sex Expression	X/A ratio
Diploid	AA + XX	Female	1.00
Diploid	AA + XY	Male	0.50 (1/2)
Diploid	AA + XYY	Male	0.50 (1/2)
Triploid	AAA + XXX	Female	1.00
Triploid	AAA + XXY	Male	0.67 (2/3)
Tetraploid	AAAA + XXXX	Female	1.00
Tetraploid	AAAA + XXXY	Male	0.75 (3/4)

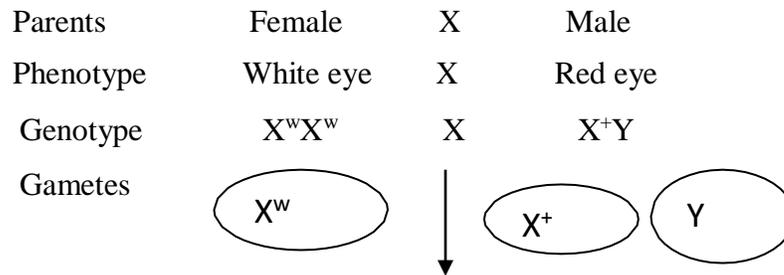
In these two organisms, studies have revealed that irrespective of number of ‘X’ chromosomes, and / or autosomal sets, presence of a single ‘Y’ chromosome is essential to produce male flowers in diploid, triploid and tetraploid species. The pistillate plants are XX and the staminate plants are XY.

**Sex determination due to environmental Factors:** In many reptiles, sex is determined by environmental factors like temperature. In most turtle species only females are produced at high temperature (30 – 35°C) while only males are produced at low temperatures (23 – 28°C). Sex ratio changes suddenly from all males to all females with just change in temperature of 2°C during the incubation. In Crocodiles and Lizards, (reverse is the case) the males are produced at high temperature while females are produced at low temperature. In *Bonellia viridis*, a marine worm, all larvae are genetically and cytologically similar. If a particular larva settles near proboscis of adult female, it becomes a male individual. If larva develops freely in water, it becomes a female. In some plants, sex determination depends on day length, temperature and hormones. For example, in cucumber (*Cucumis sativa*) and muskmelon, treatment with ethylene enhances production

**SEX LINKED INHERITANCE**

The characters for which genes are located on sex or ‘X’ or analogous ‘Z’ chromosomes are known as sex linked traits. Such genes are called sex linked genes and linkage of such genes is referred to as sex linkage. Inheritance of such genes or characters is known as sex linked inheritance. The sex linkage was first discovered by

T.H. Morgan in *Drosophila* and the first sex linked gene found in *Drosophila* was recessive gene 'w' responsible for white eye colour.

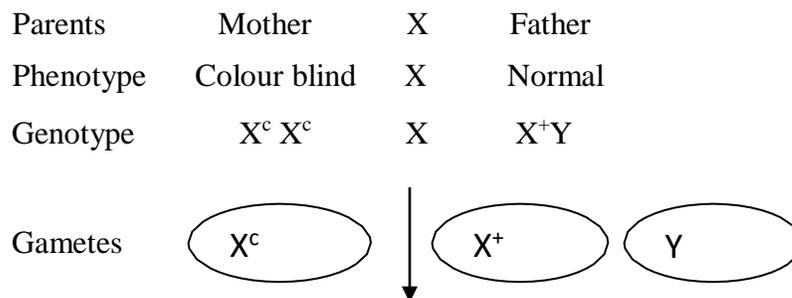


	$X^+$	$Y$
$X^w$	$X^w X^+$ Red eye female	$X^w Y$ Red eye female

When white eyed females are crossed with wild type (red eye) males, all the male offspring have white eyes like the mother and all the female offspring have red eyes like their father.

In human beings, colour blindness and haemophilia (bleeder's disease) are well known hereditary characters showing a peculiar relationship to sex.

**Colour blindness:** A marriage between colour blind woman and a normal man gives rise to all normal daughters and colour blind sons.

