Sex-determination system

A sex-determination system is a biological system that determines the development of sexual characteristics in an organism. Most sexual organisms have two sexes. In many cases, sex determination is genetic: males and females have different alleles or even different genes that specify their sexual morphology. In animals, this is often accompanied by chromosomal differences. In other cases, sex is determined by environmental variables (such as temperature) or social variables (the size of an organism relative to other members of its population). The details of some sex-determination systems are not yet fully understood.

Genetic mechanisms of sex determination

In 335 B.C.E., Aristotle proposed that the heat of the male partner during intercourse determined sex. At least in the case of reptiles, Aristotle was on to something. What about in other animals?

Whether an animal will become a male, a female, or a hermaphrodite is determined very early in development. Scientists have worked for hundreds of years to understand the sex-determination system. For instance, in 335 B.C.E., Aristotle proposed that the heat of the male partner during intercourse determined sex. If the male's heat could overwhelm the female's coldness, then a male child would form. In contrast, if the female's coldness was too strong (or the male's heat too weak), a female child would form. Environmental theories of sex determination, such as Aristotle's, were popular until about 1900, when sex chromosomes were discovered. As it turns out, Aristotle was on to something, at least in the case of some reptiles, in which the temperature of the nest determines the sex of the embryo. For most animals, however, sex is determined chromosomally.

In most organisms, the number of sexes has been reduced to just two.

An animal possessing both male and female reproductive organs is usually referred to as a hermaphrodite.

In plants where staminate (male) and pistillate (female) flowers occur on the same plant, the term of preference is monoecious. (Perfect flower). Relatively few angiosperms are dicoecious.

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 evolutionary process of natural selection depends upon this genetic variability to supply the raw material from which the better adapted types usually survive to reproduce their kind.

Many subsidiary mechanisms have evolved to ensure cross fertilization in most species as a means for generating new genetic combinations in each generation.

The plant life cycle has mitosis occurring in spores, produced by meiosis, that germinate into the gametophyte phase. Gametophyte size ranges from three cells (in pollen) to several million (in a "lower plant" such as moss). Alternation of generations occurs in plants, where the sporophyte phase is succeeded by the gametophyte phase. The sporophyte phase produces spores by meiosis within a sporangium. The gametophyte phase produces gametes by mitosis within an antheridium (producing sperm) and/or archegonium (producing eggs). Within the plant kingdom the dominance of phases varies. Nonvascular plants, the mosses and liverworts, have the gametophyte phase dominant. Vascular plants show a progression of increasing sporophyte dominance from the ferns and "fern allies" to angiosperms.

1 Chromosomal basis of sex determination

Most mechanisms for the determination of sex under genetic control and may be classified into one of the following categories.

