Meiosis and Sexual Reproduction

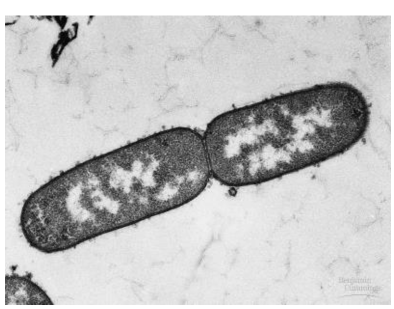
I. Reproduction: new individual

- sexual: by union (fertilization) of gametes 配子
  offspring are genetically different from the parents

- asexual: not involve the union of gametes
  offspring are genetically identical to the parent

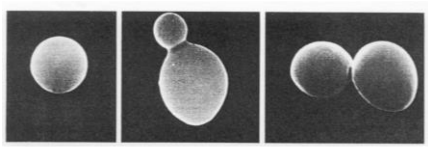
1

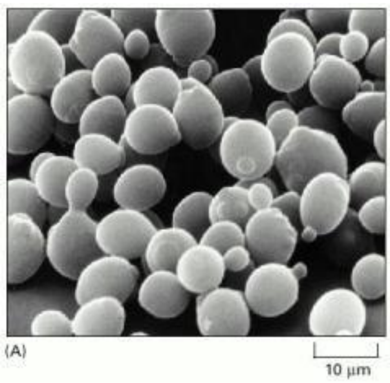
I. Asexual reproduction
- unicellular (single-cell) microorganisms
  -> cell division -> reproduction
  e.g., bacteria, yeast



2

The yeast *Saccharomyces cerevisiae.*





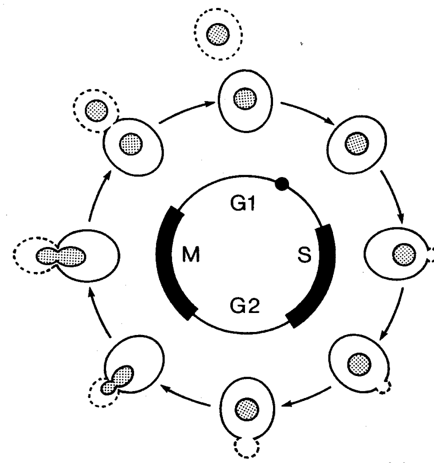


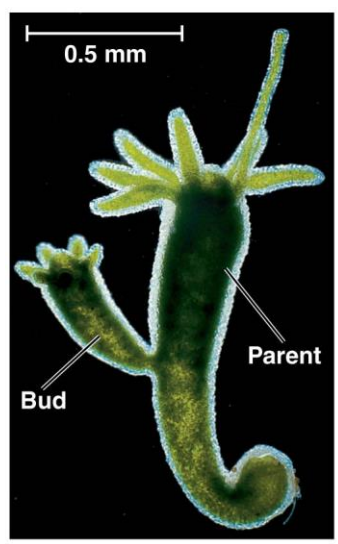
FIG. 1. *S. cerevisiae* mitotic cell cycle. The phases of the cell cycle are drawn in approximate proportion to their length. The mother cell is drawn with a solid line; the daughter bud and cell are drawn with a dotted line. The shaded material represents the cell nucleus. S, DNA synthesis; M, mitosis (nuclear division). The circle within G1 indicates the position at which yeast cells are arrested by mating factors. (Modified from reference 120 with permission.)

3

-multicellular organisms

-> multiple cell division
-> differentiation 分化
-> individual
-> reproduction

e.g., Hydra水螅, plants



(a) Hydra

4

asexual reproduction in plants

- stems above ground (runners or stolons)

走莖、匍匐莖

: strawberry

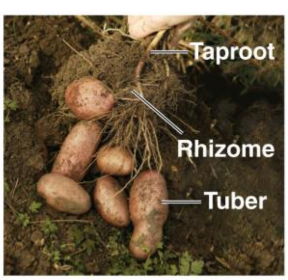
3. asexual reproduction in plants

- underground stems,

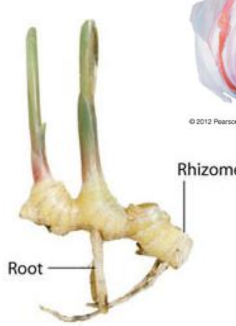
rhizomes (bulbs, tubers)

地下莖、球莖、塊莖

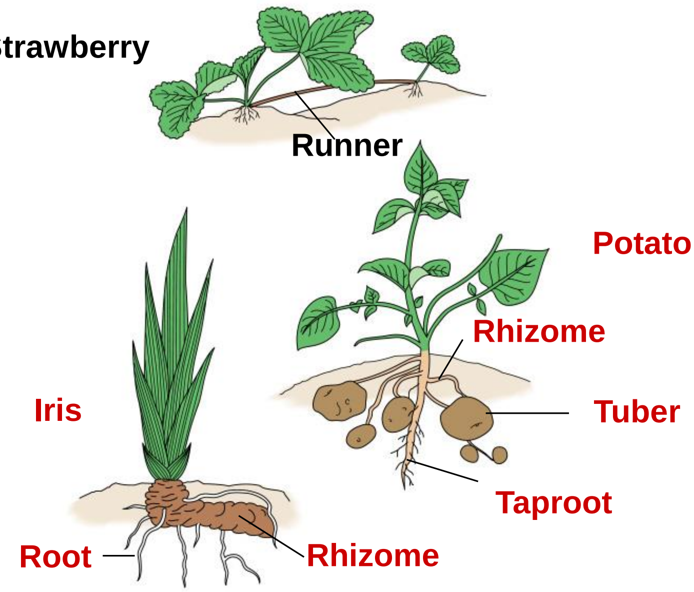
: grasses, potato



Potato plant



Iris plant



7

3. asexual reproduction in plants
- roots: redwood, creosote bushes

8

3. asexual reproduction in plants

- leaf: fern

Essay 8 Figure 2
Biology of Plants, Seventh Edition

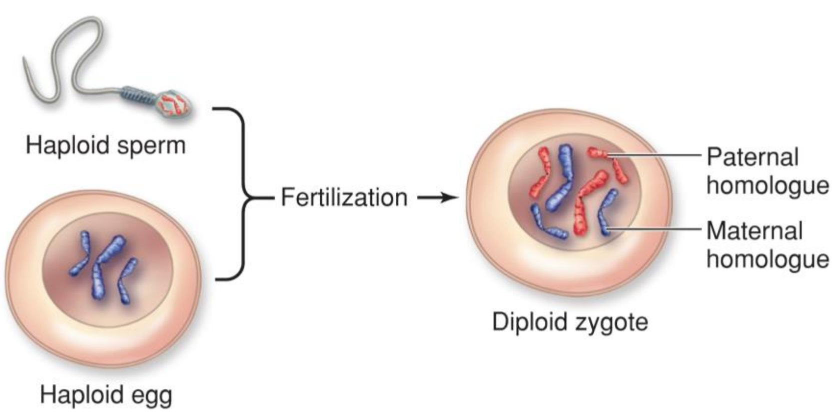
Essay 8 Figure 3
Biology of Plants, Seventh Edition

9

II. Sexual reproduction

-> fertilization: fusion of two gametes

- multicellular organisms, plants, animals
- single-celled organisms, e.g., yeast



10

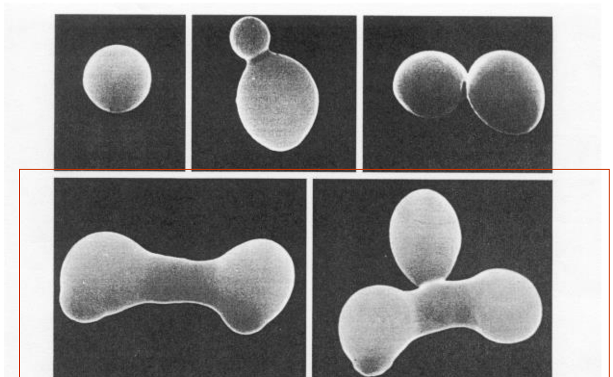
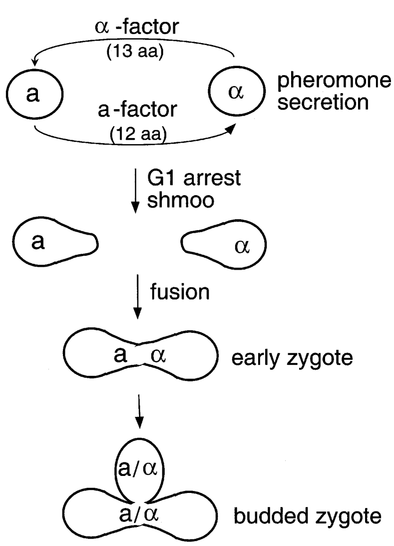


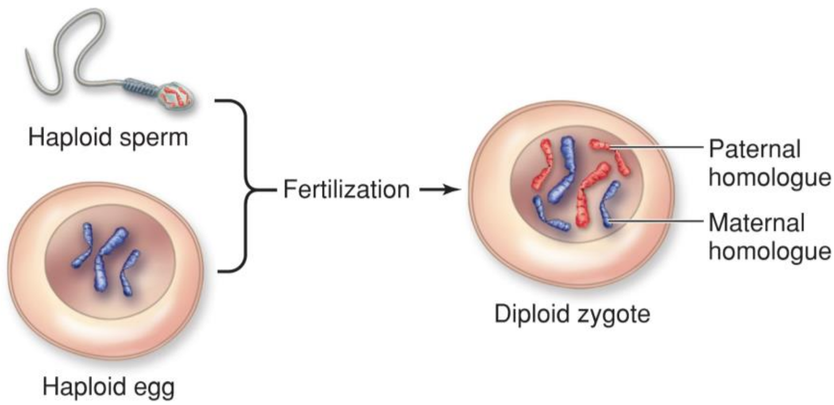
FIG. 3. Morphology of budding and unbudded *S. cerevisiae* cells and zygotes. Top row shows an unbudded cell (upper left) and cells with buds of different sizes. The size of the bud indicates roughly the position of the yeast cell in the cell cycle (Fig. 1). For example, unbudded cells are in G1. The zygote (lower left) was formed by mating between an **a** and an α cell. It produces daughter **a**/α cells by budding, often from the neck of the zygote (lower right). Both the daughter diploid and the original zygote continue to produce daughter cells. Photo was taken by Eric Schabtach, University of Oregon, Eugene. Magnification, approximately ×6,000.

11



12

II. Sexual reproduction
-> fertilization: fusion of two gametes



13

II. Sexual reproduction
-> fertilization: fusion of two gametes
-> combination of genetic materials
- cause constant increase of chromosome number?

generation 1	1+1->2
generation 2	2+2->4
generation 3	4+4->8
generation 4	8+8->16

……

14

- every species has a fixed number of chromosomes in their somatic cells體細胞 and sex cells生殖細胞, respectively

  human: 46 / 23

  maize: 20 / 10

15

- chromosomes vary in size, location of the centromere

-> array of an individual's chromosomes (metaphase)

=> karyotype 核型

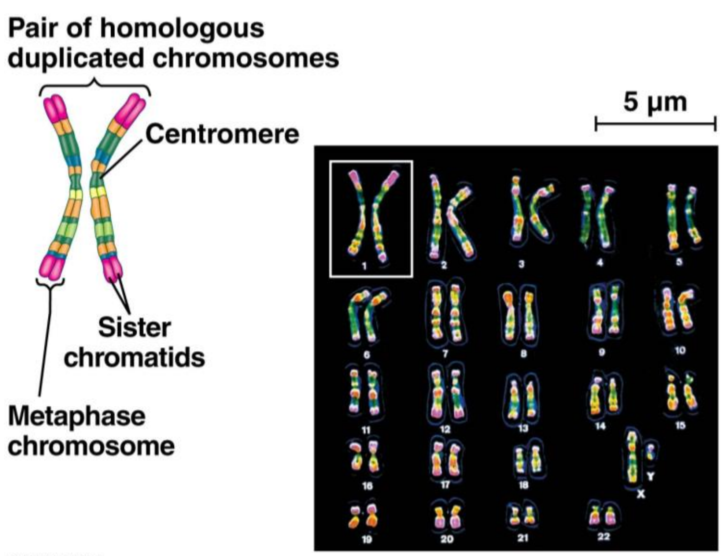
16

1). haploid and diploid
a. diploid
- somatic cells contain 2 copies (1 pair) of each particular chromosome, similar in appearance (size, centromere position, staining pattern)

=> homologous chromosomes (homologs)
同源染色體

-> carry the same set of genetic information (genes)

17



18

1). haploid and diploid
- somatic cells -> diploid cells 二倍體細胞
- the number of total chromosomes
  => diploid number (2n),
  fixed for each species and constant form generation to generation

