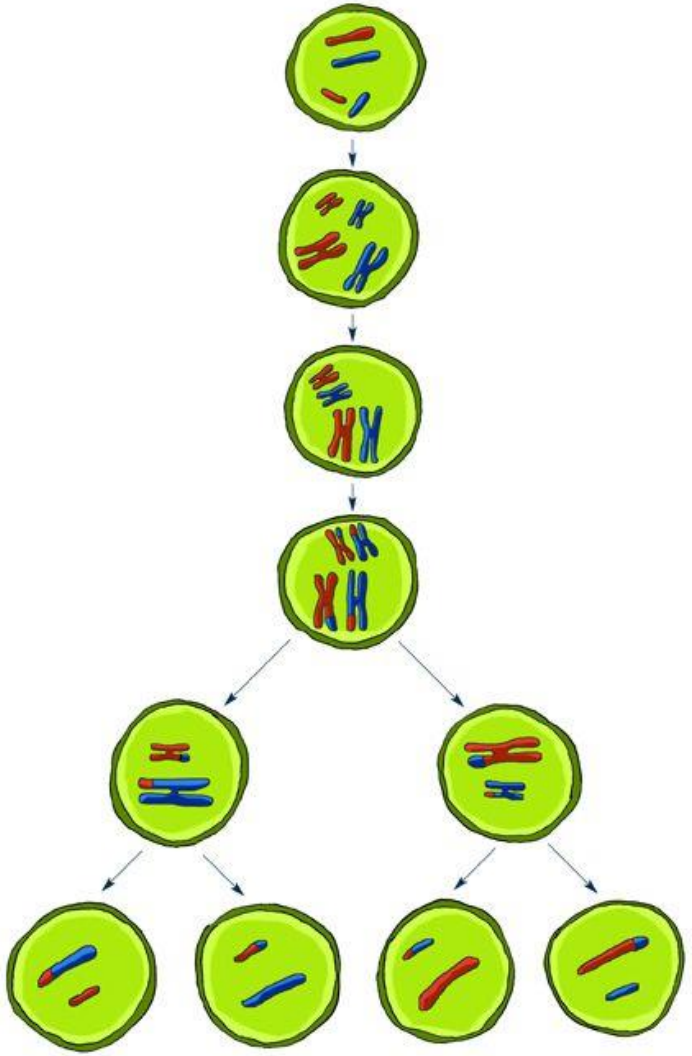
Today's class – Meiosis

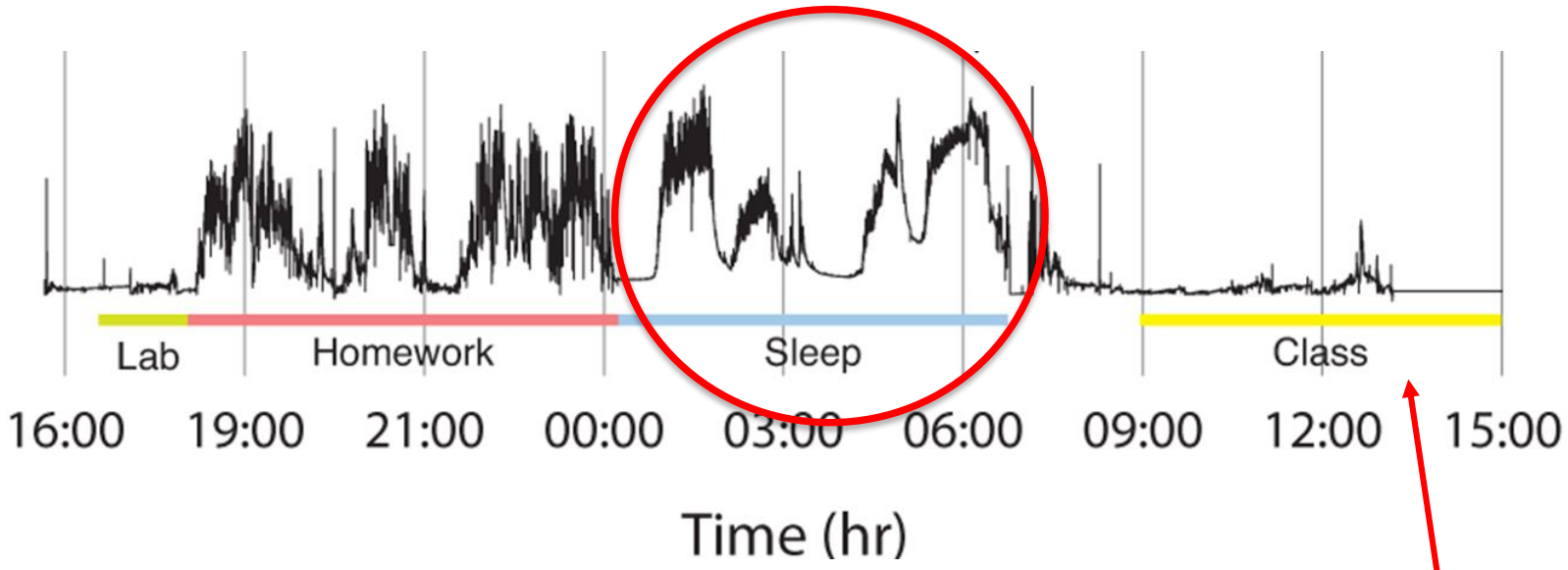


https://www.livescience.com/39473-chromosome-miscounts-potential-therapies-nigms.html

Tip #6 - Midterms are not far away - Get enough sleep!!!

