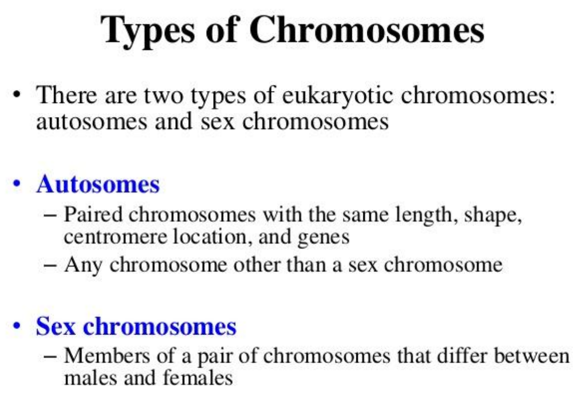
Sex determination in animals

Contents: Types of chromosomes; Mechanisms of sex determination- Genetic; Hormonal; Environmental and Metabolic; Sexual abnormalities; Gynandromorphs; Intersexes; Sex mosaics; Suggested reading.

Types of chromosomes in animals

Basically, there are two types of chromosomes as shown below.



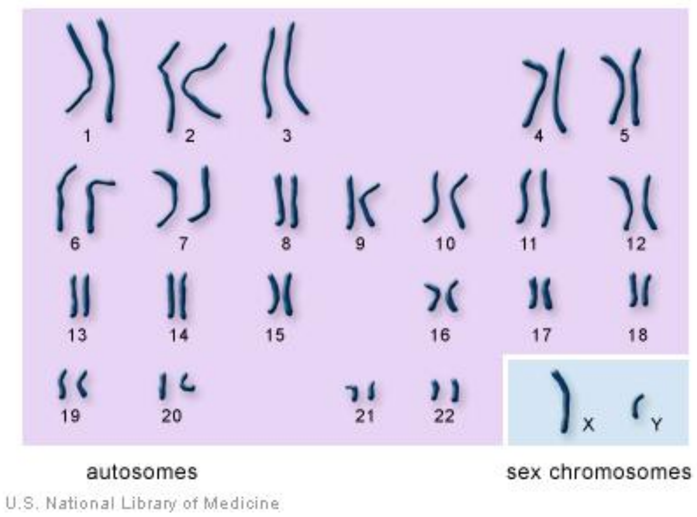


Fig. 8.1 Twenty two pairs of autosomes and a pair of sex chromosomes (bottom right) in man

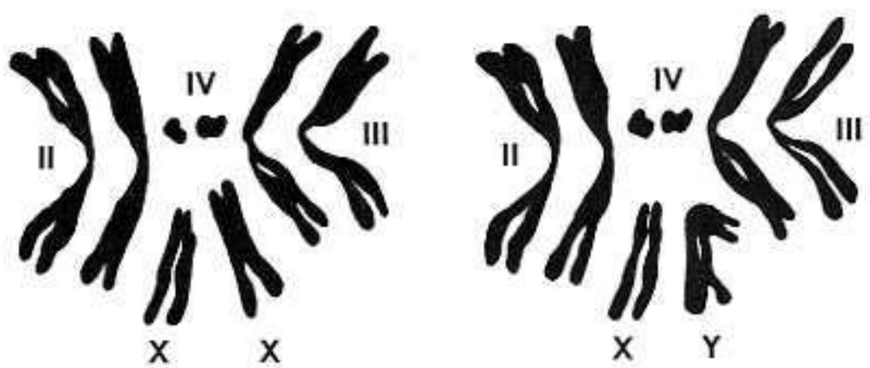


Fig. 8.2 Autosomes and sex chromosomes in a female (left) and a male (right) in *Drosophila*

Mechanisms of sex determination in animals

There are four principal mechanisms:

1. Genetic;
2. Hormonal;
3. Environmental; and
4. Metabolic.

1. Genetic mechanism of sex determination is explained mainly by:

A. Chromosomal theory
B. Genic balance theory

A. Chromosomal theory of sex determination

a. Heterogametic males:

(i) XX-XY method
(ii) XX-XO method

b. Heterogametic females:

(i) ZZ-ZW method
(ii) ZZ-ZO method

c. Haplodiploidy (male haploidy or arrhenotoky):

a. Heterogametic males

Males are heterogametic but females are homogametic

(i) XX-XY method: *e.g*. Man and other mammals, *Drosophila* etc. (Fig. 8.3).