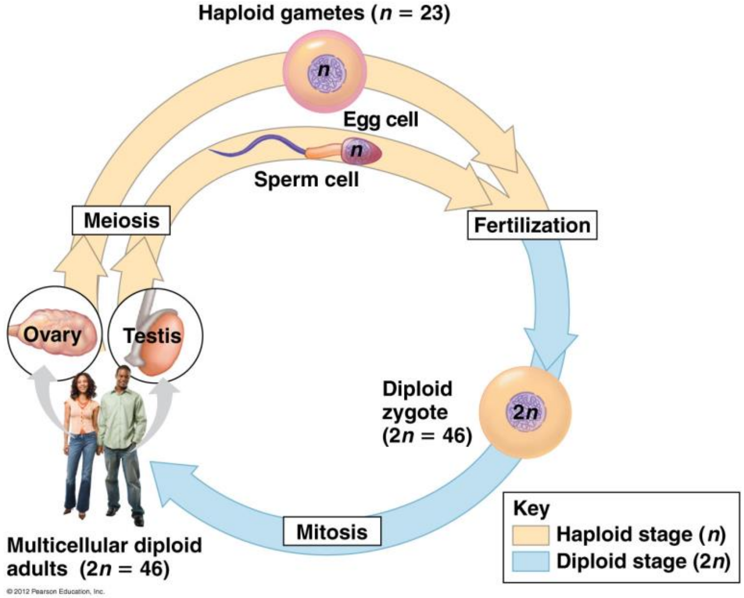
human somatic cell:
46 chromosomes (2n=46, n=23)
44 autosomes, 2 sex chromosomes: XX or XY
體染色體 性染色體
23 pairs of homologous chromosomes

19

b. haploid
- sex cells (gametes) contain only 1 copy of each pair of homologous chromosomes
- the number of chromosomes is half of the somatic cells
  => haploid number (n)
  sex cells -> haploid cells 單倍體細胞
  human sperm or egg:
  23 chromosomes
  haploid number n=23

20

2). balance b/w fertilization and gametes production



21

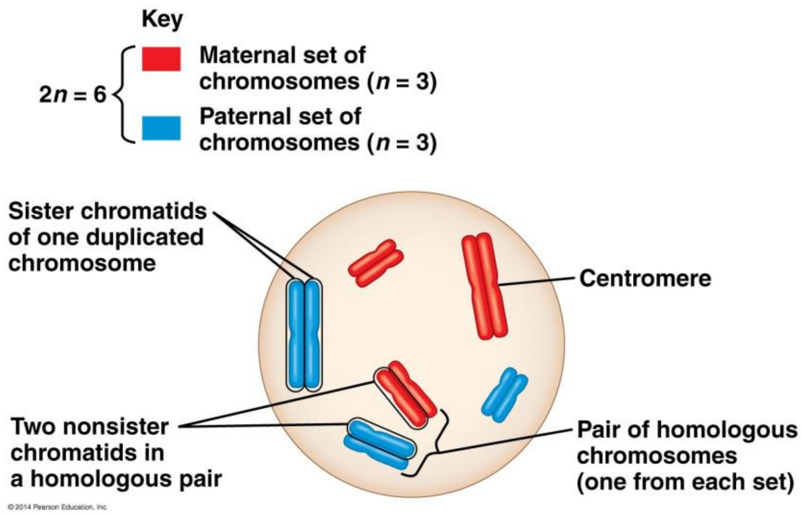
2). balance b/w fertilization and meiosis

meiosis: the process to produce haploid gametes
減數分裂 from a diploid cell
diploid cell --> gametes
2n 1n

fertilization: the fusion of two haploid gamete to form a diploid zygote
gamete + gamete --> zygote（合子）
1n 1n 2n

22

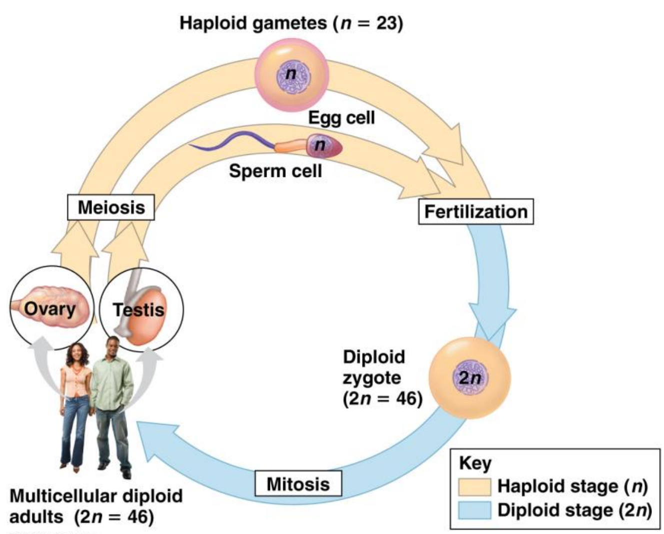
for each pair of homologous chromosomes in a diploid cell, one from each parent



23

3). variety of sexual life cycle

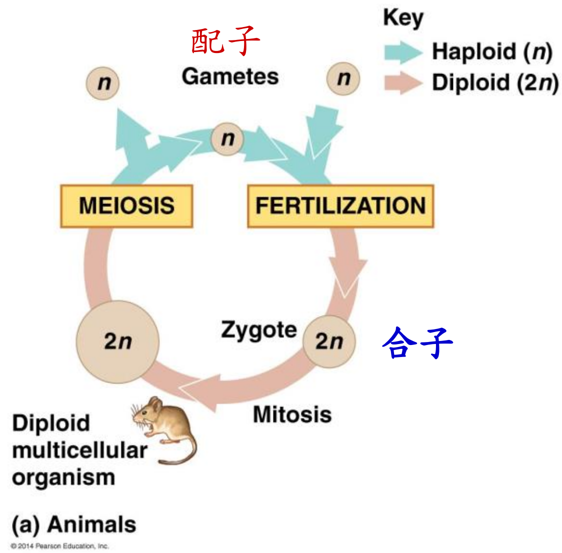
a. animals, gametes are the only haploid cells



24

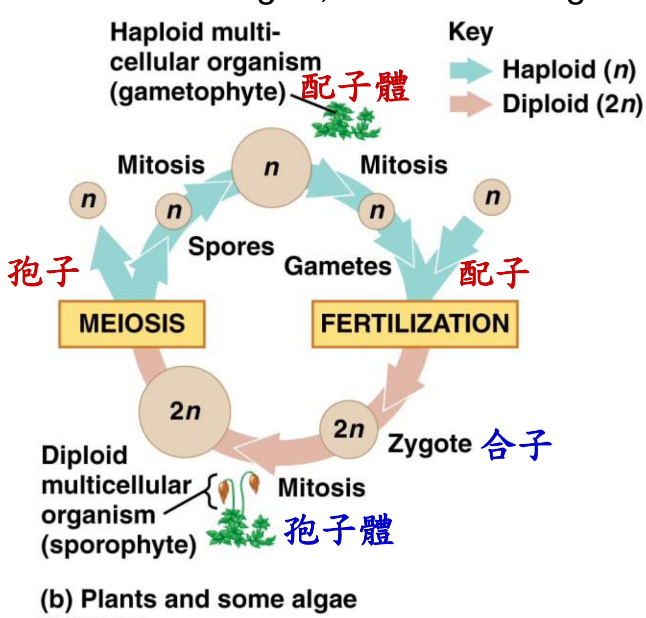
3). variety of sexual life cycle

a. animals, gametes are the only haploid cells



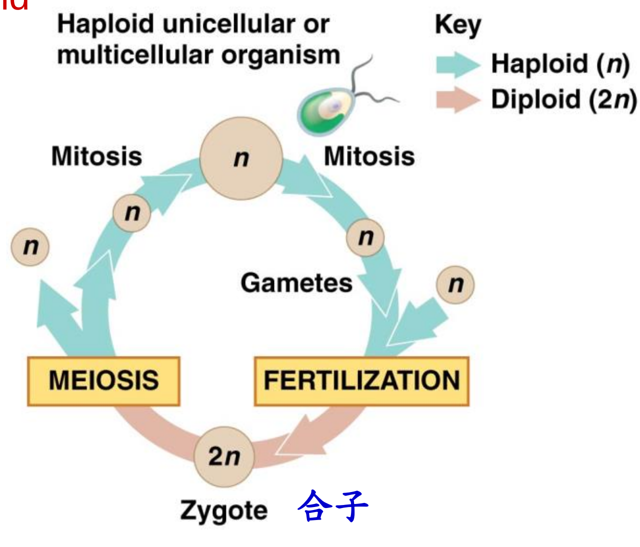
25

b. plants and some algae, alternation of generations

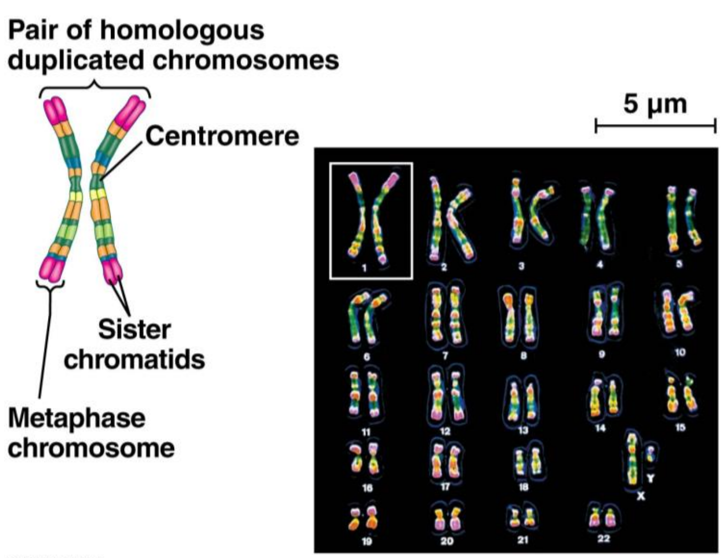


26

c. most fungi, some protist, single-celled zygote is the only diploid



(c) Most fungi and some protists



28

II. Meiosis

1). key points

A. a diploid cell (2n)

-> 1x chromosome duplication

-> 2x nuclear divisions

(chromosome segregations)

meiosis I: separation of homologous chromosomes

meiosis II: separation of sister chromatids (= mitosis)

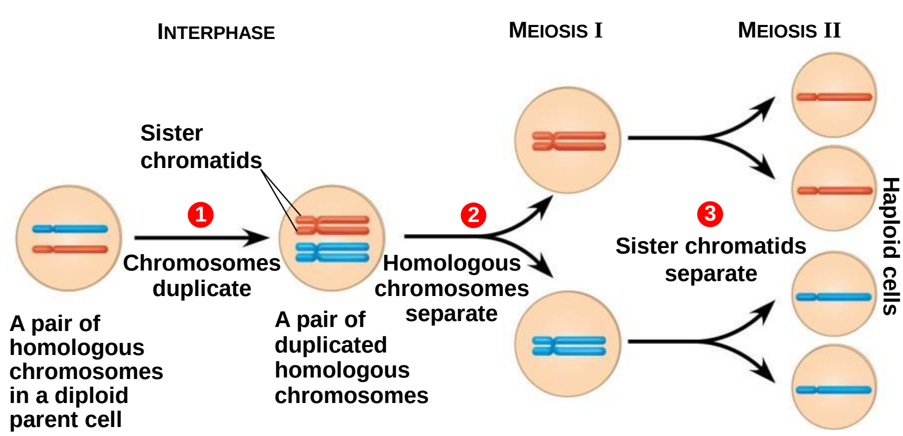
-> 4 daughter cells (1n)

29

1x chromosome duplication

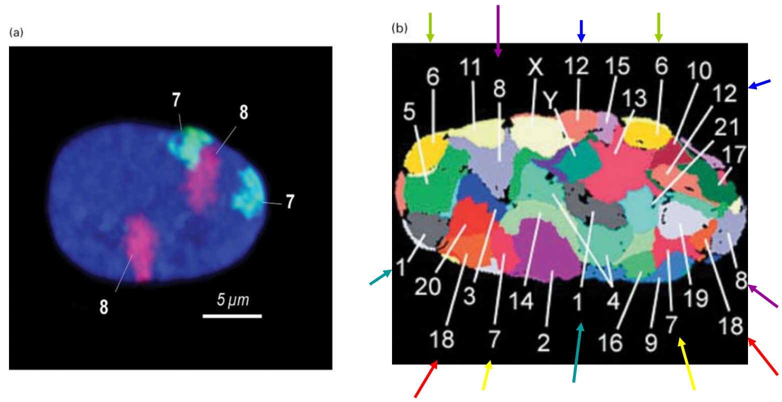
2x nuclear divisions

(chromosome segregations)



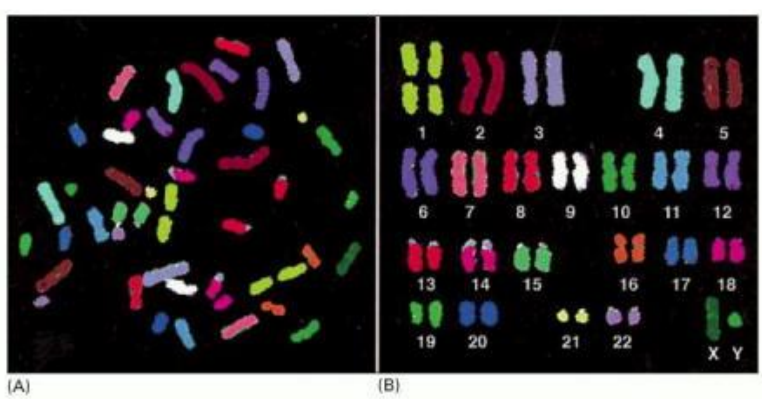
30

Homologs are not paired during interphase



Molecular Cell Biology, Lodish et al.