Your brain is still active while you sleep – organizing/storing information/clearing toxins

Measure of nervous system activity



Ming-Zher et al. 2010

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Reminders

Tonight: Pam's Genetic Survey – Part I (1% of grade)

- due tonight by 11:59 pm

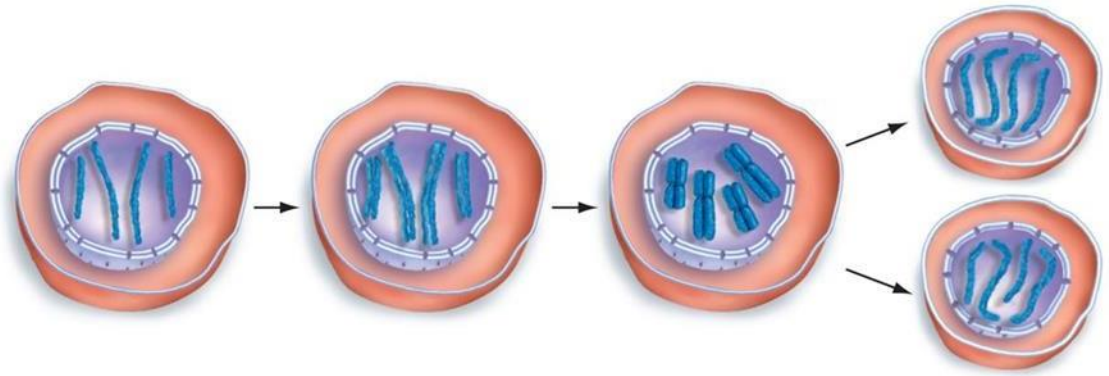
Due Sunday night @ 1159 pm

- Quiz 1 and Quiz 2
- Worksheet #1 and Worksheet #2

Last class – Cell Cycle, Mitosis & Cytokinesis

- Mitosis occurs in somatic cells
- Parent cell undergoes one round of nuclear division + cytokinesis
- Goal – to produce 2 genetically identical progeny cells
  - growth, replace old/damaged cells, and reproduction for some taxa

Parent cell

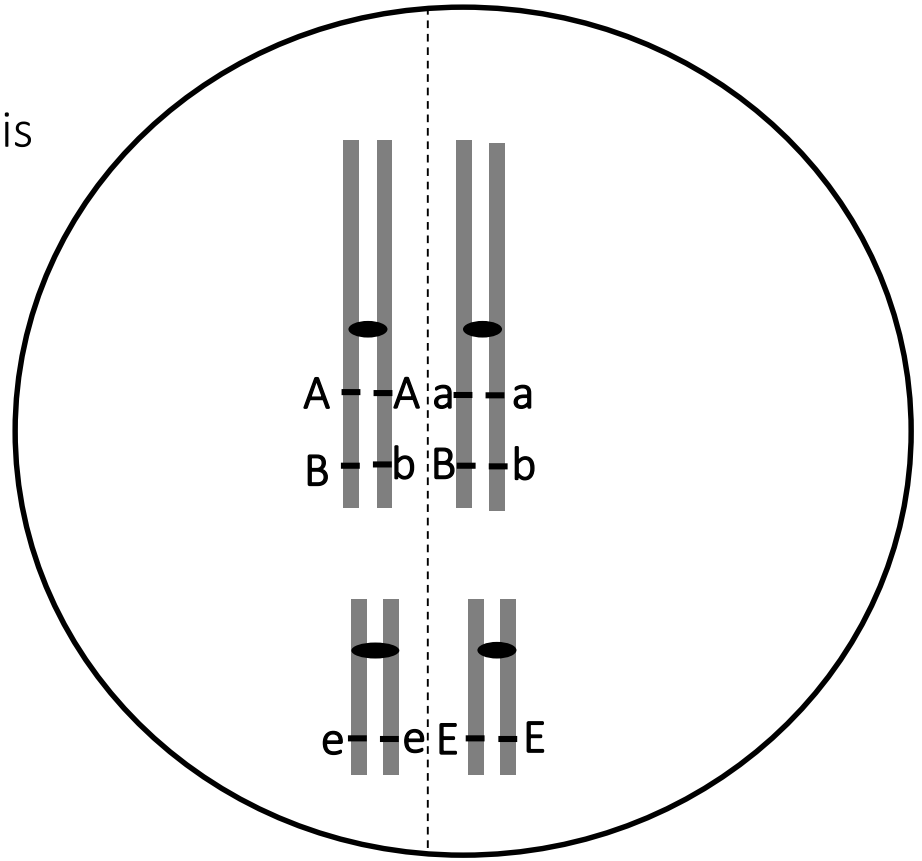


2 genetically identical progeny cells

iClicker Question

A 2n=4 organism has the genotype AaBbEe. Could the cell below be undergoing mitosis? Be prepared to explain your answer.

A. Yes - Prometaphase of Mitosis
B. Yes – Metaphase of Mitosis
C. Yes - Anaphase of Mitosis
D. No
E. Not sure



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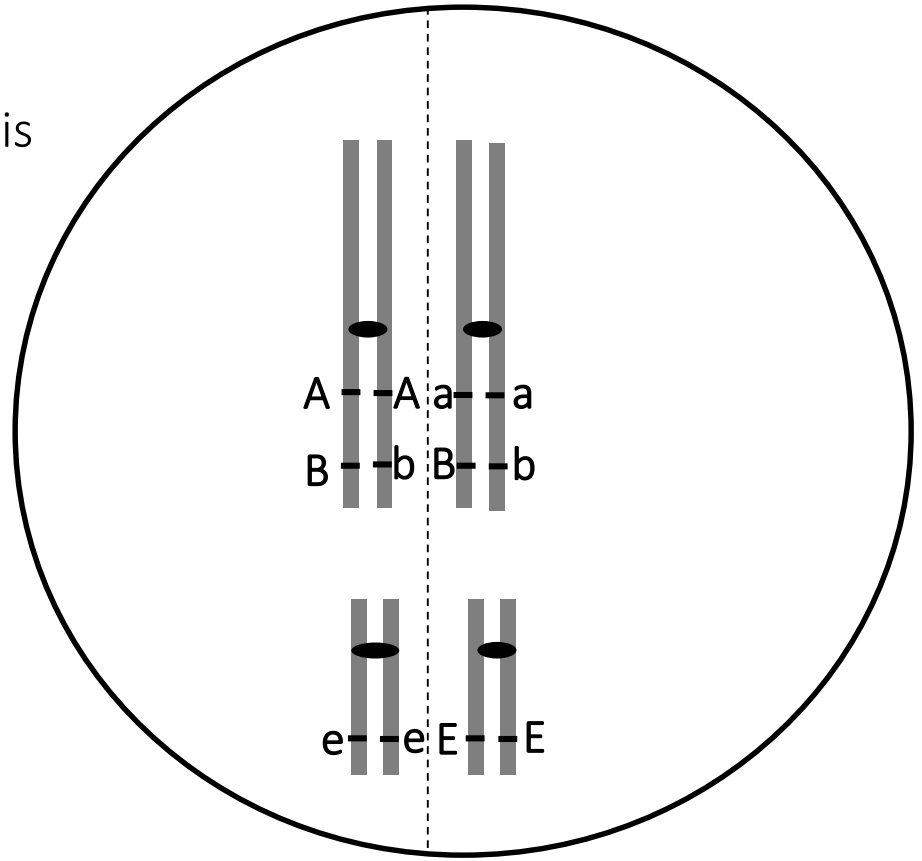