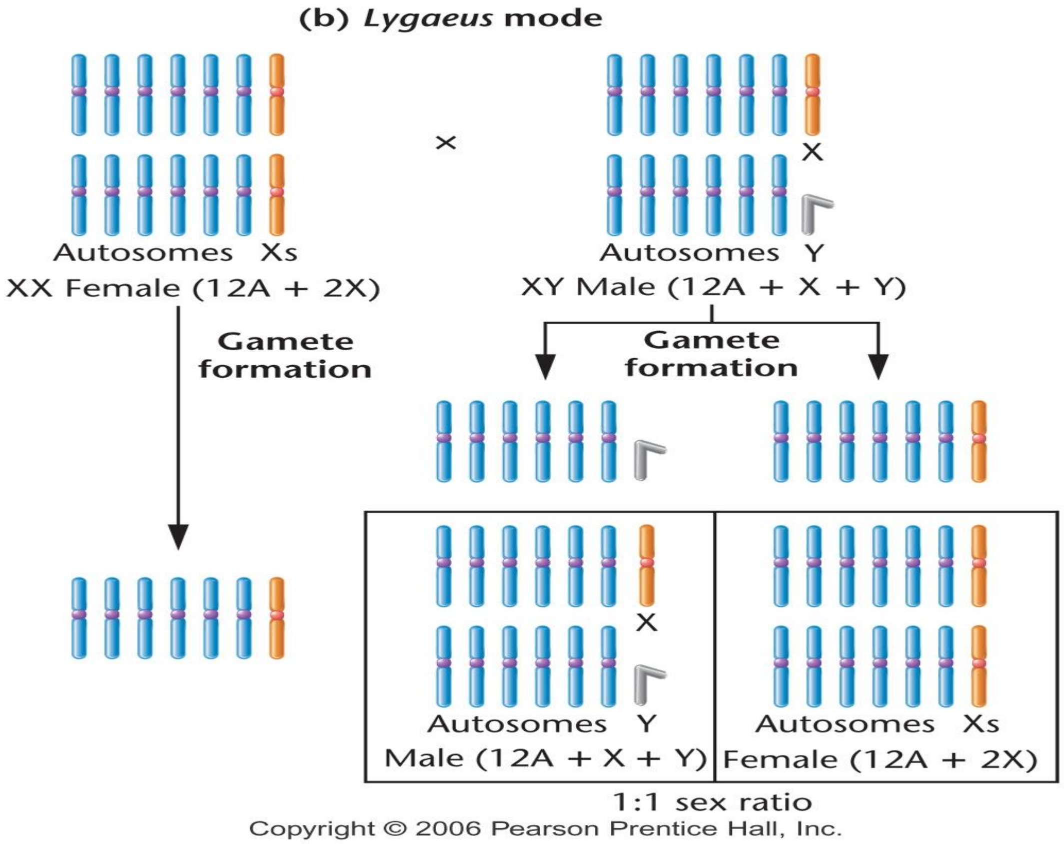
1- Heterogametic males:

a- Lygaeus Mode of Sex Determination (XX/XY)

In human and other mammals, the presence of Y- chromosome may determine a tendency to maleness. Normal males are XY and normal female are XX. The males produces two kinds of gametes (Y-bearing sperm and X-bearing sperm), while females producing one type of gametes (homogametic cells).

Lygaeus turicus

Insect has 14 chromosomes
12 autosomes and 2 X chromosomes – Female
12 autosomes and 1 X + 1 Y - Male
Females produce only X chromosomes
Males produce X and Y chromosomes