P:	♀ (44XX)	×	♂ (44XY)
G:	22X		22X, 22Y
Offspring:	♀ (44XX)		♂ (44XY)

(ii) XX-XO method: *e.g*. Cockroach, Grasshopper etc. (O. Orthoptera) (Fig. 8.4).

P:	♀ (22XX)	×	♂ (22X)
G:	11X		11X, 11
Offspring:	♀ (22XX)		♂ (22X)

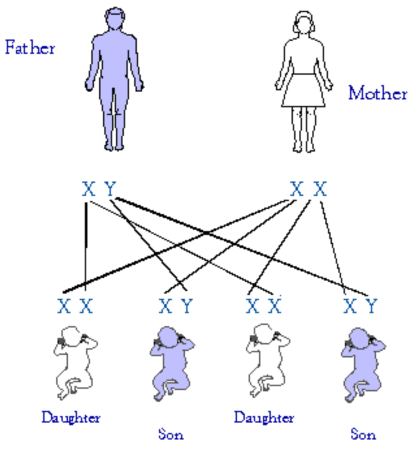


Fig. 8.3 XY-method of sex determination in man

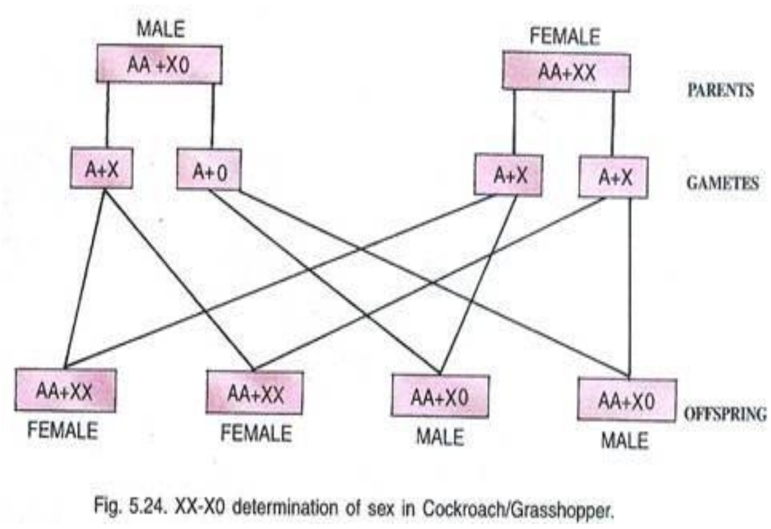


Fig. 8.4 XO-method of sex determination in insects

b. Heterogametic females

Here the females are heterogametic but the males are homogametic.
Examples are provided below:

(i) ZZ-ZW method: e.g. Birds, reptiles, fishes etc (Figs. 8.5 and 8.6).

P:	♀ (76ZW)	×	♂ (76ZZ)
G:	38Z, 38W		38Z
Offspring:	♀ (76ZW)		♂ (76ZZ)

(ii) ZZ-ZO method: e.g. Moths, butterflies etc (O. Lepidoptera) (Fig. 8.7).

P:	♀ (60Z)	×	♂ (60ZZ)
G:	30Z, 30		30Z
Offspring:	♀ (60Z)		♂ (60ZZ)