Crossing-over and recombination does not occur in mitosis (see B gene)

The homologs do not align on opposite sides of the metaphase plate in mitosis

iClicker Question

In metaphase of mitosis, which structures align on either side of the metaphase plate?

A. Homologous chromosomes
B. Non-homologous chromosomes
C. Sister chromatids
D. Non-sister chromatids
E. Not sure

Answer

In metaphase of mitosis, which structures align on either side of the metaphase plate?

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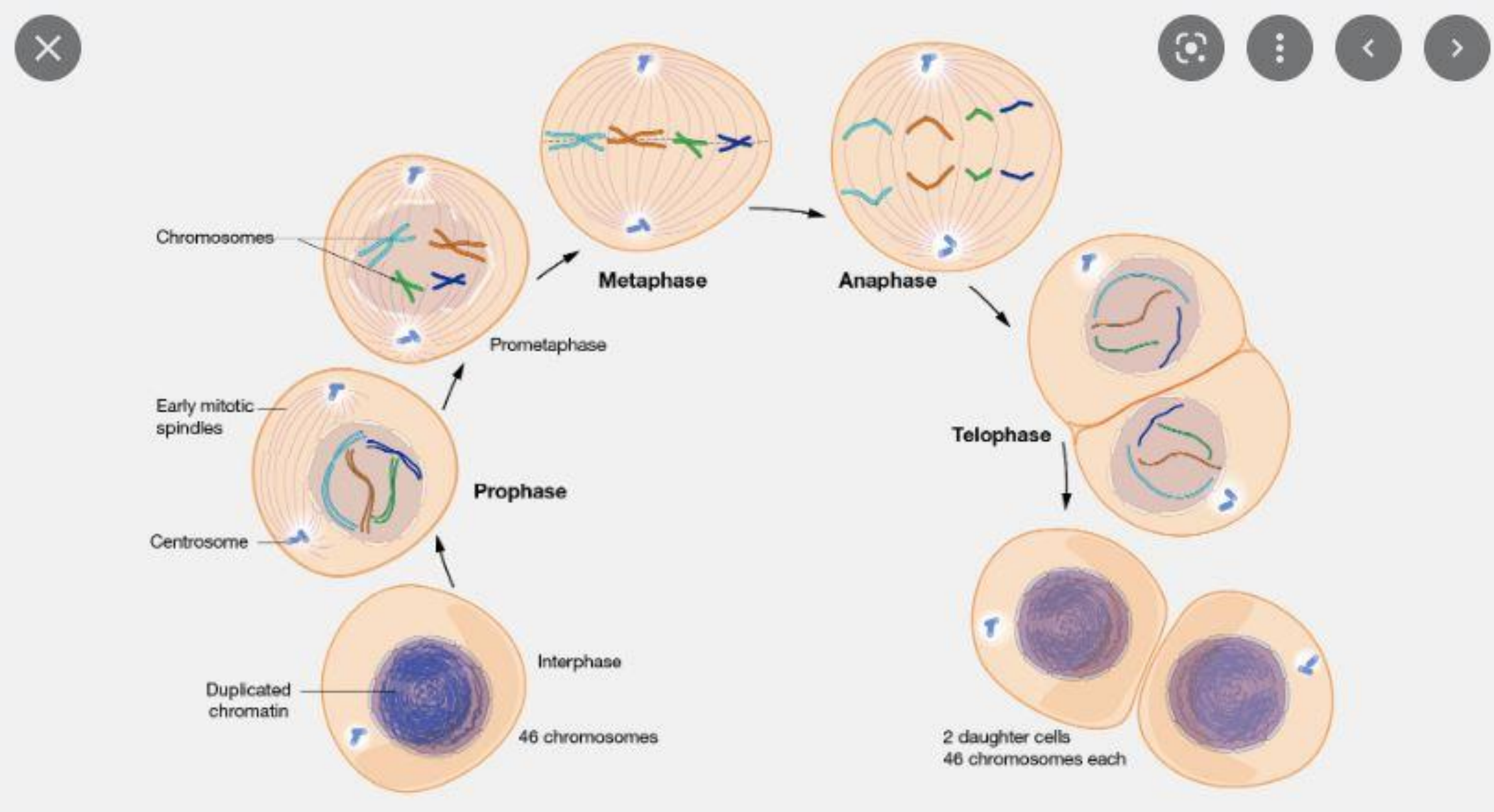
B. Non-homologous chromosomes