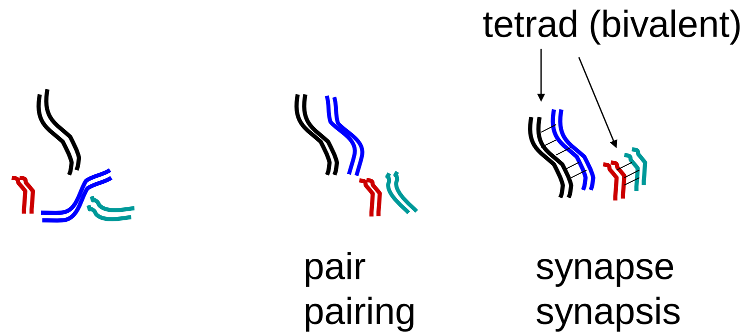
31



Human chromosomes

32

II. Meiosis
1). key points 配對 聯會
B. homologous chromosomes pair and synapse to form a tetrad 四分體 (bivalent 二價體)



33

key events:
- homologs pairing and synapsis (via synaptonemal complex) 聯會複合體
-> form a bivalent (tetrad), as one unit

pairing ≠ synapsis
close together connected by a structure

34

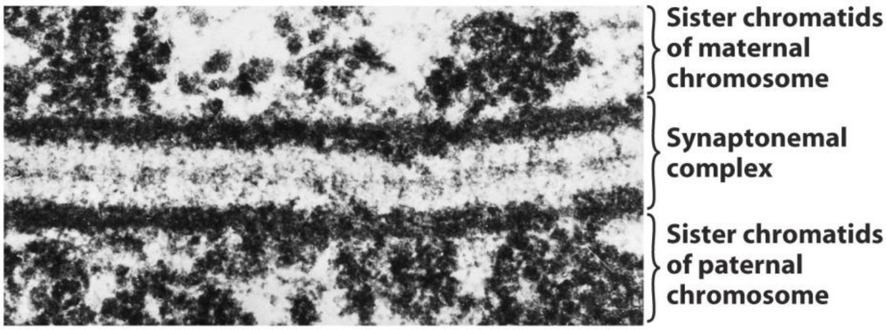


Figure 8-6b
Biology of Plants, Seventh Edition

35

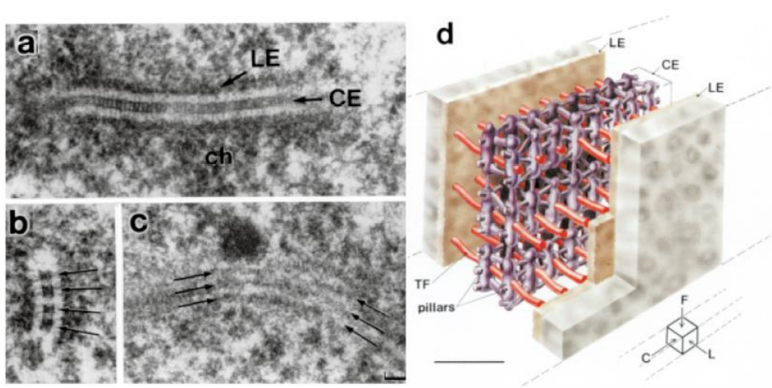
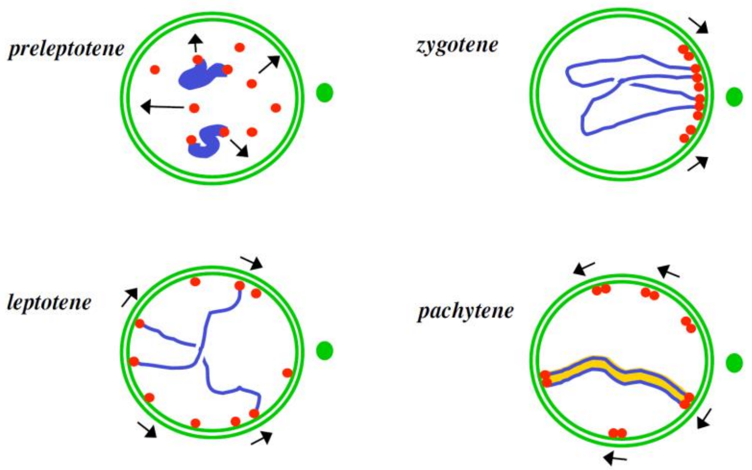


Figure 1 The synaptonemal complex (SC). (*a*) Longitudinal section of *Blaps cribrosa*

36

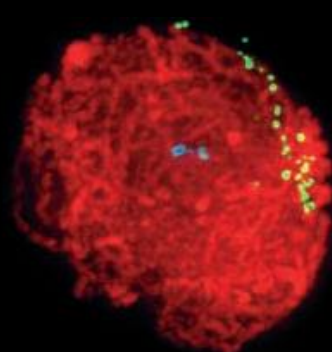
Telomere (端粒) movement in meiotic prophase



Saint-André 2008, Biochimie

37

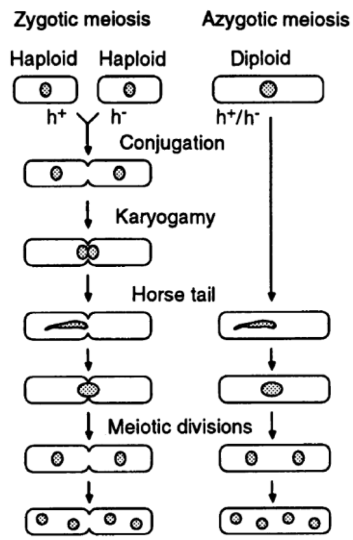
Bouquet of chromosomes in maize

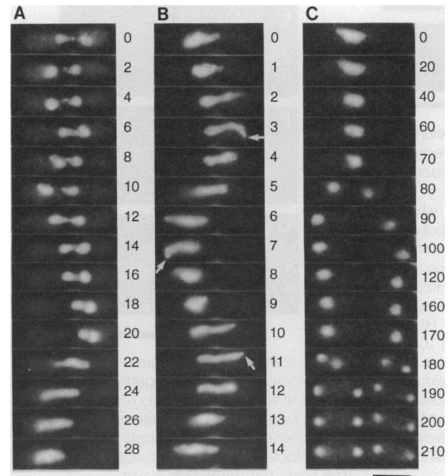


green: telomeres
red: chromatin
blue: 5s rDNA

J Cell Sci 117, 4025-4032

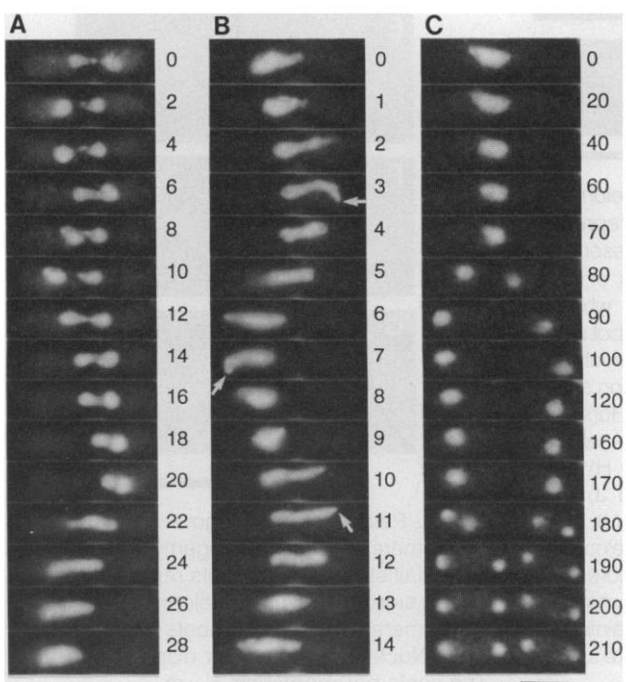
Telomere-led premeiotic chromosome movement
- Horse tail movement





Chikashige 1994, Science

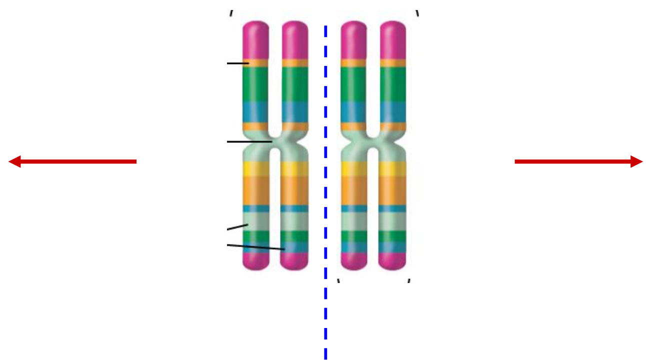
39



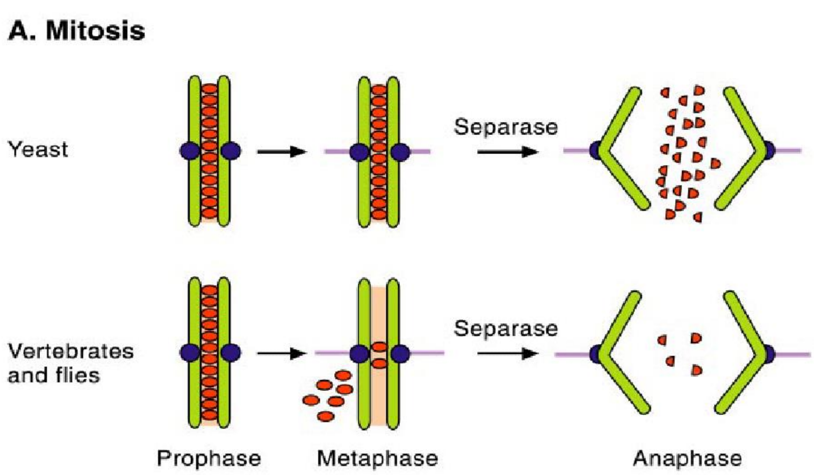
Chikashige 1994, Science

40

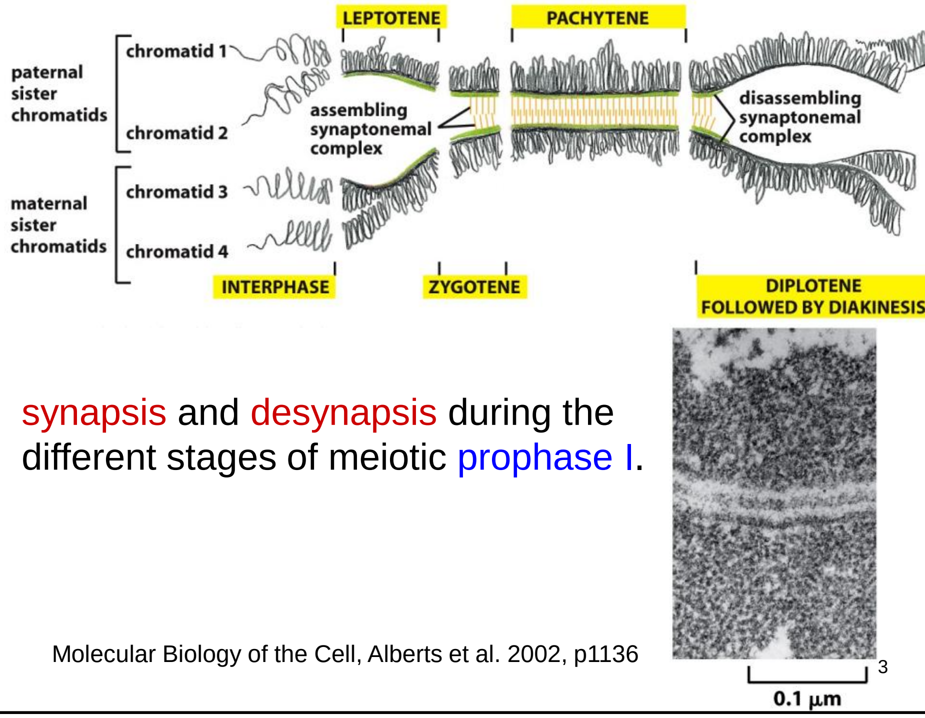
II. Meiosis
1). key points
B. homologous chromosomes pair and synapse to form a tetrad -> as one unit at prophase I and metaphase I
-> homologous chromosomes separate at meiosis I, (sister chromatids move to the same pole)



41



42



synapsis and desynapsis during the different stages of meiotic prophase I.