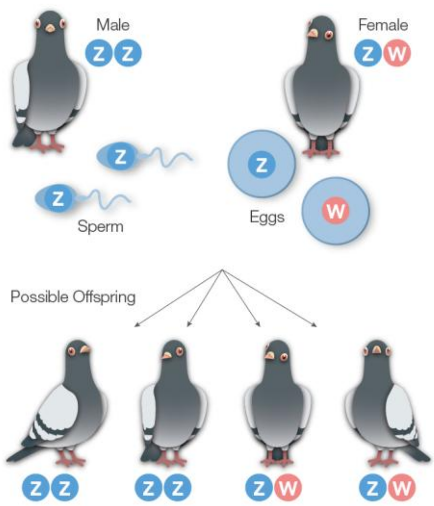


Fig. 8.5 ZZ-ZW method of sex determination in pigeon

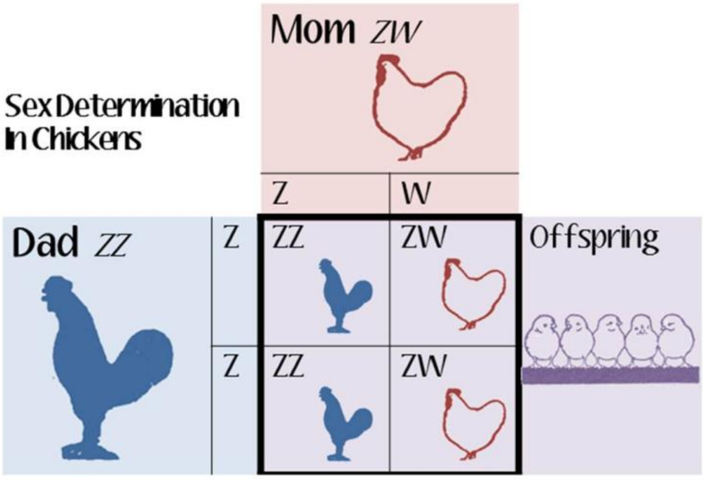


Fig. 8.6 ZZ-ZW method of sex determination in chickens

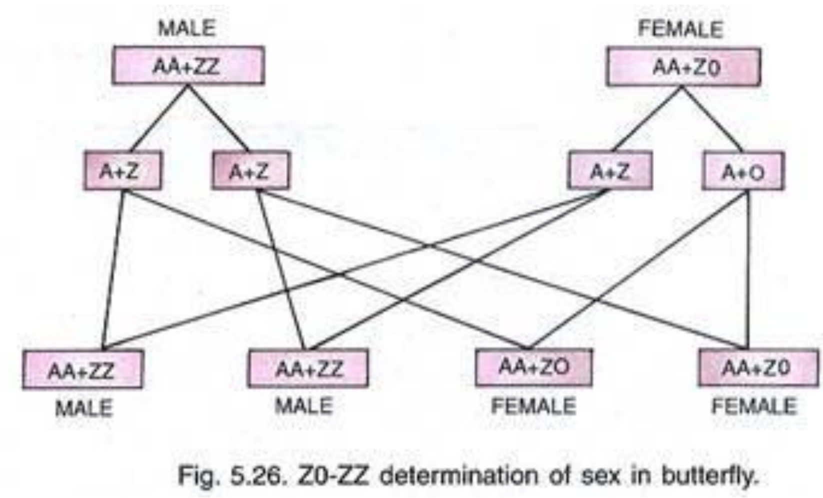


Fig. 8.7 ZZ-ZO method of sex determination in butterflies and moths

c. Haplodiploidy (male haploidy or arrhenotoky)

In this method the females are diploid and develop from fertilized eggs, but males are haploid and develop parthenogenetically from unfertilized eggs. Examples include honey bees, ants and wasps belonging to the Order Hymenoptera (Fig. 8.8).

P:	♀ (2n=32)	×	♂ (n=16)
G:	16		16
Offspring:	♀ (2n=32)		♂ (n=16)
	Queen, workers		Drones