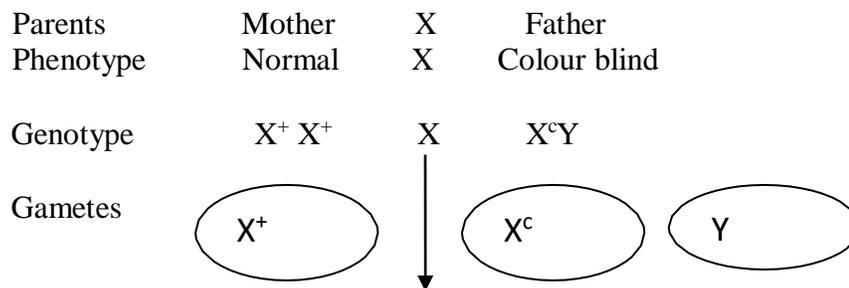


	$X^+$	Y
$X^c$	$X^c X^+$ Normal daughter	$X^c Y$ Colourblind son

The allele for colour blindness (c) is found on both 'X' chromosomes of mother and therefore she is colour blind. The only one 'X' chromosome of father in this marriage carries a wild type (+) allele and hence he has normal vision. The 'Y' chromosome lacks both the alleles (+ and c). The reduction division produces one kind of egg in contrast to two kinds of sperms. Fertilization results in the usual sex ratio of 1 male: 1 female. All the daughters have normal vision since they receive dominant allele '+' from their father. All the sons are colour blind, because their single 'X' chromosome derived from mother carries the allele 'c' for colour blindness. This result is known as crisscross inheritance because daughters are normal like father and sons have colour blindness like mother. However, the daughters are heterozygous carriers. This crisscross method of inheritance is characteristic of sex-linked genes. This peculiar type of inheritance is due to the fact that Y chromosome carries no alleles homologous to those on the X chromosome. Thus, males carry only one allele for sex linked traits. This one allelic condition is termed as hemizygous in contrast to homozygous and heterozygous possibilities in female. The expression of recessive gene in hemizygous condition is termed as pseudo-dominance.

The inheritance of colour blindness can be studied in the following three others possible types of marriages:

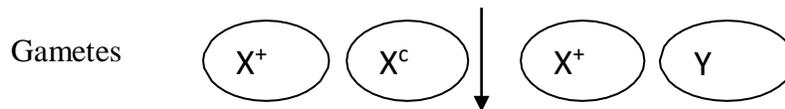
**a) Marriage between normal woman and colour blind man:**



	$X^c$	Y
$X^+$	$X^+X^c$ Normal daughter (Carrier)	$X^+ Y$ Normal son

**b) Marriage between normal (carrier) woman and normal man:**

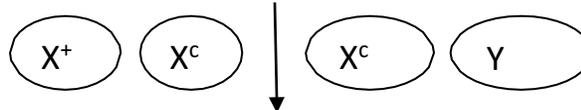
Parents          Mother          X          Father  
 Phenotype      Normal          X          Normal  
 Genotype         $X^+ X^c$         X         $X^+ Y$



	$X^+$	Y
$X^+$	$X^+ X^+$ Normal daughter	$X^+ Y$ Normal son
$X^c$	$X^c X^+$ Normal daughter	$X^c Y$ Colour blind son

**c) Marriage between normal (carrier) woman and colour blind man:**

Parents          Mother          X          Father  
 Phenotype      Normal          X          Colour blind  
 Genotype         $X^+ X^c$         X         $X^c Y$   
 Gametes



	$X^c$	Y
$X^+$	$X^+ X^c$ Normal daughter	$X^+ Y$ Normal son
$X^c$	$X^c X^c$ Colour blind daughter	$X^c Y$ Colour blind son

Results of possible four marriages make it clear why there are more colour blind males than females in the population. In three marriages colour blind sons were produced where as in only one of the marriages, colour blind daughters were observed, where the mother is heterozygous (carrier) and the father is colour blind. Nearly all colour blind women must come from the last type of marriage, since the only other possible source of colour blind females is mating between two colour blind persons – naturally a rare occurrence.

Haemophilia is a recessive sex-linked disease and the inheritance pattern of haemophilia is similar to that of colour blindness in human beings.