C. Sister chromatids

D. Non-sister chromatids

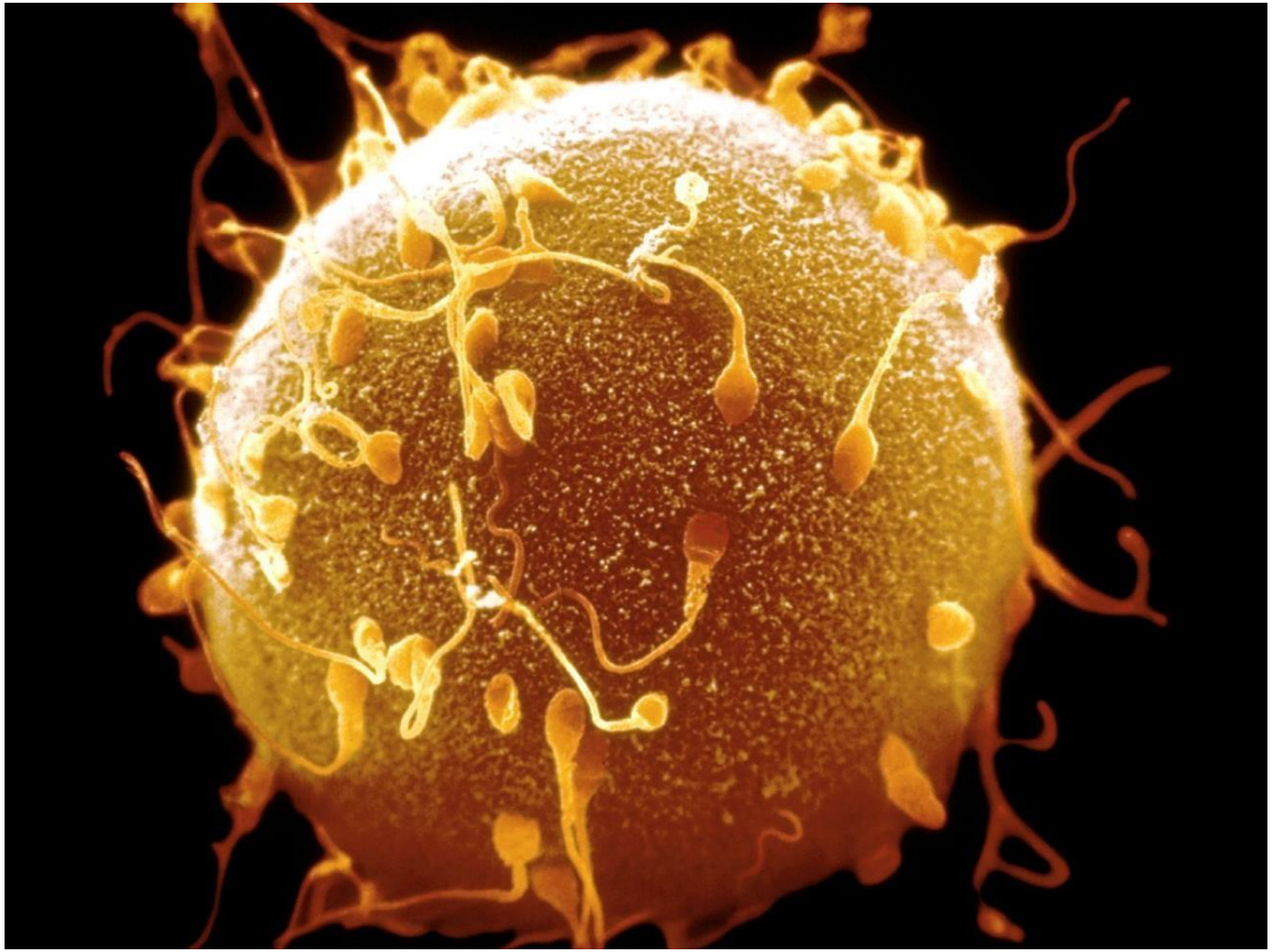
E. Not sure

Compare to meiosis



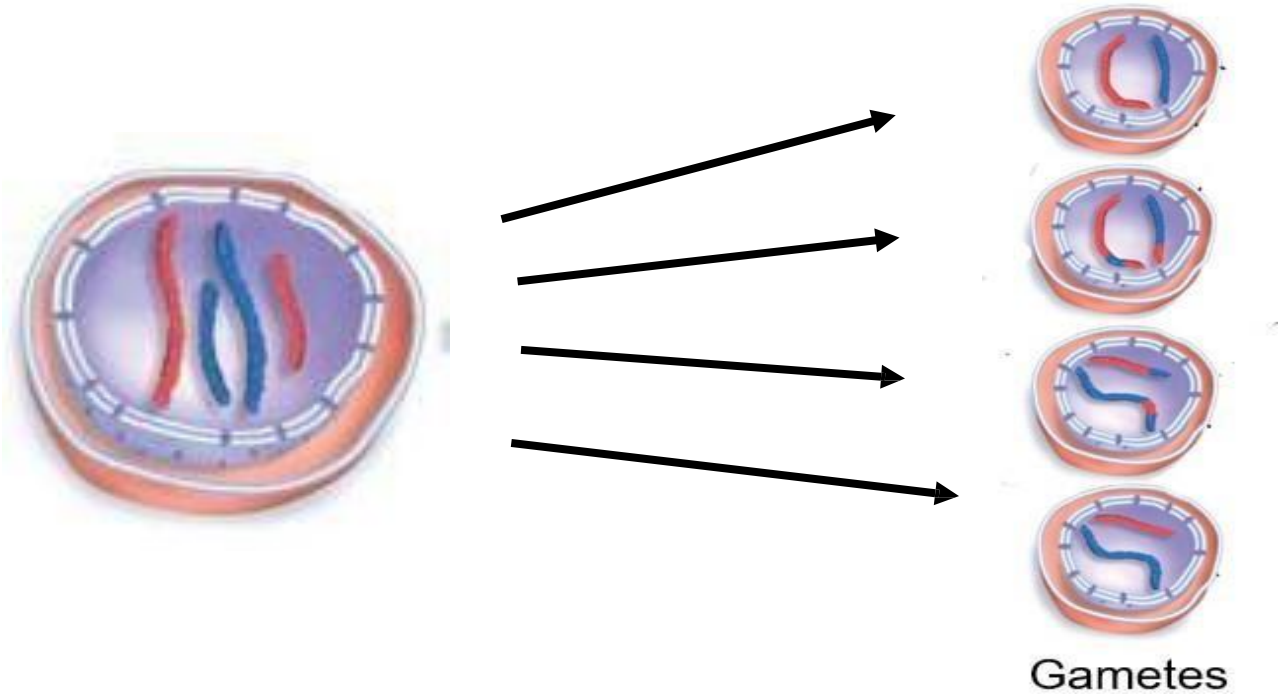
Source: National Human Genome Research Institute