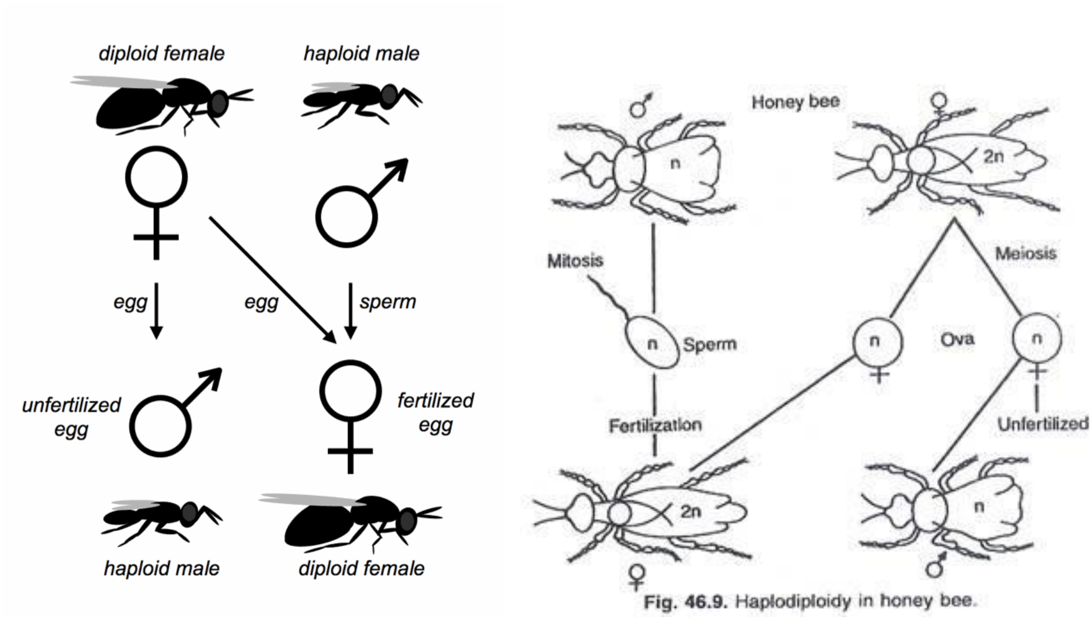


Fig. 8.8 Haplodiploidy method of sex determination in an ant (left) and a honey bee

B. Genic balance theory

- Genic balance theory was put forward by C. B. Bridges (1921)
- Sex determination in *D. melanogaster* is dependent on the ratio of X to autosome sets (*i.e.* X/A)

The following cases may arise:

If, X/A = 1.0,	it is a female;
= 0.5,	it is a male;
> 1.0,	it is a metafemale (or superfemale);
< 0.5,	it is a metamale (or supermale);
< 1.0 but > 0.5,	it is an intersex.

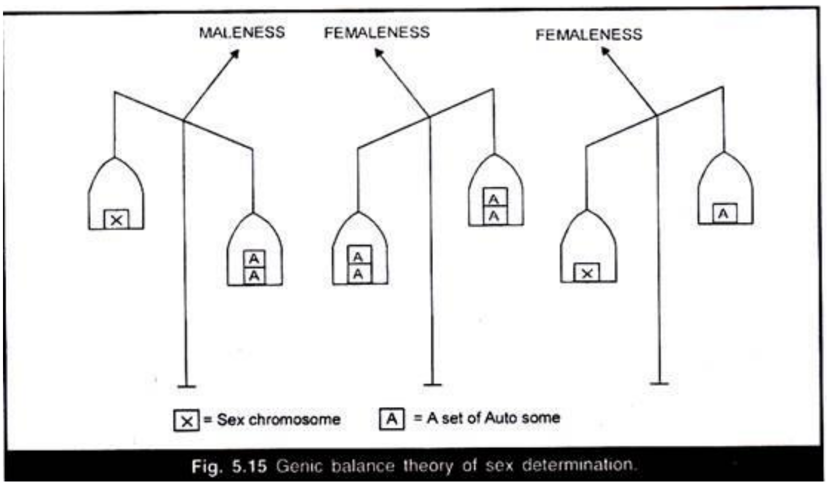


Fig. 8.9 Diagram showing the mechanism of genic balance theory for the determination of sex in *Drosophila* (see the table below)

Genic balance theory of sex determination in *Drosophila*

No. of X chromosomes	No. of autosome sets	X/A ratio	Sex of the fly
2 1	2 2	1.00 0.50	Normal female (2n) Normal male (2n)
1 1	3 4	0.33 0.25	Metamale (3n) Metamale (4n)
3 4	2 3	1.50 1.33	Metafemale (2n) Metafemale (3n)
2 3	3 4	0.67 0.75	Intersex (3n) Intersex (4n)

Ref: Sinnott *et al*. (1973)

2. Hormonal mechanism of sex determination

- ❑ Hormones (oestrogen in females and testosterone in males) play very important role in the determination of sex in vertebrates;
- ❑ Absence of sex hormones results in the development of female characters;
- ❑ In absence of female hormone, female sex does not mature, and is not functional; and
- ❑ Presence of male hormone prevents femaleness, and expression of primary and secondary male characters.