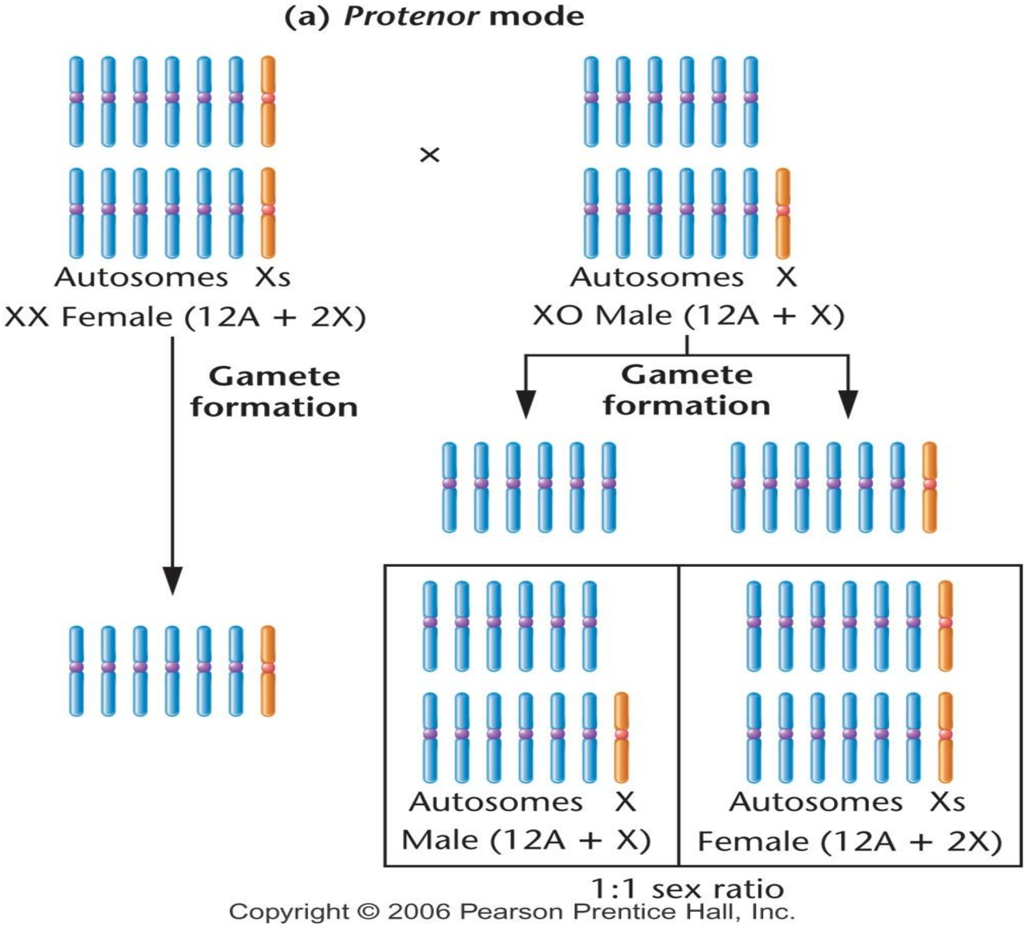


This produces a 1:1 sex ratio in each generation.

b- XX-X0 system (Protenor type):

In some insects, especially those of the order Hemiptera (true bugs) and Orthoptera (grasshoppers and roaches), males are also heterogametic, but produce either X-bearing sperm or gametes without a sex chromosome. In males of these species, the X-chromosome has no homologous pairing partner because there is no y-chromosome present. Thus males exhibit on odd number in their chromosome complement. The one-X and two-X condition determines maleness and femaleness respectively.

Protenor (insect)
1906 Edmund Wilson found female somatic cells contained 14 chromosomes, including 2 X sex chromosomes
Gametes from female contains 7 chromosomes, including 1 X chromosome
Gametes from the male contains 6 chromosomes without 1 X chromosome
Gametes from the male contains 7 chromosomes with 1 X chromosome
Fertilization by male containing X sperm – FEMALE
Fertilization by male containing O sperm – MALE



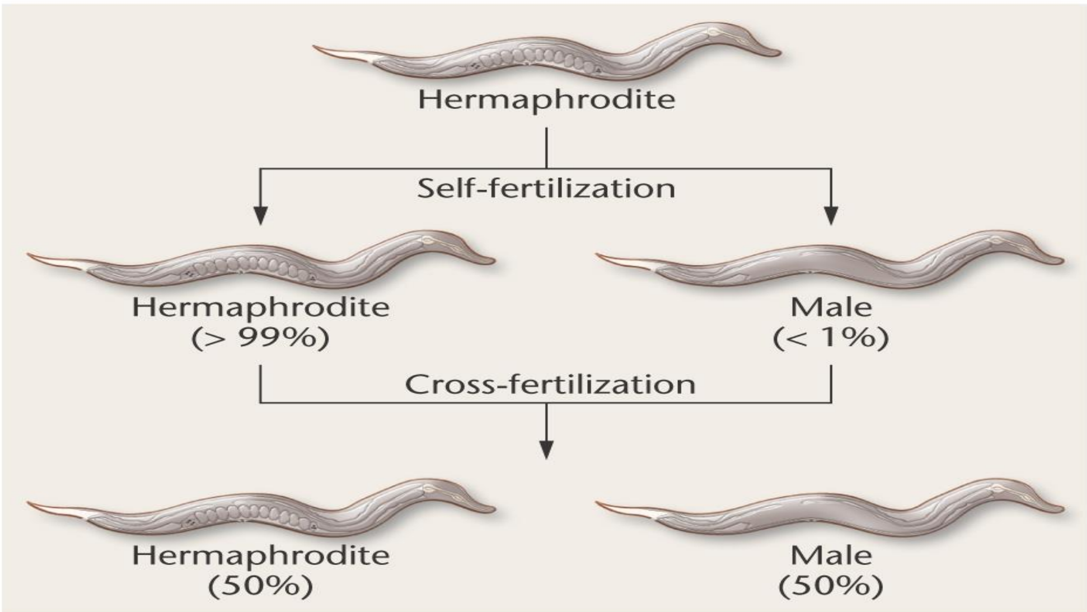
This produces a 1:1 sex ratio in each generation.