Meiosis



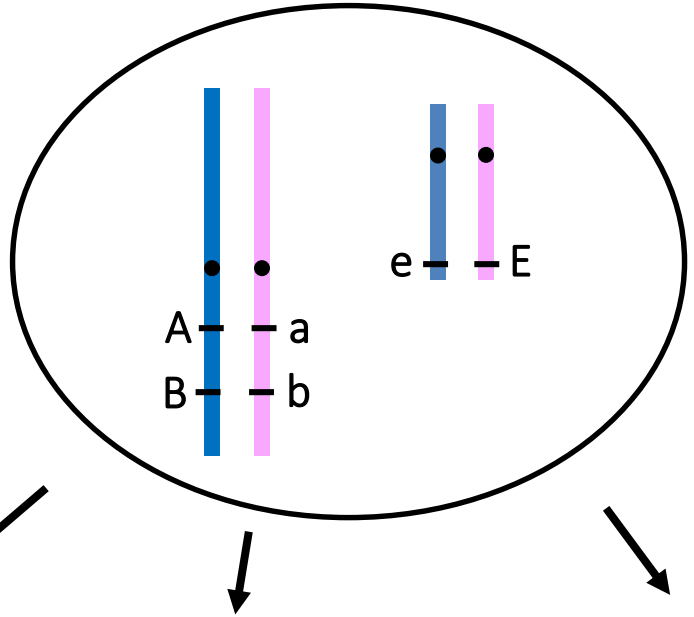
Meiosis

- Occurs in the gonads – germline cells (not somatic cells)
- The goals of meiosis are for a parent cell:
  - to produce 4 progeny cells (gametes – eggs and sperm)
  - with exactly half the number of chromosomes as the parent cells (e.g. 2n to n)
  - with genetic differences, i.e., gametes have different (unique) genotypes.



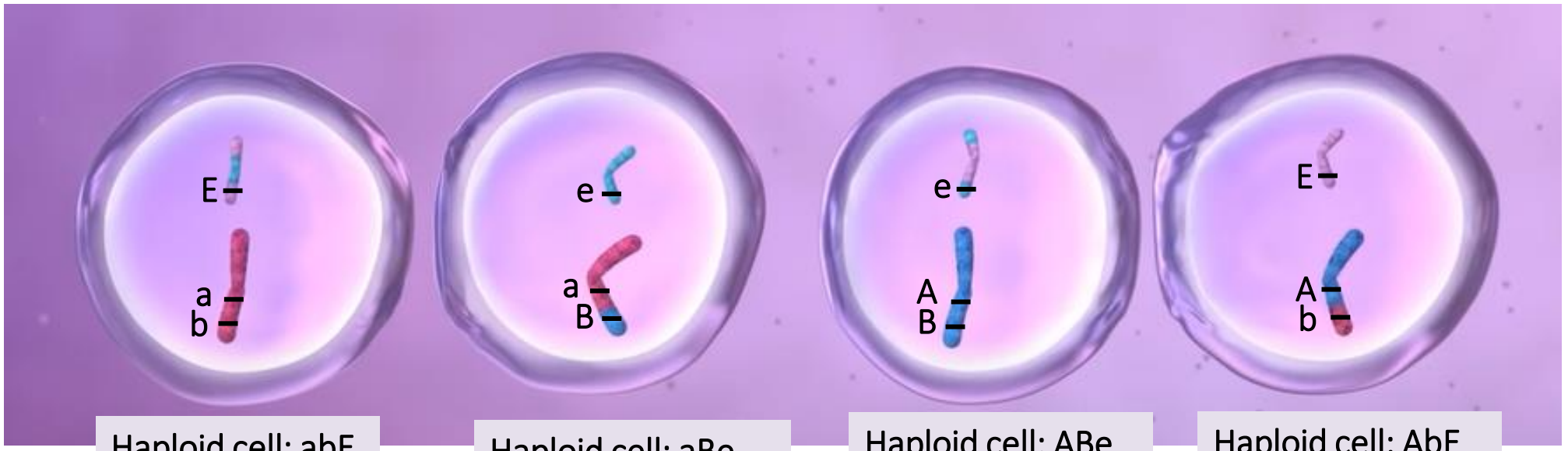
Meiosis

Diploid parent cell, 2n=4
Genotype: AaBbEe



Note:
Each daughter cell receives:

- Either a maternal or paternal chromosome (for chromosome 1 and chromosome 2)
- 1 allele of each gene