Examples of hormonal mechanism

1. Sex reversal in birds (Fig. 8.10)
   - ➢ One ovary is functional, the other one is dormant;
   - ➢ If the functional one is destroyed by accident, parasite or anatomy, the dormant ovary becomes a testis;
   - ➢ As a result, the hen turns into a cock in terms of feathers, comb and call;
   - ➢ Sometimes such sex reversed males are fertile and can be father of chicks!!
2. Freemartin in cattle (Fig. 8.11)
   - ➢ In cattle, twins of opposite sex (one male, one female) are interesting;
   - ➢ The male is normal, but the female is an intersex and sterile (freemartin); and
   - ➢ In freemartin, the external genitalia is female-like, but the internal genitalia is male-like.

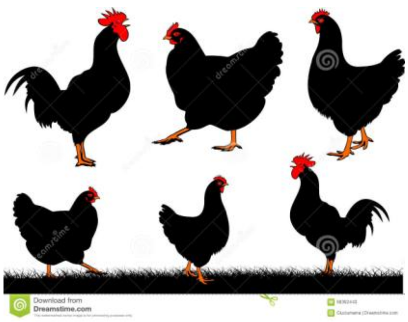


Fig. 8.10 Sex-reversal in domestic chickens (top: from right to left; bottom: from left to right)

Fig. 8.11 A twin pair of dissimilar sex in cattle, the female one is a freemartin

3. Environmental mechanism of sex determination

Environmental factors like living conditions and temperature range affect the determination of sex in some animals as described below:

(i). *Bonellia viridis* (Minor phylum Echiuroidea)

Immature individuals develop into females if reared solitary. If, however, reared in contact with adult females, they become small, parasitic males, and live in the reproductive tract of the females (Fig. 8.12).

(ii). Similar phenomenon also happens in the sea snail *Crepidula onyx* (P. Mollusca; C. Gastropoda) (Fig. 8.13).

(iii). In turtles, crocodiles and *Sphenodon*, temperature-dependent sex determination (TDS) operates (Fig. 8.14).

Fig. 8.12 Environmental sex determination in the marine worm *Bonellia viridis*

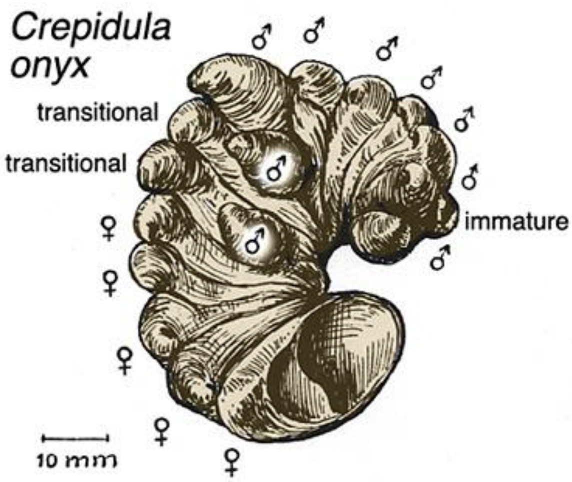


Fig 9.13 Living conditions in *Crepidula onyx* determine the sex of the individuals

Temperature-dependent sex determination (TDS) in some reptiles

Sex ratios of TDS reptiles exhibit three general patterns of response to temperature:

- Males at low temperature, but females at high (MF or Type 1A) characteristic to turtles;
- Females at low, but males at high (FM or Type 1B) as found in some lizards like tuatara (*Sphenodon*);
- Females at low and high, but males (or both sexes) at intermediate temperatures (FMF or Type II) present in crocodilians and some lizards.

Fig. 8.14 Temperature-dependent sex determination (TDS) in some reptiles

4. Metabolic mechanism of sex determination

Metabolism involves two processes *viz*., anabolism and catabolism, which determine basal metabolic rate (BMR) in animals (Fig. 8.15).