In a variant of this system, certain animals are hermaphroditic with two sex chromosomes (XX) and male with only one (X0). The model organism ***Caenorhabditis elegans*** — a nematode frequently used in biological research — is one such organism. ***C. elegans***

1. Only 1000 cells
2. 2 sexual phenotypes
3. Males – testis (functional)
4. Hermaphrodite – XX
5. Males – X (No Y chromosome)
6. Hermaphrodite – testis and ovaries
   a. During larval stage, testis produce sperm (stored)
   b. Ovaries produced but no oogenesis until adult stage
   c. Able to self fertilize
   d. If hermaphrodite mates with male – ½ hermaphrodite, ½ males

(a)

(b)



2- <u>Heterogametic females:</u>

a- <u>XX-XY (ZZ-ZW) (Abrax-type):</u>

The ZW sex-determination system is a system that determines the sex of offspring in birds, some fish, and some insects (including butterflies and moths), and some reptiles, including Komodo dragons. In the ZW system it is the ovum that determines the sex of the offspring. Males are the homogametic sex (ZZ), while females are heterogametic (ZW). The Z chromosome is larger and has more genes, like the X chromosome in the XY system.

It is unknown whether the presence of the W chromosome induces female features or the duplication of the Z chromosome induces male ones; unlike mammals, no birds with a double W chromosome (ZWW) or a single Z (Z0) have been discovered. It is possible that either condition causes embryonic death, or that both chromosomes are responsible for gender selection.

In Lepidoptera (moths and butterflies), examples of Z0, ZZW and ZZWW females can be found. This suggests that the W chromosome is essential in female determination in some species (ZZW), but not in others (Z0). In *Bombyx mori* (the commercial silkworm), the W chromosome carries the female-determining genes.

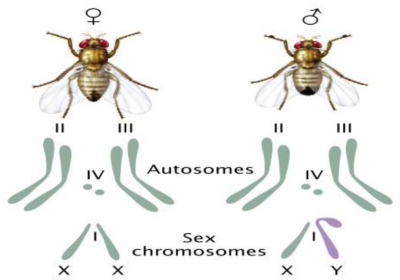
b- <u>ZZ-ZO type:</u>

The females of other species have no homologue to the single sex chromosome as in case of XO mechanisms discussed previously. To point out these differences, the symbols ZZ and ZO may be used to designate males and females respectively.

Parents ZZ X ZO
Gametes Z Z, O
F1 1 male ZZ , ZO 1 female

2- Genic balance:

The presence of Y-chromosome in *Drosophila melanogaster* is essential for maleness fertility but not sex determinant. The factors for maleness residing in all of the autosomes are weighted against the factors for femaleness residing on the X-chromosome(s). If each haploid set of autosomes carries factors with a male-determining value equal to one, then each X-chromosome carries factors with a female determining value of (1.5).



Drosophila Sexual Phenotypes
the Ratio of X to Autosomes

Sex-Chromosome Complement	Haploid Sets of Autosomes	X:A Ratio	Sexual Phenotype
XX	AA	1.0	Female
XY	AA	0.5	Male
XO	AA	0.5	Male
XXY	AA	1.0	Female
XXX	AA	1.5	Metafemale
XXXY	AA	1.5	Metafemale
XX	AAA	0.67	Intersex
XO	AAA	0.33	Metamale
XXXX	AAA	1.3	Metafemale

3- Haplodiploidy:

The haplodiploid sex-determination system is typical of bees and wasps.