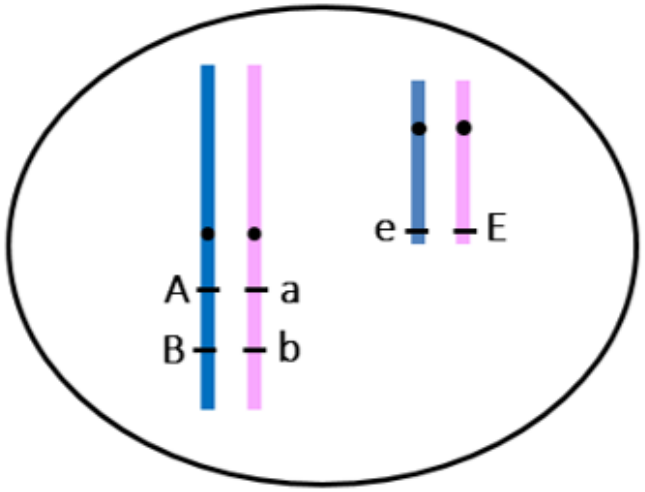
Haploid cell; abE

Haploid cell; aBe

Haploid cell; ABe

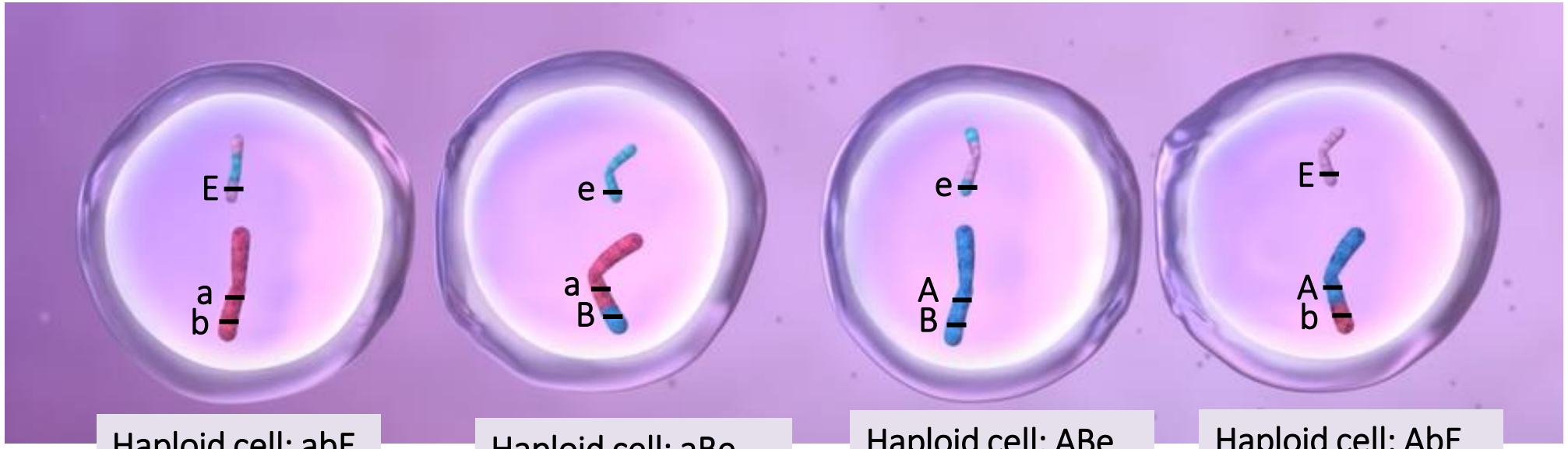
Haploid cell; AbE

Meiosis



For this diploid parent cell to produce 4 haploid daughter cells with different genotypes requires:

- 2 rounds of nuclear division
  - Meiosis 1 – homologous chromosomes separate from each other
  - Meiosis 2 – sister chromatids separate from each other
- **Crossing-over and recombination** in Prophase I, which produces chromosomes with a random combination of maternal and paternal DNA (recombinant) and their alleles
- **Independent assortment of homologous chromosomes** at Metaphase 1, which results in gametes having a random combination of maternal and paternal chromosomes.



Outline for rest of today's lecture

Start: Reviewing the phases of meiosis

Next: Go through 3 examples of a cell undergoing meiosis:

1. If genes are on different chromosomes, meaning they can assort independently at Metaphase 1.
2. If genes (heterozygous) are physically linked with no crossing over and recombination
3. If genes (heterozygous) are physically linked with crossing-over and recombination

Why: to examine what gamete genotypes can be produced and in what frequencies/ratio if two genes are:

- Unlinked
- Linked with no crossing-over and recombination
- Linked with crossing-over and recombination

Meiosis: Learning Objectives

By the end of today's lecture you should:

Know:

- The stages of meiosis:
  - How ploidy, number of chromatids and number of DNA molecules change throughout meiosis.
  - Identify genes, alleles, homologous chromosomes, sister and non-sister chromatids.
  - Similarities and differences with mitosis

Be able to:

- Interpret and/or draw diagrams of chromosomes at different stages of meiosis.
- Work forwards and backwards through meiosis

Understand/know:

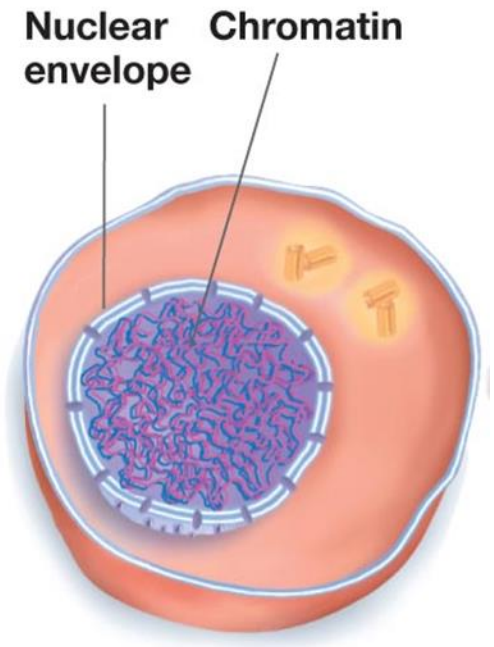
- How genetic variation amongst gametes and individuals arise and the cellular mechanisms responsible:
  - Crossing over & recombination (Prophase I)
  - Independent assortment of homologous chromosomes (Metaphase I).
  - Random fusion of gametes

Be able to predict the gamete genotypes that can be produced via meiosis (if genes are not linked, linked with no crossing-over; or linked with crossing-over), and their frequencies.

Interphase

INTERPHASE:
Prior to the start of meiosis, the cell goes through an interphase period, in which the DNA replicates, and the cell is checked to make sure that it is ready to divide.