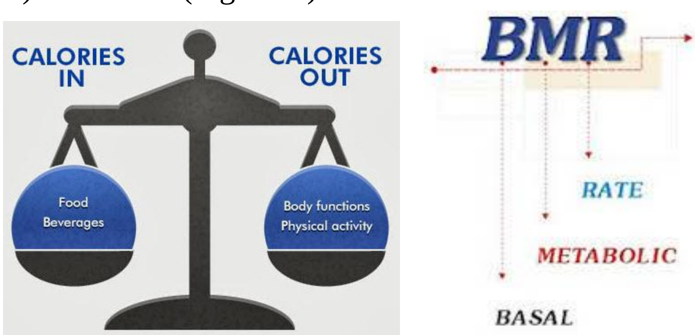


Fig. 8.15 Diagrams showing metabolism and basal metabolic rate (BMR) in animals

BMR determines sex of the individuals in rotifers, dove, pigeon etc.

(a) Increased BMR gives rise to: >50% males

(b) Decreased BMR results in: >50% females

Sexual abnormalities

As has been discussed above, the normal or natural sex of an animal is based on a delicate balance between chromosomes (genetic), hormones, environmental conditions and metabolism. Obviously, a slight disturbance in this delicate system would result in abnormal sex, ambiguous sex, or confusing sex in individuals. These aspects are described below in brief.

Common sexual abnormalities include:

1. Gynandromorphs (=gynanders)
2. Intersexes (=hermaphrodites)
3. Sex mosaics

Gynandromorphs (=gynanders)

Presence of both male and female characters in a single body *e.g.* butterflies, *Drosophila*, snails, silkworm, bees etc.

Gynandromorphs are of three general types (Fig. 8.16):

(a) Bilateral- *e.g.* female character on the left, male on the right;

(b) Anterior-posterior (=polar)- *e.g.* female on the top, male on the bottom; and

(c) Sex-piebald- *e.g.* irregular patches of two sexes throughout the body.

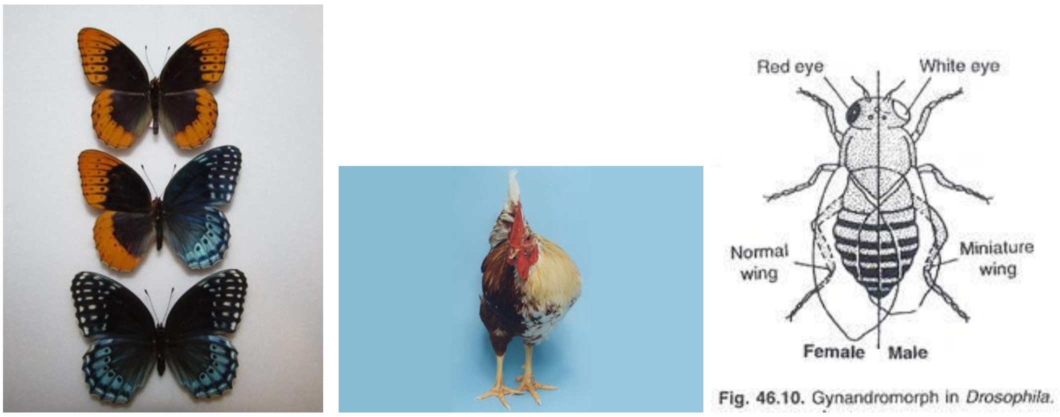


Fig. 8.16 Gynandromorphs in butterflies, chicken and *Drosophila*

Sex types and intersexes in man

The five sexes are as follows (Fig. 8.17):

1. Normal males (46, XY), two testes and no ovary;
2. Normal females (46, XX), two ovaries and no testes;
3. True hermaphrodites (48, XXXY) or 'herms', one testis and one ovary (Fig. 8.18);
4. Pseudomales or 'merms' (karyotype 46 XY, but with ambiguous female genitalia), presence of testes and some aspects of female genitalia but no ovaries (Fig. 8.18); and

5. Pseudofemales or ‘ferms’ (karyotype 46 XX, but with ambiguous male genitalia), presence of ovaries and some aspects of male genitalia but no testes (Fig. 8.19).

Apart from the above types, the South Asian hermaphrodites are commonly known as ‘hijras’ which have various degrees of sex abnormalities in terms of karyotypes and genitalia (Fig. 8.20).