Molecular Biology of the Cell, Alberts et al. 2002, p1136

3

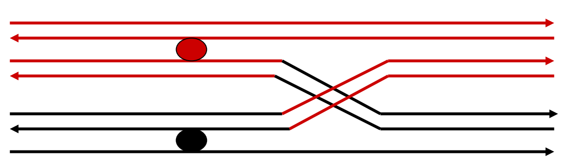
II. Meiosis

1). key points

C. crossing-over: exchange of segments of homologous chromatids

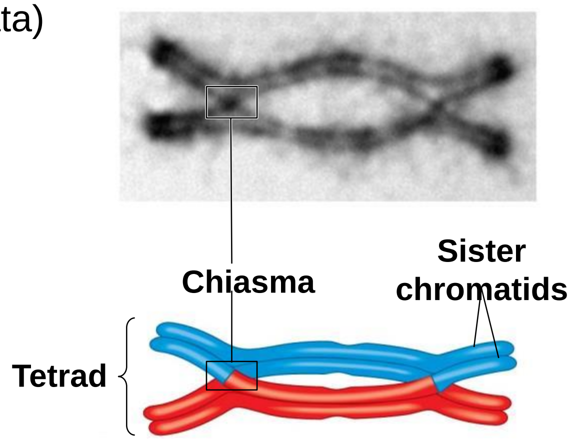
互换

-> genetic recombination



44

C. crossing-over (crossover):
exchange of segments of homologous chromatids
-> genetic recombination
-> chiasma 交叉 to hold homologs together
(*pl*. chiasmata)

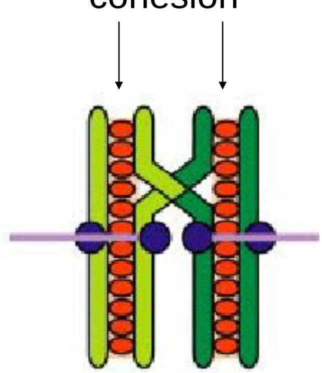


45

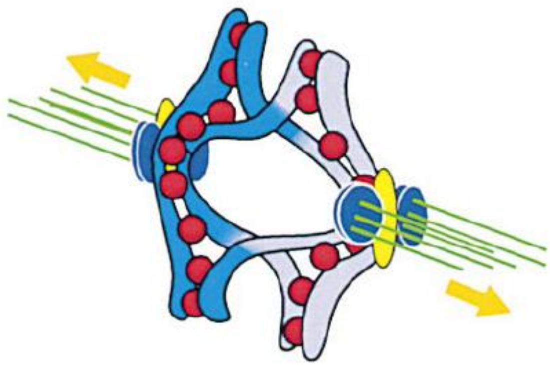
B. Meiosis

cohesion

Meiosis I



46



Cell, 2000,103:1155

47

II. Meiosis

1). key points

A. a diploid cell (2n)

-> 1x chromosome duplication

-> 2x nuclear divisions (chromosome segregations)

B. homologous chromosomes pair and synapse to form a tetrad -> as one unit at prophase I and metaphase I

C. crossing-over: exchange of segments of homologous chromatids

-> genetic recombination

-> chiasma to hold homologous chromosomes together

48

2). stages:

DNA replication

meiosis I

a. prophase I , most complex and longest

b. metaphase I

c. anaphase I

d. telophase I (+ cytokinesis in some species)

meiosis II, similar to mitosis

49

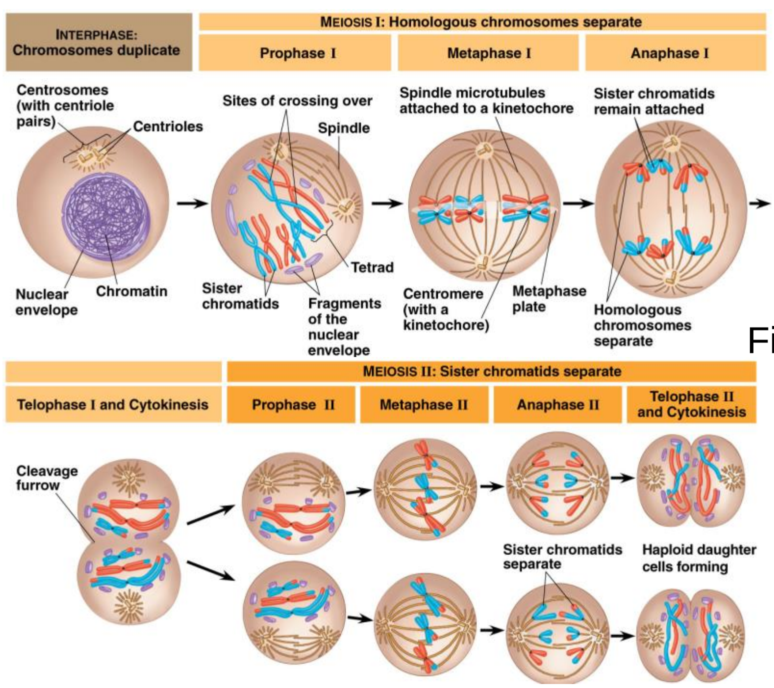
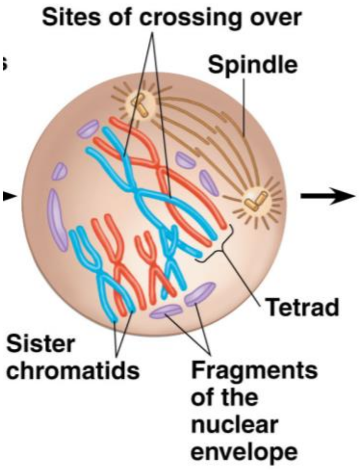


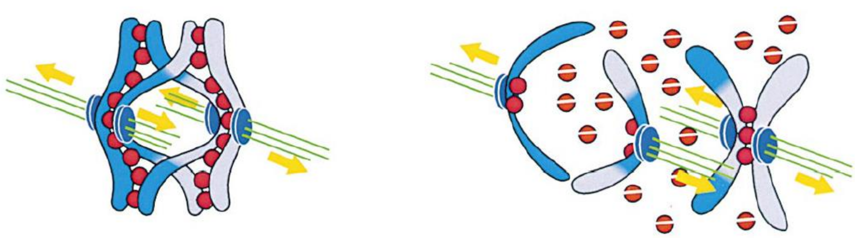
Fig.8.13

50

a. prophase I , most complex and longest
- pairing, synapsis, crossing-over
- chromosome condensation, nucleolus disappears, nuclear envelope breaks down



51

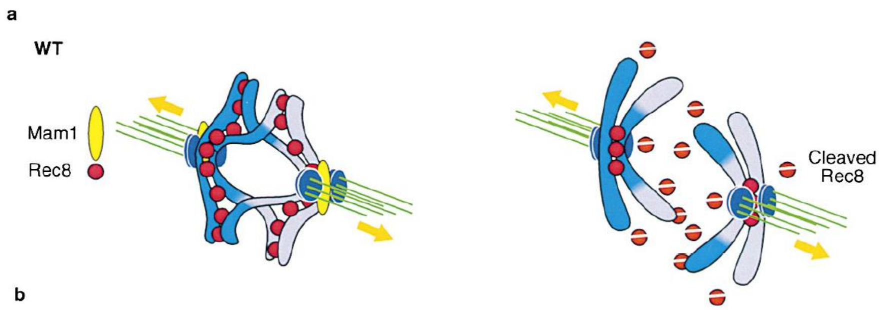


Model for Mam1 Function

Cell, 2000,103:1155

52

- kinetochores of sister chromatids are fused
-> sister chromatids are attached to the same pole



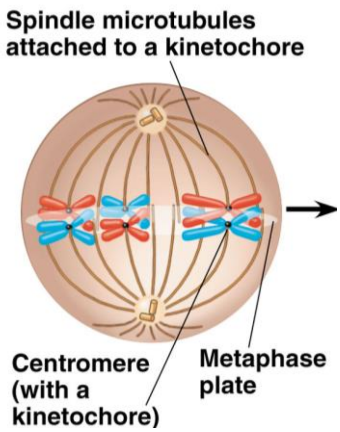
Model for Mam1 Function

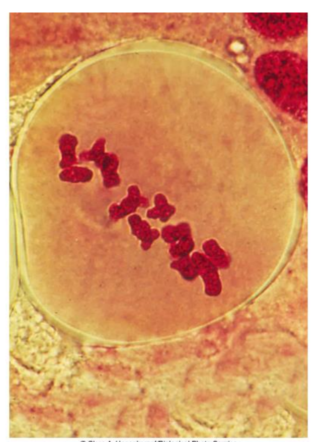
53

Cell, 2000,103:1155

b. metaphase I

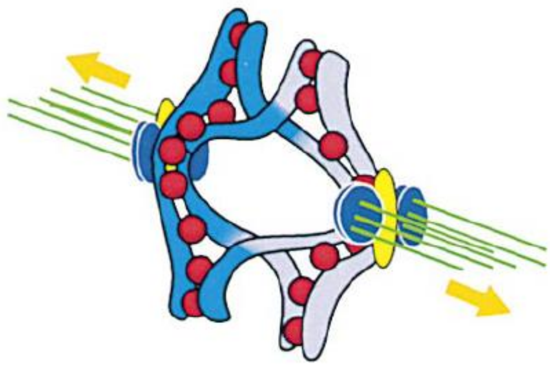
- kinetochores of homologous chromosomes are attached to microtubules from opposite spindle poles -> pairs of homologous chromosomes align along the metaphase plate





54

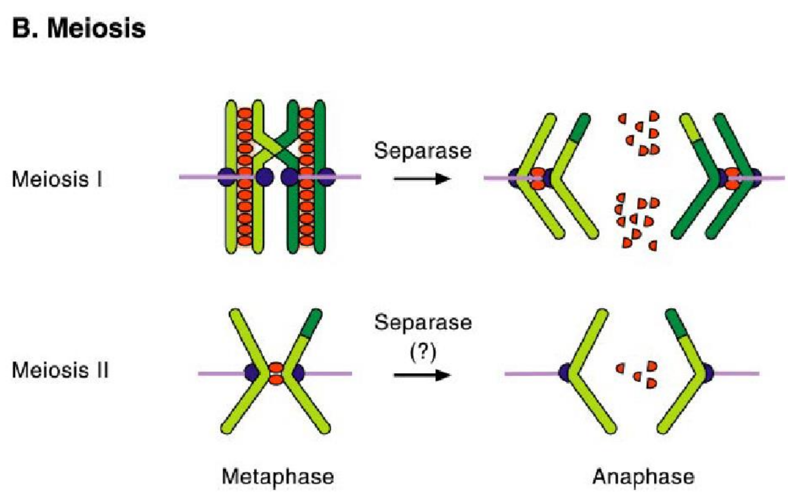
How to separate homologous chromosomes?



Cell, 2000,103:1155

55

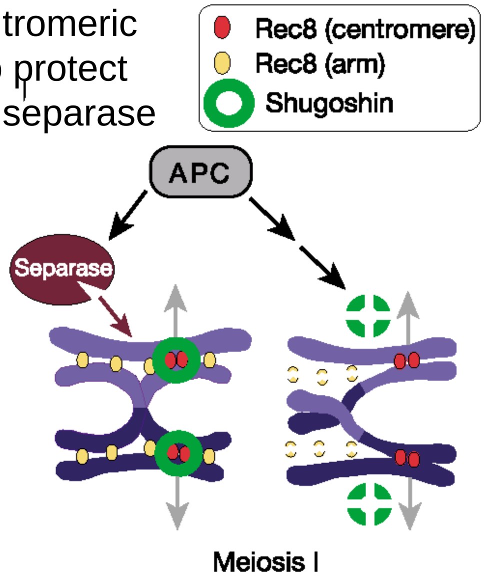
- two rounds of cohesin cleavage during meiosis
  sister chromatid cohesion is maintained at the centromere region



Annu. Rev. Cell Dev. Biol., 2001, 17:753

56

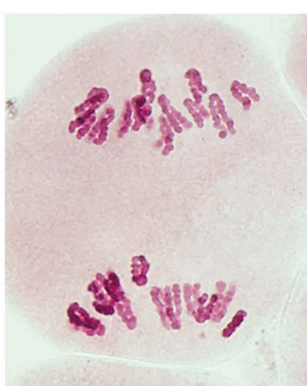
Sgo1 resides at pericentromeric regions and operates to protect Rec8 from cleavage by separase at anaphase I