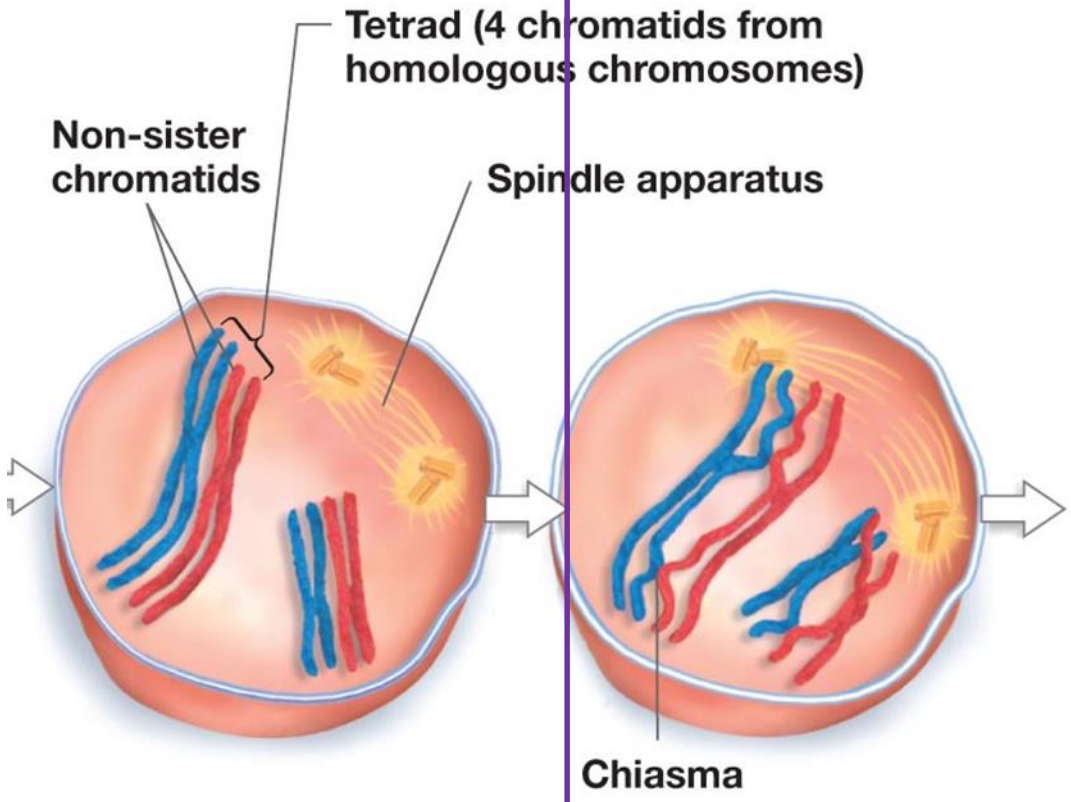
DNA is uncondensed



1. Interphase:
Chromosomes replicate in parent cell, in uncondensed state.

PROPHASE I – EARLY & LATE (no prometaphase)

2n=4 cell



2. Early Prophase I: Chromosomes condense, nuclear envelope breaks up, spindle apparatus forms. Synapsis of homologous chromosomes.

3. Late Prophase I: Crossing over of non-sister chromatids (often multiple cross-overs between the same chromatids).

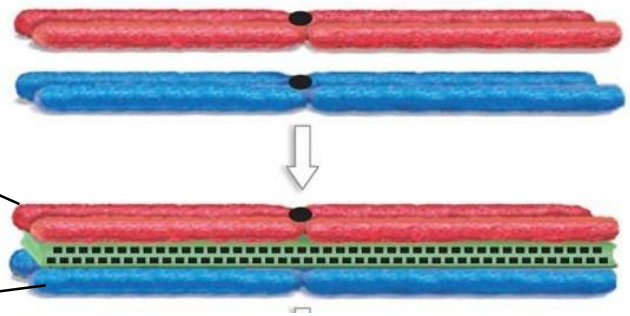
Synapsis – Early Prophase I

- Homologous chromosomes come together
  - become tightly associated along their lengths (process called synapsis)
  - structure called a tetrad (=4 chromatids) – not testable

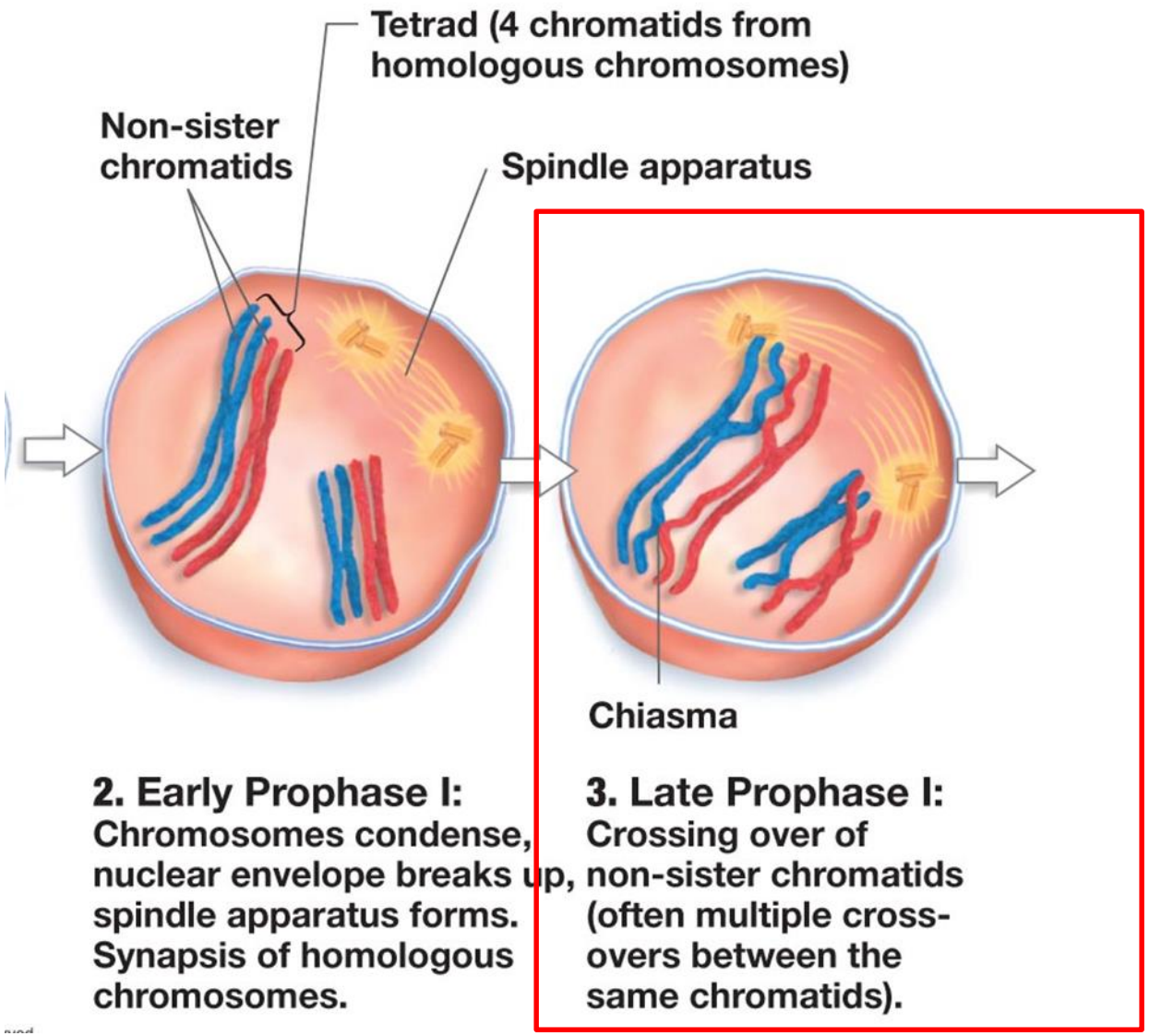
One replicated homolog (red)