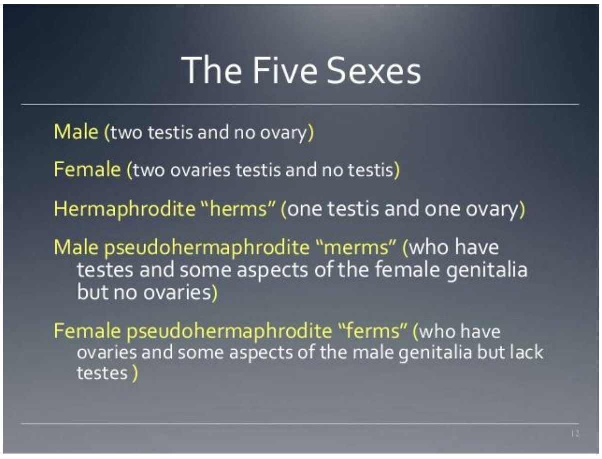


Fig. 8.17 Five types of sexes in man

Fig. 8.18 A true hermaphrodite or ‘herm’ (left) and a pseudomale or ‘merm’ (right)

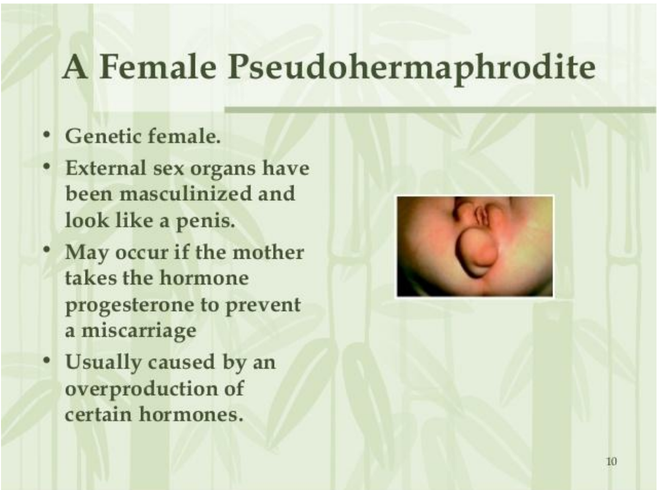


Fig. 8.19 A pseudofemale or ‘ferm’

Fig. 8.20 South Asian hermaphrodites called 'Hijras'

Sex mosaics

The number and structure of sex chromosomes are variable in different parts of the body. *e.g.* man, *Drosophila* and many insects (Fig. 8.21).

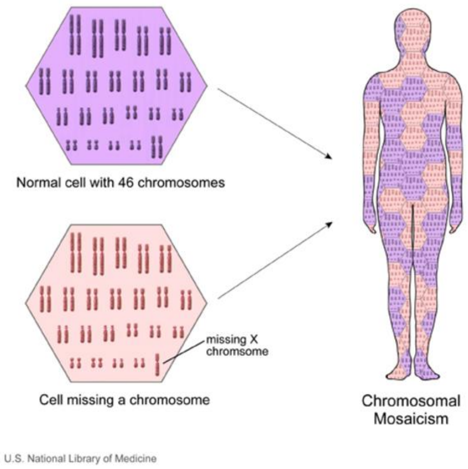


Fig. 8.21 An example of sex mosaic in man, in which some body cells contain 46 chromosomes but others have a missing chromosome (45, X0) *i.e.* karyotype of a Turner's syndrome

Suggested reading:

Ayala FJ & Kiger Jr. JA, 1980. *Modern Genetics*.
Burns, GW. 1980. *The Science of Genetics*.
Gardner *et al*. 1991. *Principles of Genetics* (8th edn)
Islam, MS. 2018. *Selected Lectures on Genetics*. LAP Lambert Academic Publishing, Germany.
Sinnott *et al.* 1973. *Principles of Genetics* (5th edn)
Stansfield, WD. 1991. *Theory and Problems of Genetics* (3rd edn)
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Winchester, AM. 1966. *Genetics* (3rd edn)
Wikipedia: www.wikipedia.com
ইসলাম, ম.সা., খান, হা.সা. ও রানা, ম.হা.তা. ২০১৭। *জেনেটিক্স: মিল ও অমিলের বিজ্ঞান*। অন্যপ্রকাশ, ঢাকা।