Male bees are known to develop parthenogenetically from unfertilized eggs (arrhenotoky) and are therefore haploid. Females (both workers and queens) originate from fertilized (diploid) eggs. Sex chromosome are not involved in this mechanism of sex determination which is characteristic of the insect order hymenoptera including the ants, bees, wasps, etc. . The quantity and quality of food available to the diploid larva determines whether that the female will become a sterile worker or a fertile queen. Thus environment here determines sterility or fertility but does not alter the genetically determined sex. The sex ratio of the offspring is under the control of queen. Most of the eggs laid in the hive will be fertilized and developed into worker females. Those eggs which the queen chooses not to fertile (from here store of sperm in the seminal receptacle) will develop into fertile haploid male. Queen bees usually mate only during their life time

This system produces a number of peculiarities (properties); chief among these is that a male has no father and cannot have sons, but he has a grandfather and can have grandsons. Haplodiploidy is postulated as having paved the way for the evolution of eusociality in the Hymenoptera and a few other taxa although this is a matter of considerable debate (discussion).

4- Single gene effect:

a) Complementary sex factors:

At least two members of the insect order hymenoptera are known to produce males by hemizygosity at a single gene locus as well as by haploid. This has been confirmed in the tiny parasitic wasp Bracon hebetor (often called *Habrobracon juglandis*), in bees also. At least nine sex alleles are known at this locus in Bracon and may be represented by S^a, S^b, S^c, S^d, S^e, S^f, S^g, S^h, S^i. All females must be heterozygote's such as S^aS^b, S^aS^c, S^dS^f, etc.. If an individual is homozygous for any of these alleles such as S^aS^a, S^cS^c, etc., it develops into a diploid male (usually sterile). Haploid males, of course, would carry only one of the alleles at this locus, e.g. S^a, S^c, S^g, etc. **Example**:

Parents: diploid female S^aS^b X S^a haploid male

Gametes: S^a, S^b S^a

F_1: Haploid male S^a, Diploid male S^aS^a , Diploid female S^aS^b , Haploid male S^b

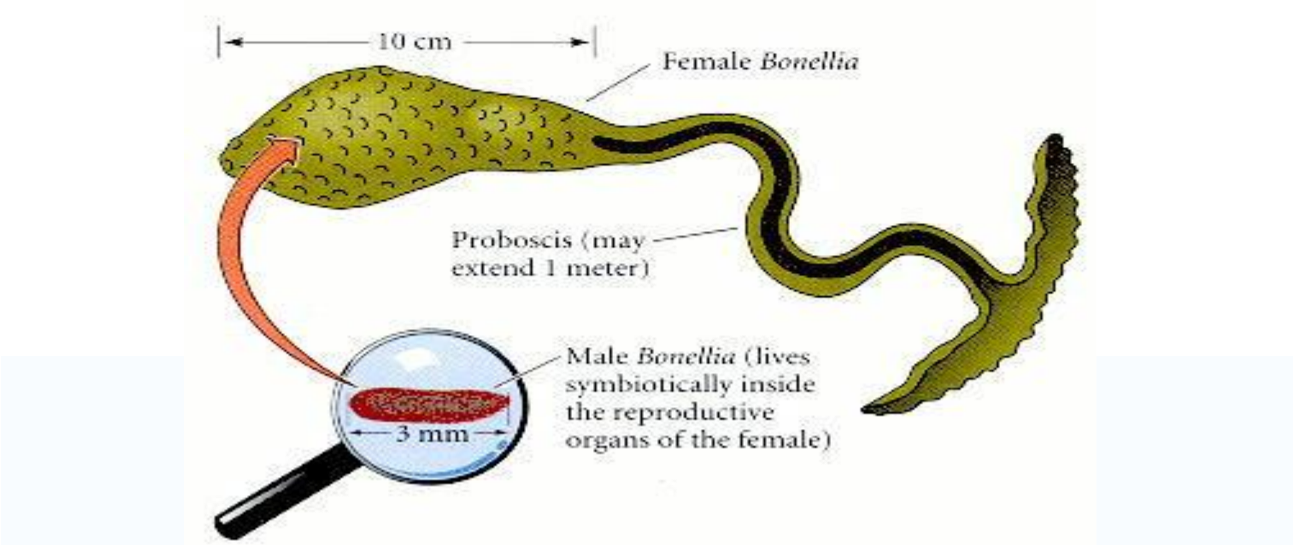
b) The "Transformer" gene of *Drosophila*:

A recessive gene (*tra*) on chromosome 3 of *Drosophila*, when homozygous, transfers a diploid female into a sterile male. The X/X, *tra,tra* individuals resemble normal males in external and internal morphology with the exception that the testes are much reduced in size. The gene is without effect in normal male. The presence of this gene can considerably alter the sex ratio. The significance of these kinds of gene resides in the fact that a mechanism of sex determination based on numerous genes throughout the genome can apparently be nullified by a single gene substitution.

Sex Determination and Environment

In *Bonellia viridis* (marine worm) both male and female are similar genotype but stimuli from environment initiate development toward one sex or the other.

Males of *Bonellia* are small and live within the reproductive tract of the larger female. All organs of the body of male are degenerate, except those of the reproductive system. Any young worm from a single isolated egg become a female, if the released newly hatched worms into water containing mature females. Some young worms are attached to a female and proboscis this are transformed into a male and eventually migrated to the female reproductive tract were they become parasitic. Genetic determines for both sexes apparently present in young worms, extract male from female proboscis influences young worms toward maleness.



Among the vertebrates, temperature also has a strong influence on sex determination in certain groups of reptiles. For example, in crocodilian reptiles and most turtles, sex is determined by egg incubation temperature. There are several variations on this theme. In the alligator snapping turtle, *Macroclemys temminckii*, incubation of eggs below 22°C or above 28°C gives rise to females, while incubation at intermediate temperatures produces predominantly males. American alligators show a similar biphasic dependence on temperature, but the curve is shifted to higher temperatures. In the European pond turtle, *Trachemys scripta*, incubation temperatures above 30°C produce all females, whereas incubation temperatures below 25°C produce all males. At 28.5°C, equal numbers of males and females are produced.

Environmental factors introduce additional wrinkles into the developmental process.

It is important to realize that although environmental factors trigger the particular sexual development pathway in this system, the pathways themselves are under genetic control. Environmental sex determination mechanisms are much rarer than the genotypic mechanisms.

Questions and answers:

Q1. Sex determination in the grasshopper is by the XO method. The somatic cells of a grasshopper are analyzed and found to contain 23 chromosomes. (a) What sex is this individual? (b) Determine the frequency with which different types of gametes number of autosomes and sex chromosomes) can be formed in this individual. (c) What is the diploid number of the opposite sex? **Answer:** (a)male (b)½(11A+1X): ½(11A) (c)24

Q2. Suppose that a female undergoes sex reversal to become a functional male and is then mated to a normal female. Determine the expected F1 sex ratios from such matings in species with (a) ZW method of sex determination, (b) XY method of sex determination. **Answer:** (a) 2 female: 1 male (b) all females

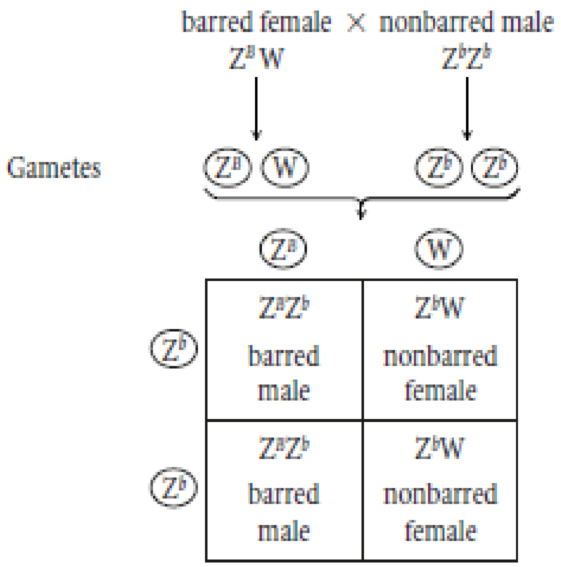
Q3. A fruit fly has XXXYY sex chromosomes; all the autosomal chromosomes are normal.What sexual phenotype will this fly have?