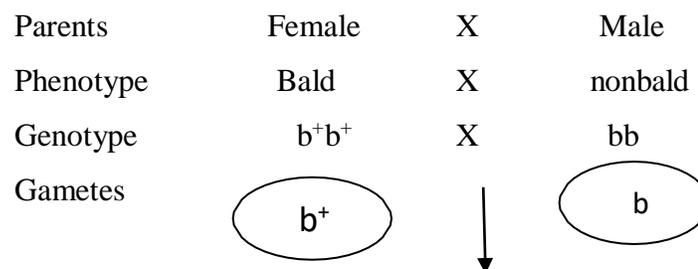
Genes present in the non-homologous region of the Y chromosome pass directly from male to male. In man, the genes present on Y chromosome (holandric genes) such as the gene causing hypertrichosis (causing excessive development of hairs on the pinna of ear) are transmitted directly from father to son.

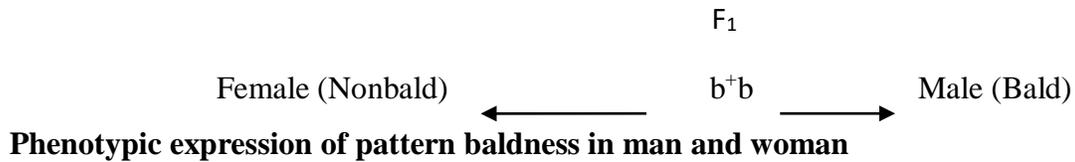
### Sex influenced inheritance

Sex influenced genes are the autosomal genes present in both males and females, whose phenotypic expression is different in different sexes in such a way that they act as  $X^+ X^c$  dominant in one sex and recessive in the other i.e. in a pair of alleles one seems to be dominant in males while the other in females.

Eg.: Pattern baldness in human beings and horns in sheep. Pattern baldness in human beings is a condition in which a low fringe of hair is present on the head in human beings. It is a genetically inherited condition, where the allele for baldness B is dominant in males and recessive in females. In heterozygous condition, males are bald and females are nonbald. If a woman heterozygous for this gene marries a heterozygous bald man, in the offspring, the ratio of bald to non-bald in males is 3 : 1, while in females it is 1 : 3.

### Inheritance of pattern baldness in human being





Genotype	Phenotype	Genotype
	Female	
$b^+ b^+$	Nonbald	$b^+ b^+$
$b^+ b$	Nonbald	$b^+ b$
$bb$	Bald	$bb$

### Sex limited characters or Secondary Sexual characters

Sex limited genes are autosomal genes, whose phenotypic expression is limited to one sex only. Their phenotypic expression is influenced by the sex hormones. The sex-limited genes are mainly responsible for secondary sex characters in cattle, human beings and fowl. Eg.: milk production in cattle, beard development in human beings, plumage in male fowls etc.

**Milk production in cattle:** Just as the cow, the bull carries genes for milk production, but the bull obviously cannot express this trait. Bull may however transmit these genes for  $b^+ b$  high milk production to the female progeny and the male progeny are unable to express this trait. Some bulls are so well endowed with such genes that they are known to breed calves, which always yield greater milk than their mothers.

However, in plants no secondary sexual characters are known except the absence of one or the other sporangia.

### Differences between sex linked and sex-limited characters

Sex Linked characters	Sex Limited characters
1. They are located on sex or X chromosome	1. They are located on sex chromosomes or autosomes
2. They can express in both the sexes	2. They can express in one sex only
3. Include characters not related to sex	3. Include primary and secondary sex characters
4. Examples: White eye in <i>Drosophila</i> , haemophilia and colour blindness in human beings	4. Examples: milk production in cattle, beard development in human beings, plumage in male fowls etc

## **Inter sex**

In a few rare cases, various mixtures of male and female characteristics may occur in animals, which normally have separate sexes because of various abnormalities of chromosomes or hormonal deficiencies. Such individuals are called inter sex. These can be of two types.

**1. Pseudo -hermaphrodites:** In mammals, there are rare cases in which, both sexes are well developed in one body, these are abnormal one and hence sterile.

**2. Gynandromorphs or gynanders:** Among animals and insects that do not have sex hormones, there may be sex intergrades with distinct areas of the body showing male and female tissues. For example: *Drosophila gynander*, a bilateral sex mosaic, is male on one side and female on the other.