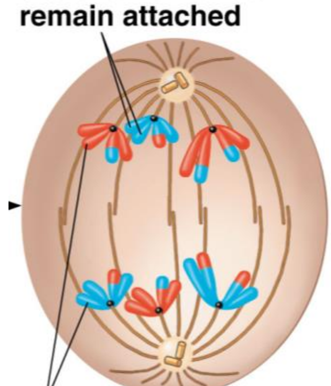


57

c. anaphase I

homologous chromosomes separate





58

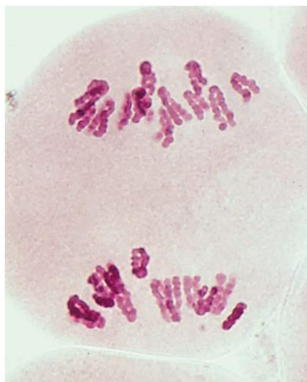
c. anaphase I

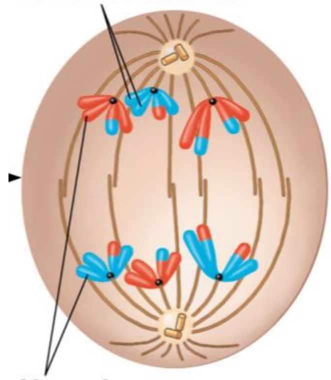
homologous chromosomes separate

-> haploid chromosomes set

-> reductional division

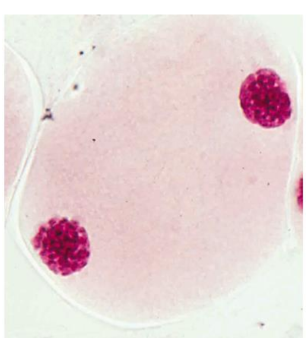
(2n -> 1n)

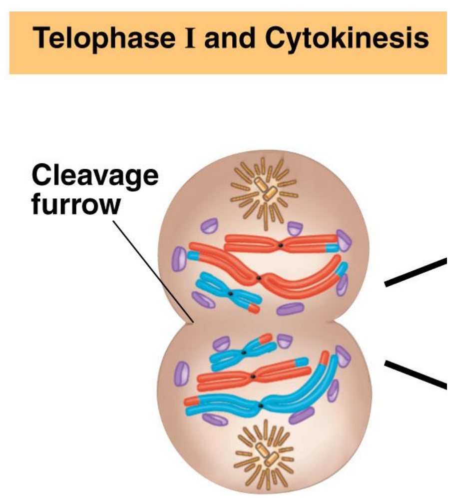




59

d. telophase I (+ cytokinesis) -> 2 haploid cells





60

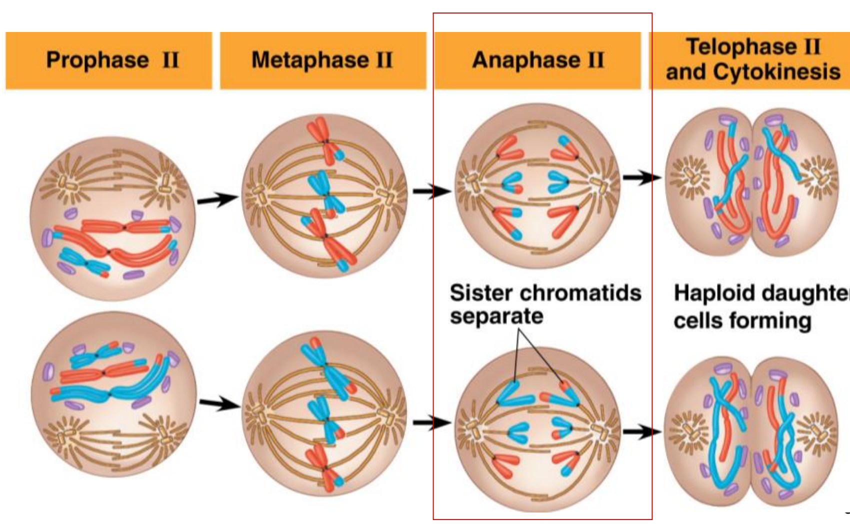
d. telophase I (+ cytokinesis) -> 2 haploid cells

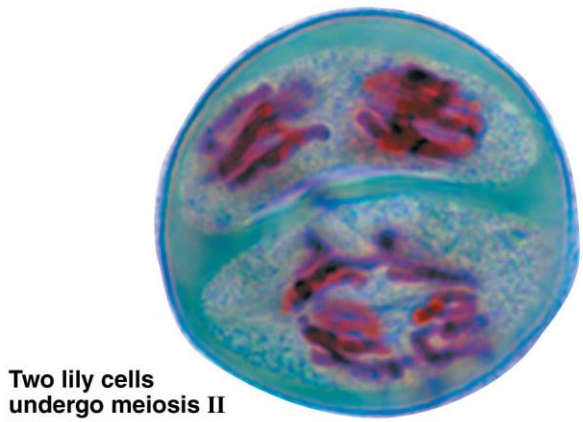
§ continue meiosis II, or enter into interphase

§ no DNA replication before meiosis II

61

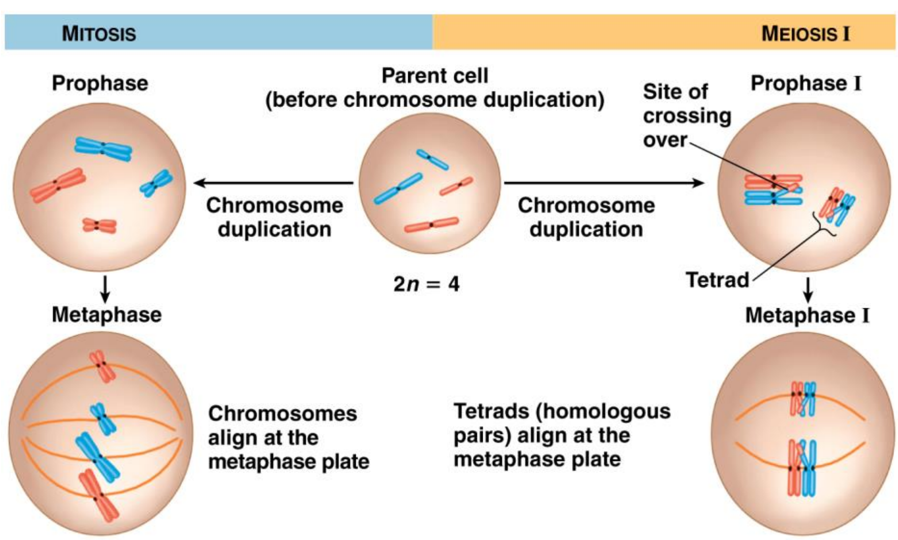
e. meiosis II, essentially, the same as mitosis,
sister chromatids separate -> 4 haploid daughter cells
=> equational division (1n -> 1n)





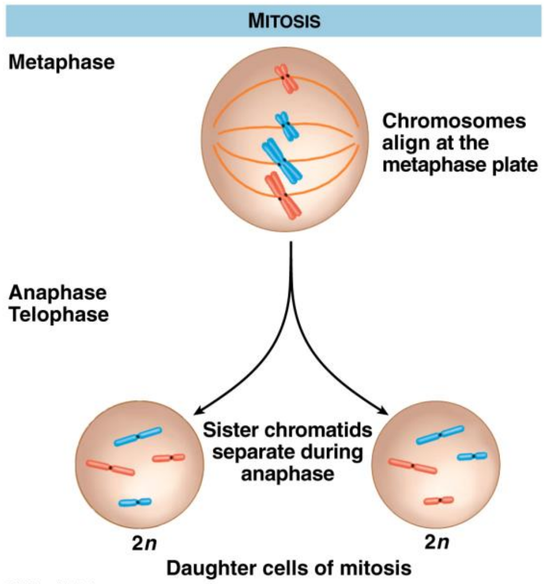
63

§ comparison of mitosis and meiosis



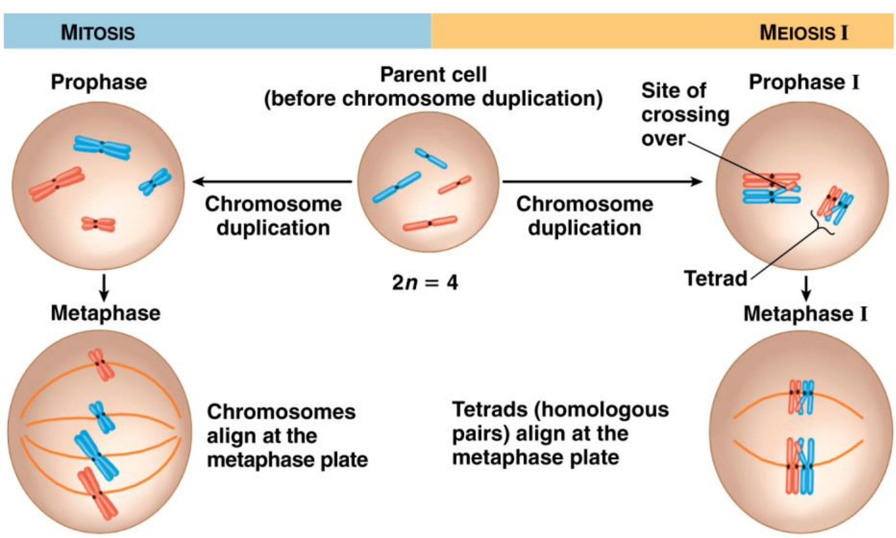
64

§ comparison of mitosis and meiosis



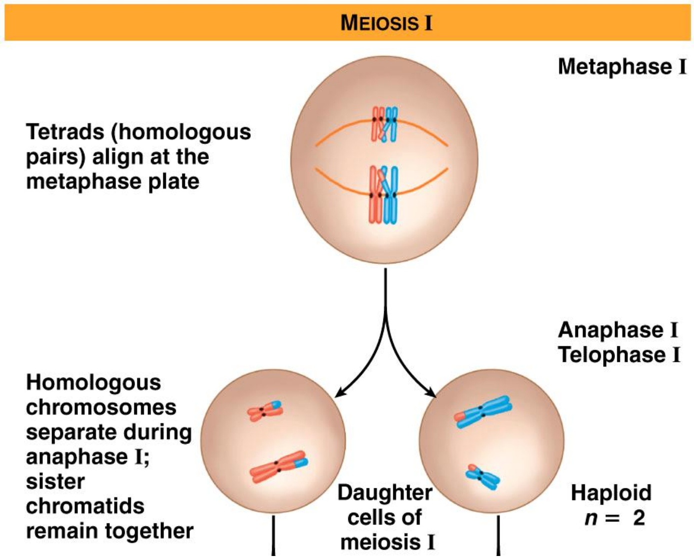
65

§ comparison of mitosis and meiosis



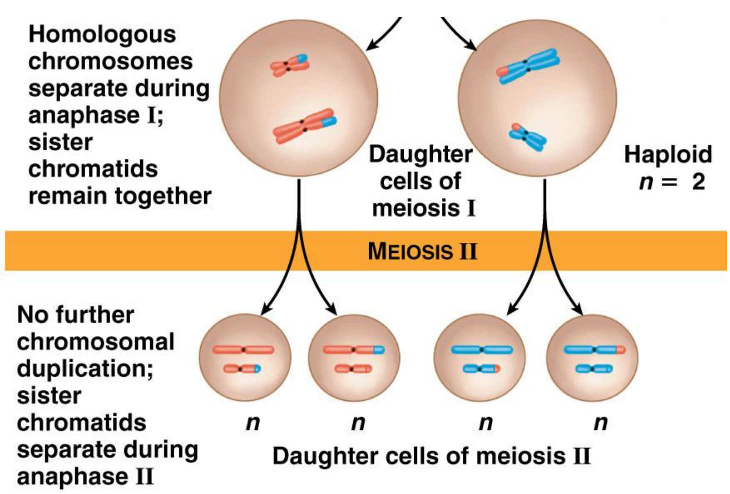
66

§ comparison of mitosis and meiosis



67

§ comparison of mitosis and meiosis



68

§ comparison of mitosis and meiosis

mitosis produces daughter cells genetically identical to their parent cell and to each other

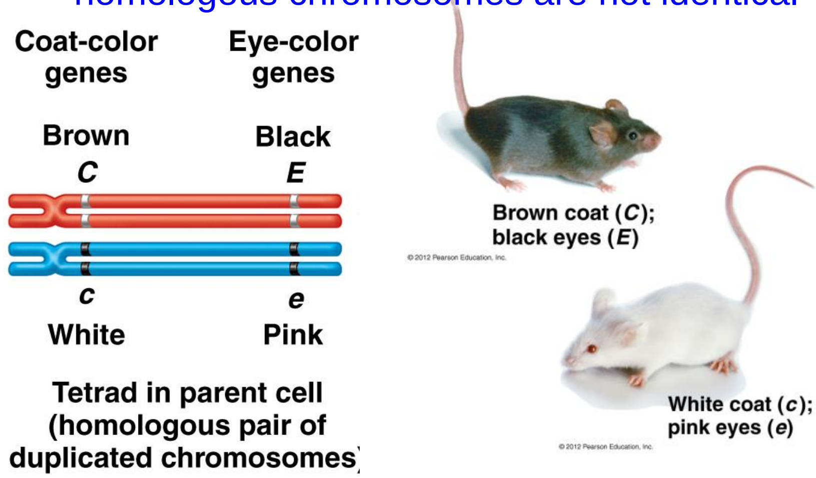
meiosis produces cells genetically different from their parent cell and to each other