Answer: Sex in fruit flies is determined by the X:A ratio—the ratio of the number of X chromosomes to the number of haploid autosomal sets. An X:A ratio of 1.0 produces a female fly; an X:A ratio of 0.5 produces a male. If the X:A ratio is greater than 1.0, the fly is a metafemale; if it is less than 0.5, the fly is a metamale; if the X:A ratio is between 1.0 and 0.5, the fly is an intersex. This fly has three X chromosomes and normal autosomes. Normal diploid flies have two autosomal sets of chromosomes; so the X:A ratio in this case is $3/2$, or 1.5. Thus, this fly is a metafemale.

Q4. Chickens, like all birds, have ZZ-ZW sex determination. The bar-feathered phenotype in chickens results from a Z-linked allele that is dominant over the allele for nonbar feathers. A barred female is crossed with a nonbarred male. The F_1 from this cross are intercrossed to produce the F_2.What will the phenotypes and their proportions be in the F_1 and F_2 progeny?

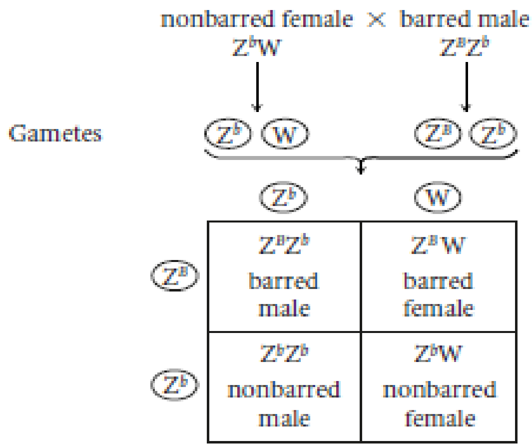
Answer: With the ZZ-ZW system of sex determination, females are the heterogametic sex, possessing a Z chromosome and a W chromosome; males are the homogametic sex, with two Z chromosomes.

In this problem, the barred female is hemizygous for the bar phenotype (Z^BW). Because bar is dominant over nonbar, the nonbarred male must be homozygous for nonbar (Z^bZ^b). Crossing these two chickens, we obtain:



Thus, all the males in the F_1 will be barred (Z^BZ^b), and all the females will be nonbarred (Z^bW).

We now cross the F_1 to produce the F_2:



So, ¼ of the F_2 are barred males, ¼ are nonbarred males, ¼ are barred females, and ¼ are nonbarred females.

Q5. What is the pseudoautosomal region? How does the inheritance of genes in this region differ from the inheritance of other Y-linked characteristics?

Q6. How is sex determined in insects with haplodiploid sex determination?

Q7. What is meant by genic sex determination?

Q8. What is the sexual phenotype of fruit flies having the following chromosomes?

	Sex chromosomes	Autosomal chromosomes		Sex chromosomes	Autosomal chromosomes
a.	XX	all normal	**b.**	XY	all normal
c.	XO	all normal	**d.**	XXY	all normal
e.	XYY	all normal	**f.**	XXYY	all normal
g.	XXX	all normal	**h.**	XX	four haploid sets
i.	XXX	four haploid sets	**j.**	XXX	three haploid sets
k.	X	three haploid sets	**l.**	XY	three haploid sets
m.	XX	three haploid sets			

Answer:

(**a**) Female; (**b**) male; (**c**) male, sterile; (**d**) female; (**e**) male; (**f**) female; (**g**) metafemale; (**h**) male; (**i**) intersex; (**j**) female; (**k**) metamale, sterile; (**l**) metamale; (**m**) intersex.