69

III. Variability from meiosis -> diversity

- homologous chromosomes may carry different versions of genes

homologous chromosomes are not identical

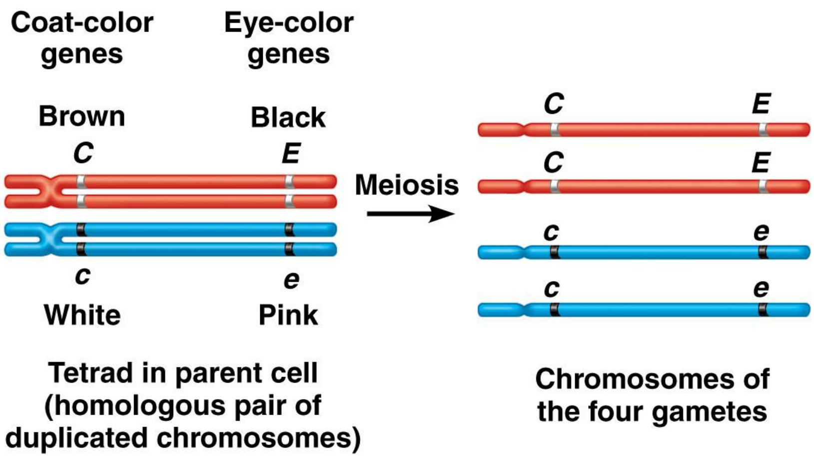


70

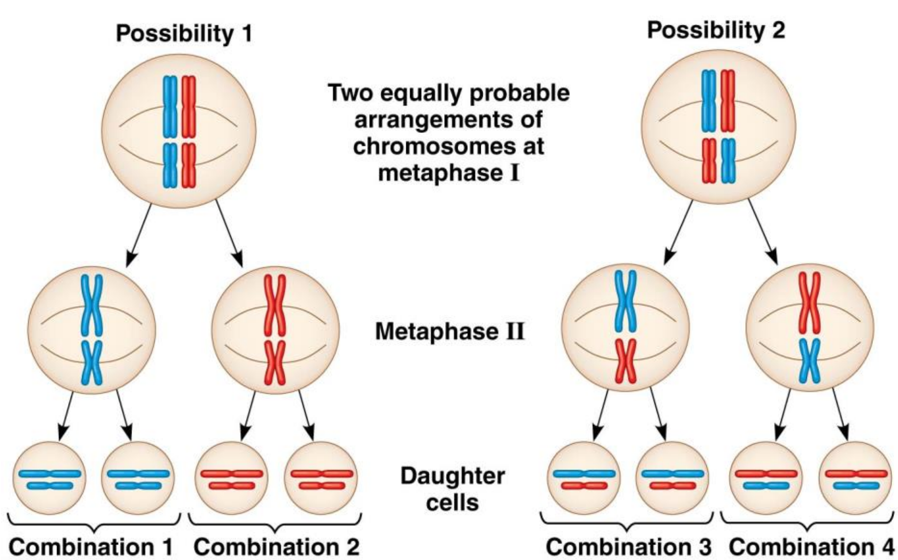
III. Variability from meiosis -> diversity

- homologous chromosomes may carry different versions of genes

homologous chromosomes are not identical



71



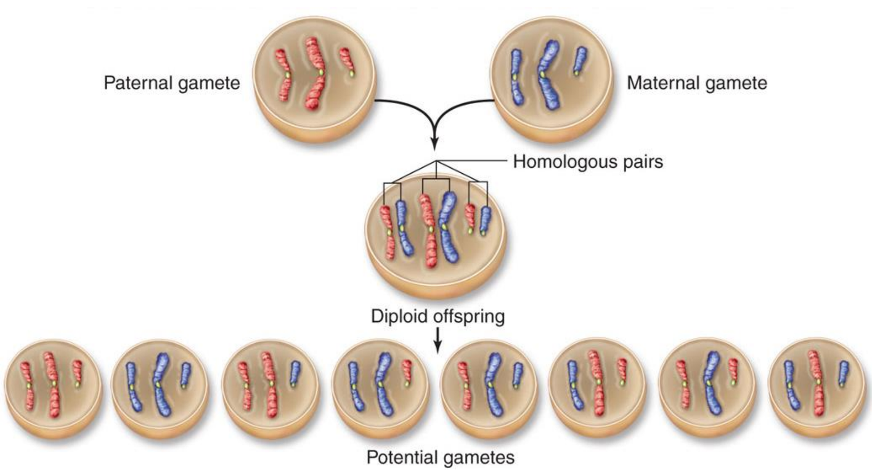
72

homologous chromosomes are not identical

III. Variability from meiosis --> diversity

1. independent assortment
   when ≥ 2 pairs of homologous chromosomes are considered
- random orientation of tetrads at metaphase I
  -> random combination of chromosomes after meiosis I

73



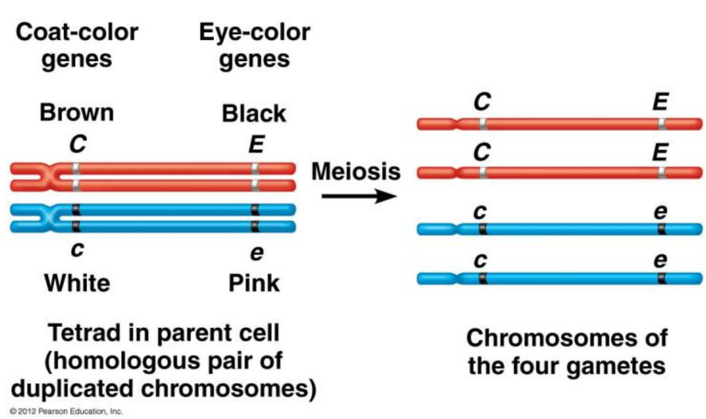
74

1. independent assortment
when ≥ 2 pairs of homologous chromosomes are considered
- random orientation of tetrads at metaphase I
-> random combination of chromosomes after meiosis I
- possible combination of chromosomes in gametes
2^n, n = haploid number

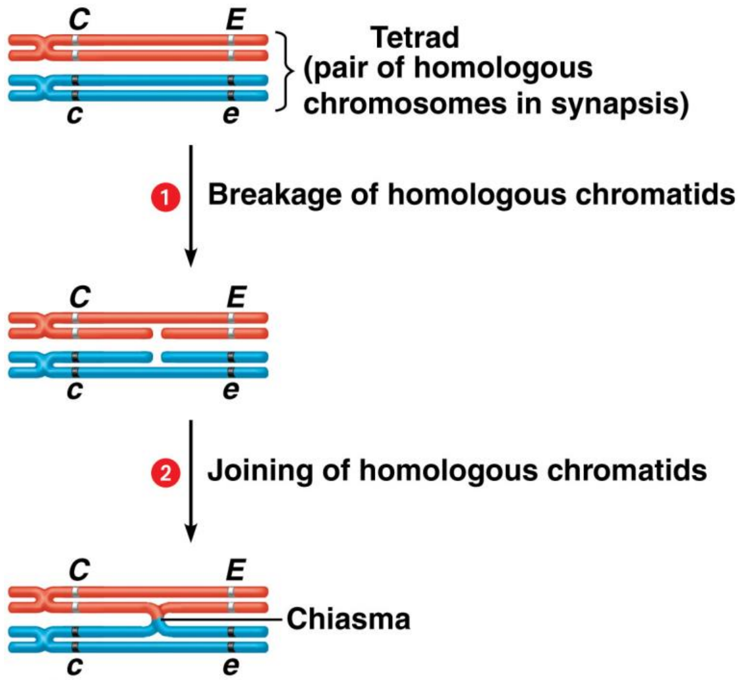
human: 2^{23} = 8,388,608

75

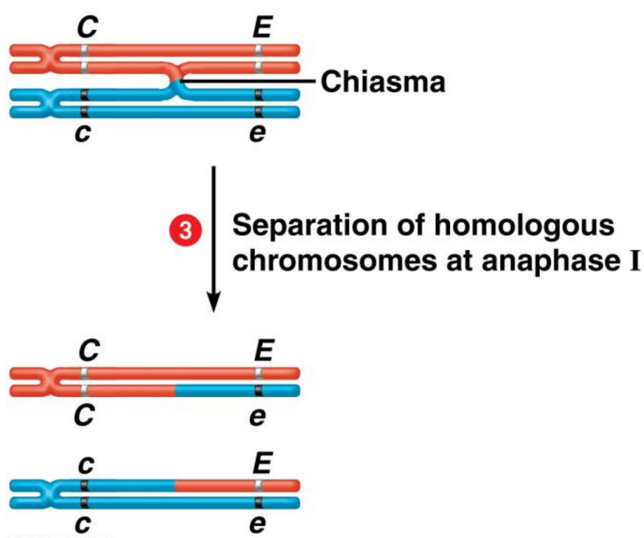
2). crossing-over: genetic recombination, adds more variety in meiosis



76

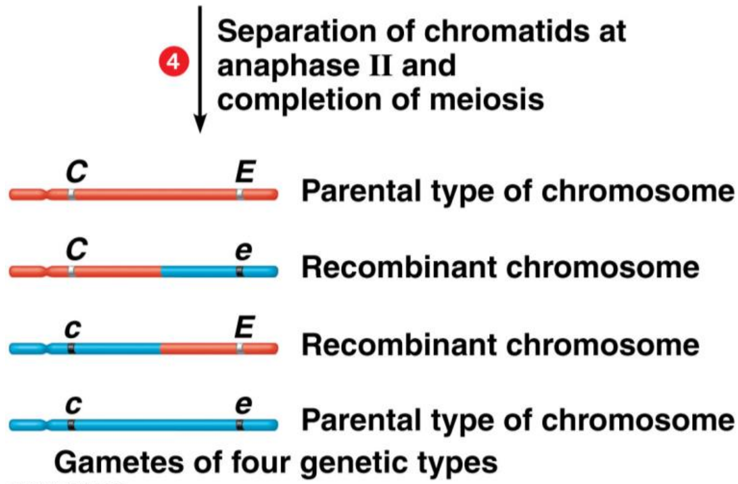

C
E
c
e
Tetrad
(pair of homologous
chromosomes in synapsis)
1 Breakage of homologous chromatids
C
E
c
e
2 Joining of homologous chromatids
C
E
Chiasma
c
e

77


C
E
Chiasma
c
e
3 Separation of homologous
chromosomes at anaphase I
C
E
C
e
c
E
c
e

78

2). crossing-over: genetic recombination,
adds more variety in meiosis



79

3). random fertilization

-> more variability for sexual reproduction

- fertilization

-> random combination of sperms and eggs

\# of possible zygote
= (possible # of sperm) x (possible # of egg)

human: $2^{23} \times 2^{23} = 2^{46} \approx 7 \times 10^{13}$

You are unique!

80

IV. Alterations of chromosome number and structure

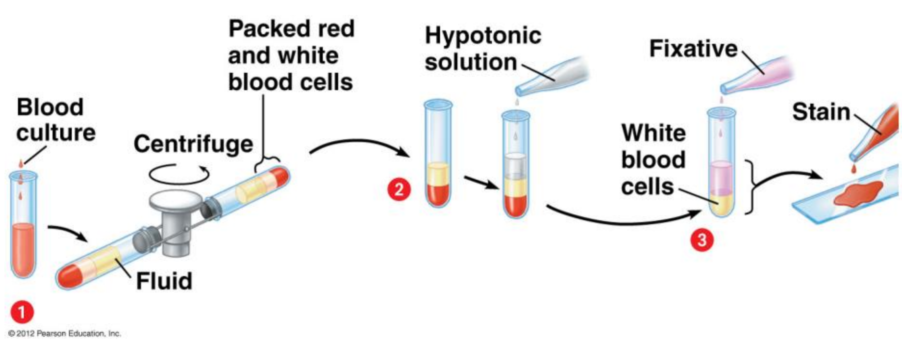
- karyotype:
  a display of microphotographs of metaphase chromosomes of a cell, arranged by size and centromere position, often used lymphocyte (a type of white blood cell), pre-grow and arrest at metaphase

-> an overview of a person's genome

-> to screen for abnormal numbers of chromosomes and for defective chromosomes

81

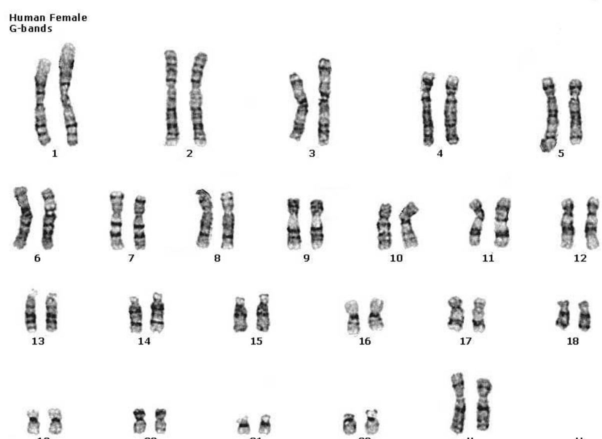
- karyotype:



82

- karyotype:

83



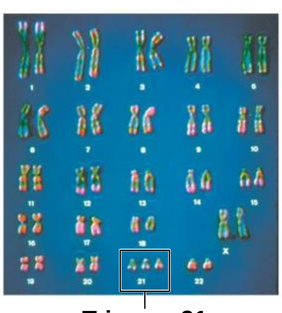
84

1). abnormal numbers of chromosomes
-> aneuploid（非整倍性）

2n-1 -> monosomy (e.g., XO)
2n+1 -> trisomy, most spontaneous abortions, few live-born (e.g., trisomy 8, 13, 18, 21, Y, or X),

85

a. trisomy 21 (Down syndrome)
- most common serious birth defect 1 in 850 (USA)


Trisomy 21


A person with Down syndrome

86

a. trisomy 21 (Down syndrome)
- syndrome:
  characteristic facial features, short stature,
  heart defects,
  susceptibility to diseases (respiratory infection, leukemia,·····)
  mental retardation
  short life span

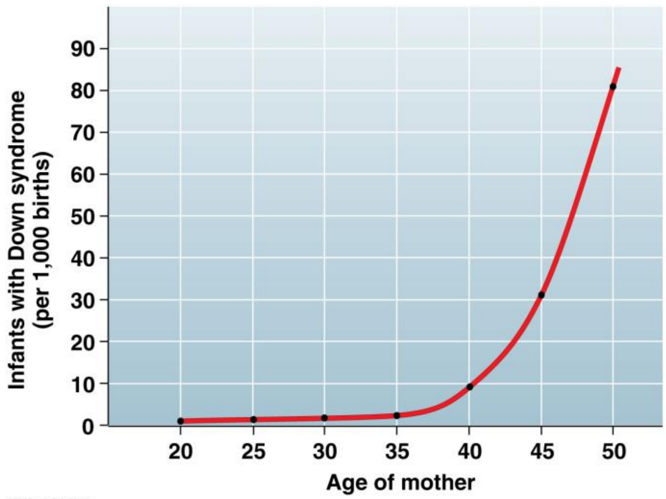
87

a. trisomy 21 (Down syndrome)
- syndrome:
  characteristic facial features, short stature, heart defects, susceptibility to diseases (respiratory infection, leukemia,·····), mental retardation, short life span

88

a. trisomy 21 (Down syndrome)
- older age of the mother, higher the risk of Down syndrome children

under 30: < 0.05% 40 yr.: ~1%



89

- in female, meiosis begins before birth, but arrested at prophase I; only one egg matures every month

-> maybe, longer the time lag, greater the chance that eggs to be damaged (meiosis or checkpoint)

90

human somatic cell:

46 chromosomes (2n=46)

44 autosomes, 2 sex chromosomes: XX or XY

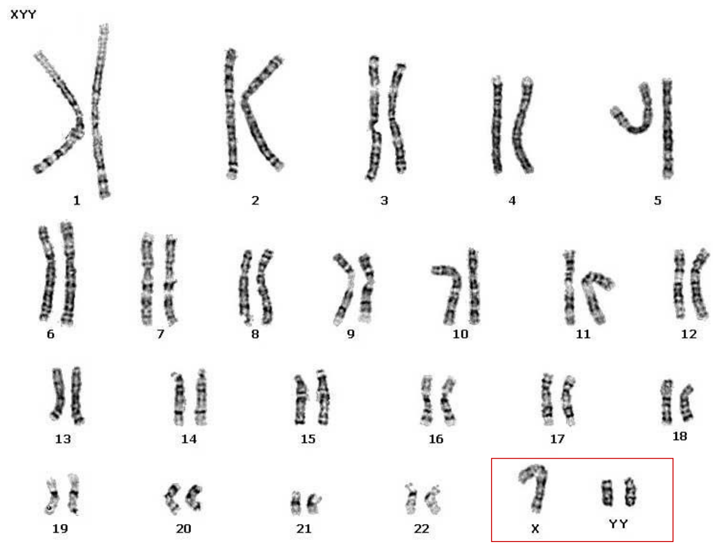
體染色體 性染色體

23 pairs of homologous chromosomes

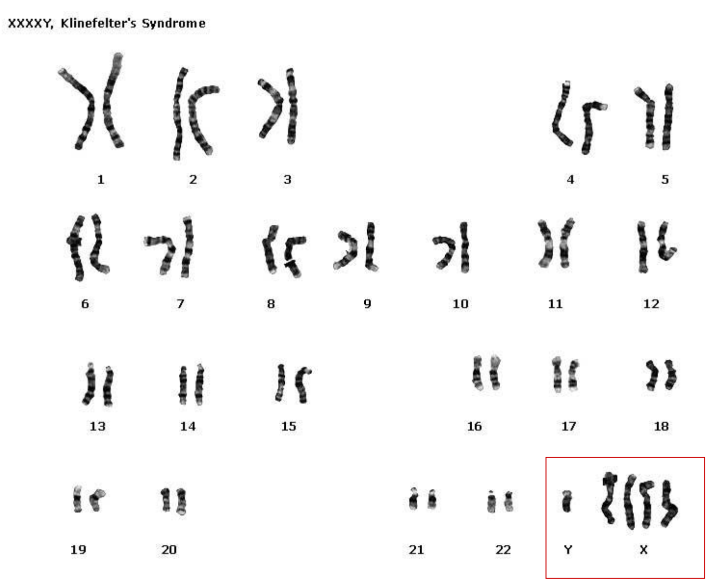
b. aneuploid of sex chromosome

- less harmful than autosome aneuploid
- relative few genes on Y chromosome, regulation on X -> only one X is active

XO	Turner syndrome (female)	sterile
XXX	metafemale syndrome	limited fertility
XXY	Klinefelter syndrome (male)	sterile
XYY	normal male	normal


XYY
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
X
YY

93


XXXXY, Klinefelter's Syndrome
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Y
X

94

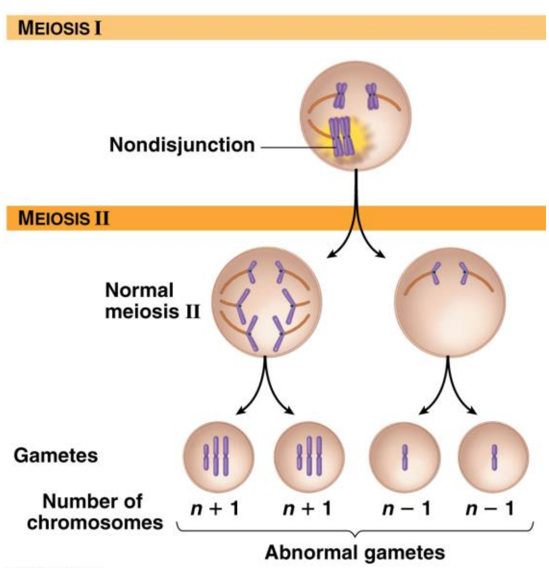
c. causes of aneuploid:
chromosome nondisjunction during meiosis
-> members of a chromosome pair fail to separate

- meiosis I:
  homologous chromosomes not separate
  -> 4 gametes: n+1, n+1, n-1, n-1

- meiosis II:
  sister chromatids not separate
  -> 4 gametes: n+1, n-1, n, n

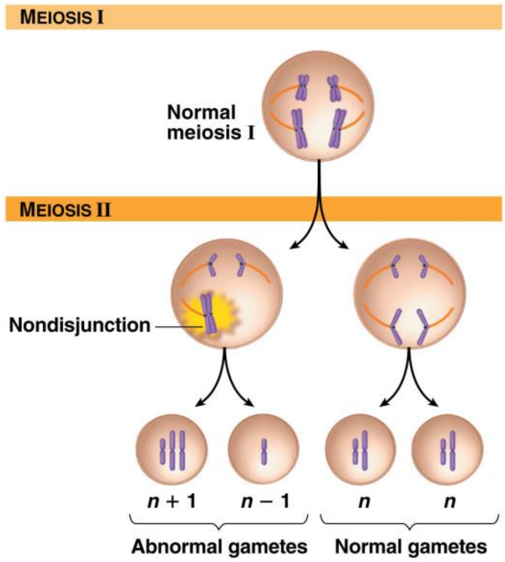
95

- meiosis I: homologous chromosomes not separate
  -> 4 gametes: n+1, n+1, n-1, n-1

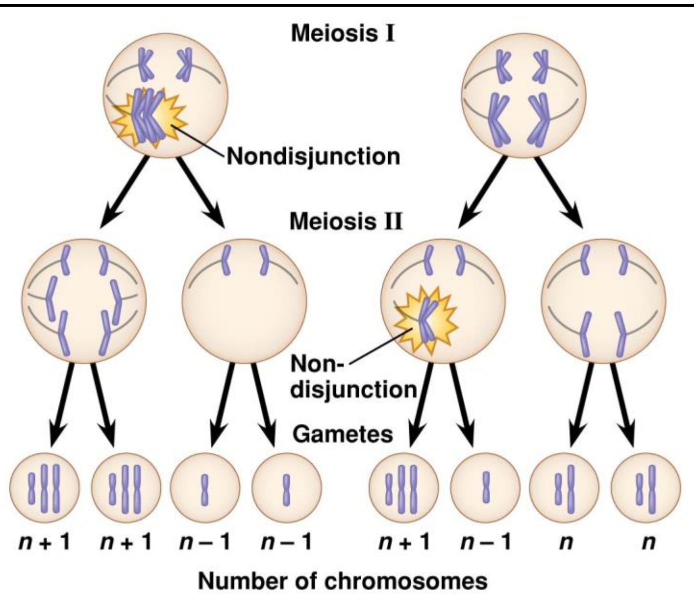


96

- meiosis II: sister chromatids not separate
  -> 4 gametes: n+1, n-1, n, n



97

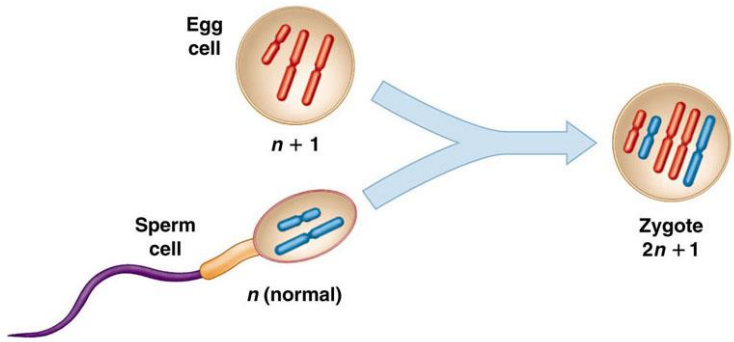


(a) Nondisjunction of homologous chromosomes in meiosis I

(b) Nondisjunction of sister chromatids in meiosis II

98

- gamete + gamete = zygote
  (n+1) + n = (2n+1) (n-1) + n = (2n-1)

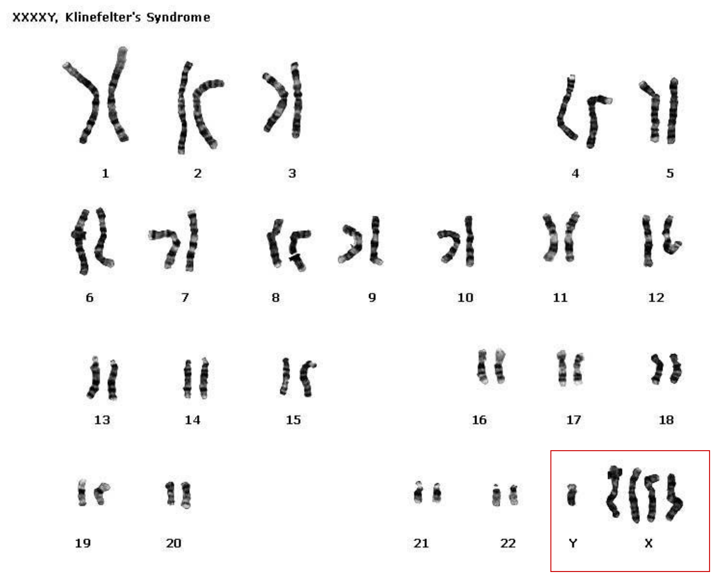


99

Homework-2 due date 4/12

type	sperm or egg	nondisjunction at meiosis I, II, or I or II
XXY	sperm egg	I I or II
XYY	sperm	?
XXX	?	?
XO	?	?

100



101

1). abnormal numbers of chromosomes
-> aneuploid（非整倍性）

2n-1 -> monosomy (e.g., XO)
2n+1 -> trisomy, most spontaneous abortions,
few live-born (e.g., trisomy 8, 13, 18,
21, Y, or X),

compare to polyploidy (e.g., 3n, 4n)

102

d. polyploidy:

more than two complete chromosome sets

- triploidy (3n), tetraploidy (4n)
- common in plants, e.g., wheat (6n), strawberry (8n)
- polyploidy fish and amphibian
- gametogenesis by mitosis or zygote failed to divide after DNA replication

103

2). Alterations of chromosome structure

on single or b/w homologous chromosomes

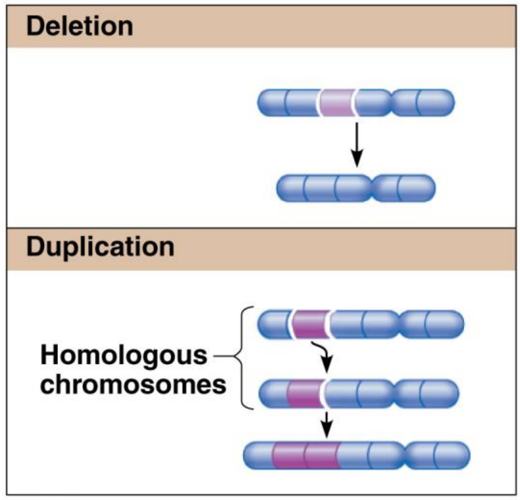
- deletion 缺失
- duplication 重複
- inversion 倒位

between nonhomologous chromosome

- translocation 易位

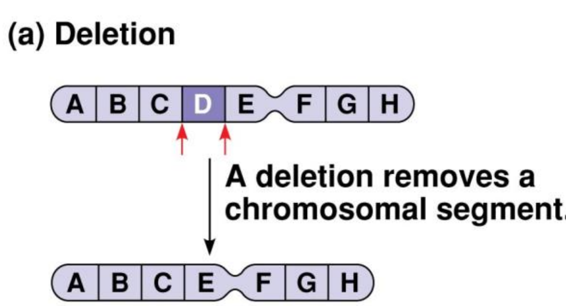
104

2). Alterations of chromosome structure
- deletion: loss of a segment of a chromosome
- duplication: repetition of part of a chromosome



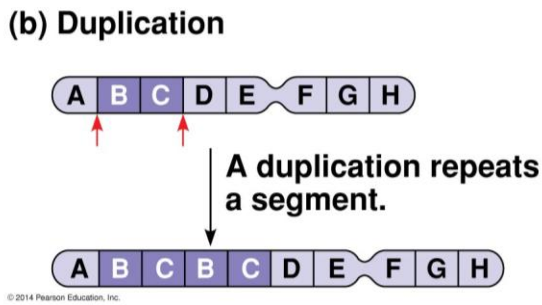
105

2). Alterations of chromosome structure
- deletion: loss of a segment of a chromosome



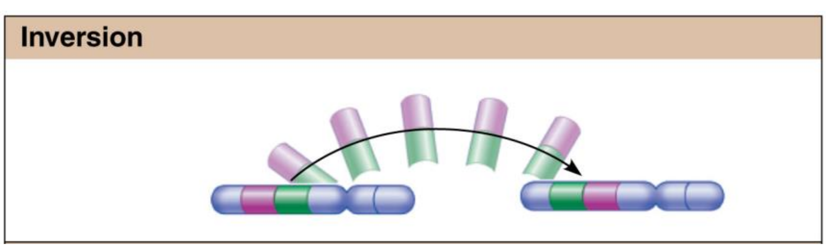
106

2). Alterations of chromosome structure
- duplication: repetition of part of a chromosome



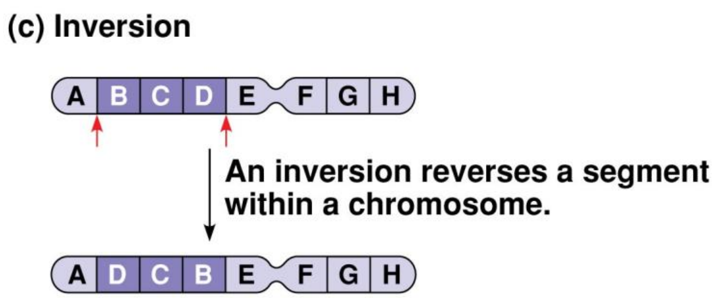
107

2). Alterations of chromosome structure
- deletion: loss of a segment of a chromosome
- duplication: repetition of part of a chromosome
- inversion: change in the orientation of a segment of a chromosome, less harmful



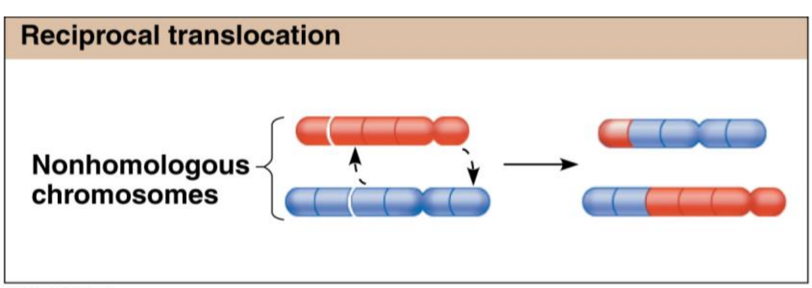
108

2). Alterations of chromosome structure
- inversion: change in the orientation of a segment of a chromosome, less harmful



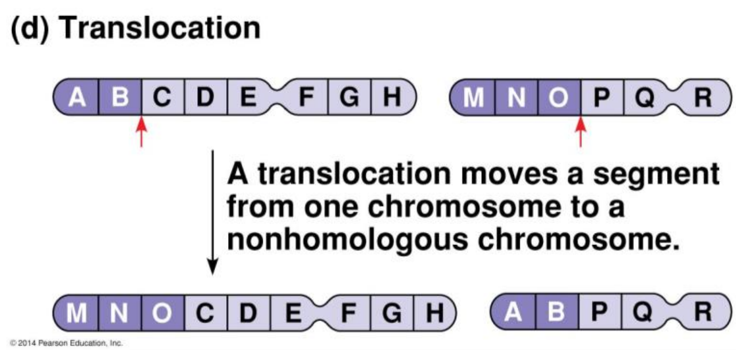
109

2). Alterations of chromosome structure
- translocation: one fragment of a chromosome breaks off and becomes attached to a nonhomologous chromosome, reciprocal or nonreciprocal



110

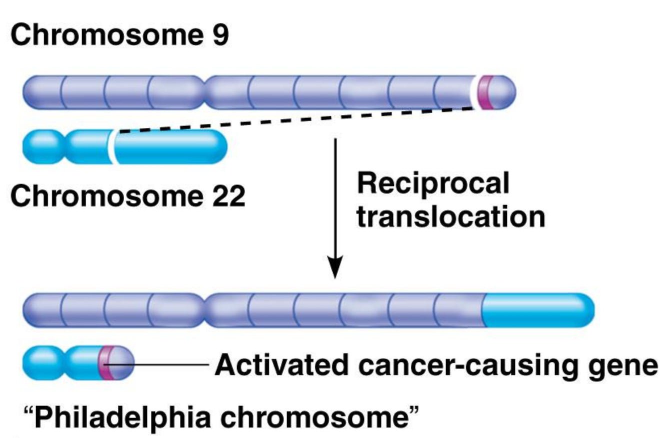
2). Alterations of chromosome structure
- translocation: one fragment of a chromosome breaks off and becomes attached to a nonhomologous chromosome,
  reciprocal or nonreciprocal



111

2). Alterations of chromosome structure
a. in sperm or egg -> inherited disorder

b. in somatic cells -> may cause cancer
e.g., Philadelphia chromosome: **22** + 9 -> leukemia



112

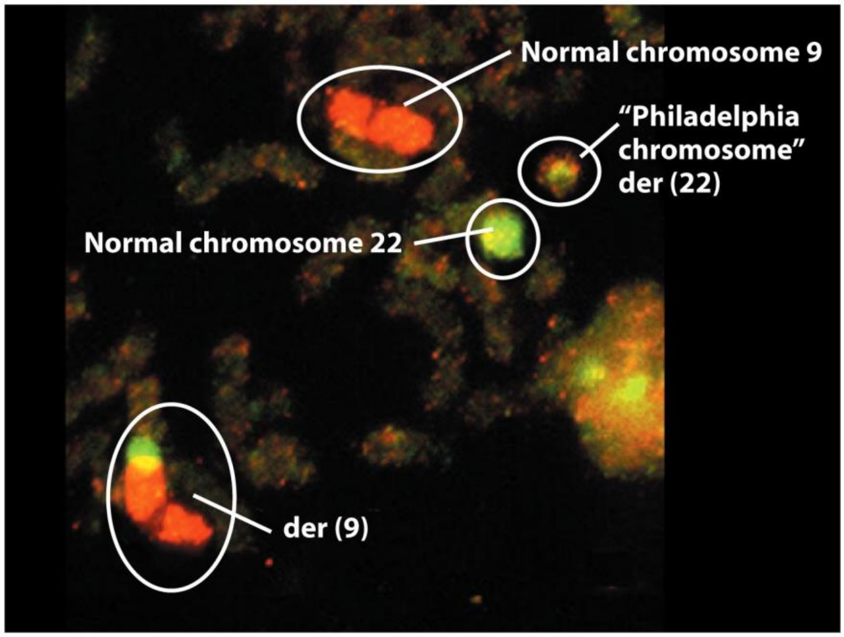
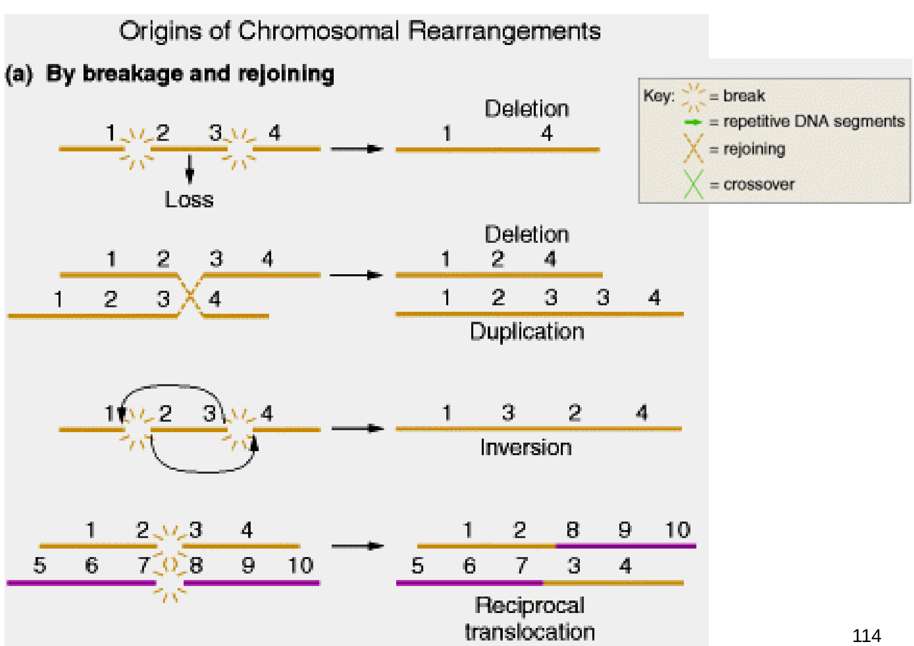
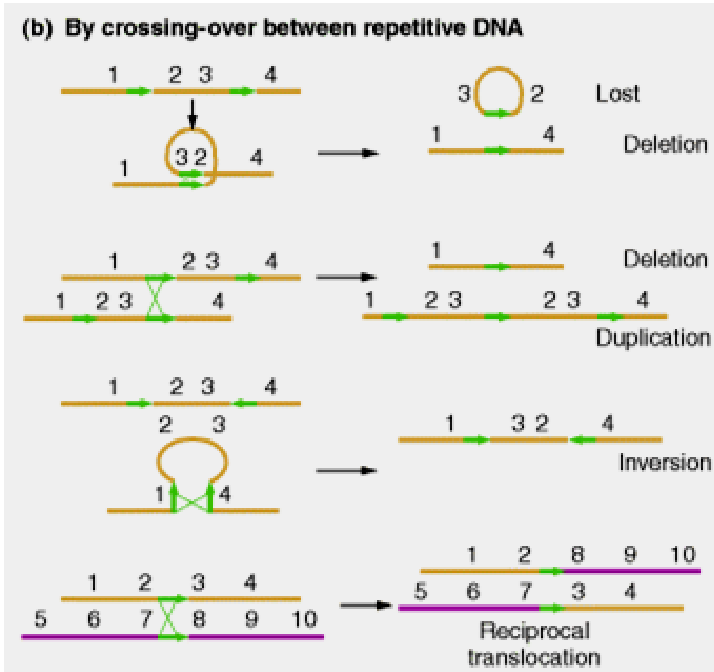


Figure 6-42b
Molecular Cell Biology, Sixth Edition



114


(b) By crossing-over between repetitive DNA
1
2 3
4
3 2
Lost
Deletion
Deletion
Duplication
Inversion
5
6
7
8
9
10
Reciprocal
translocation

115