Protein complex (green)

Second replicated homolog (blue)



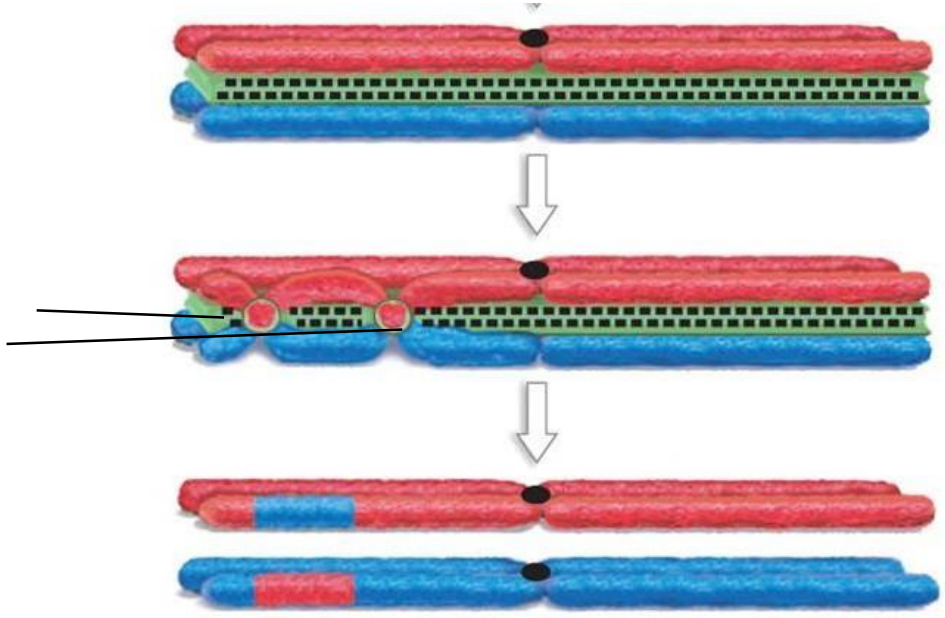
Late Prophase I – crossing-over and recombination occur between non-sister chromatids



Chiasma (*pl.* chiasmata)

- Contact points between non-sister chromatids occur.
- The name of these contact points are called chiasma (or chiasmata)
- These are the sites of DNA breakage by specialized enzymes.

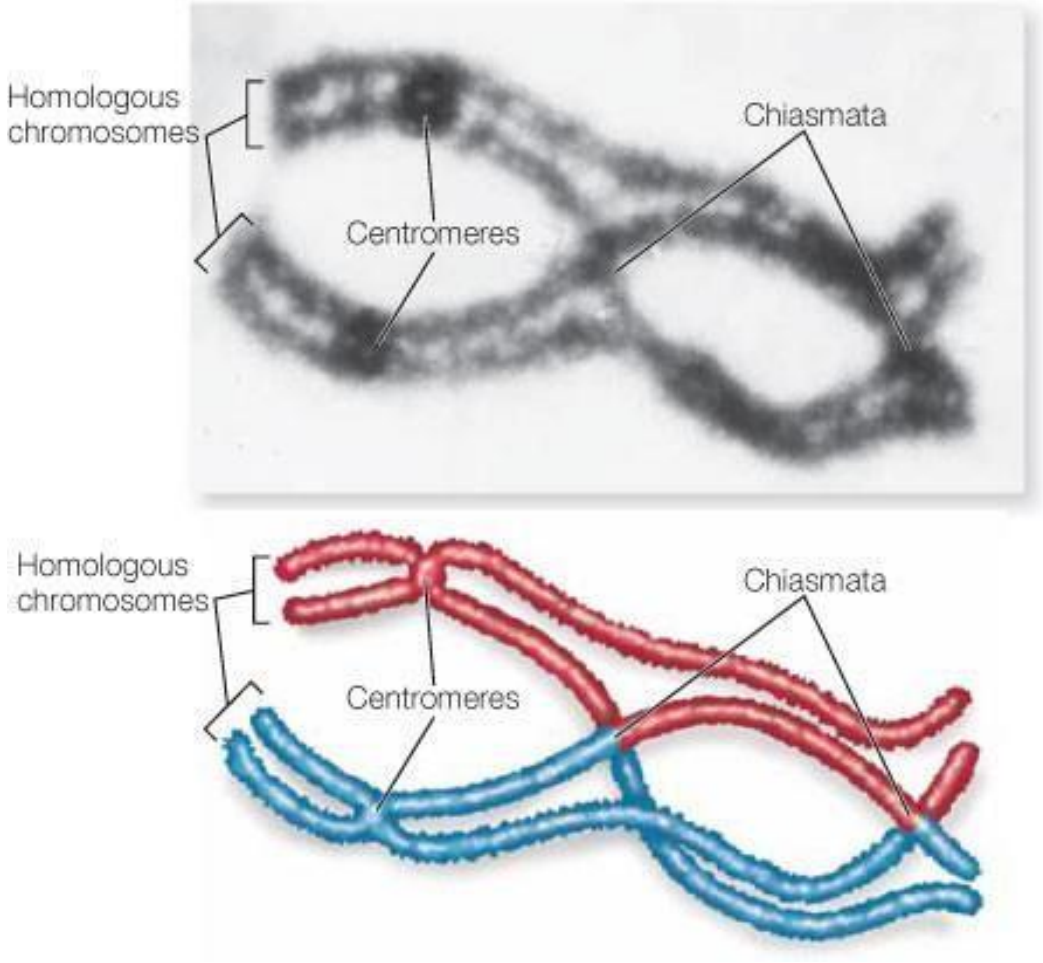
Chiasmata



2 crossing-over points

Crossing over has occurred

Chiasmata



2 crossing-over locations

www.Wikipedia.org

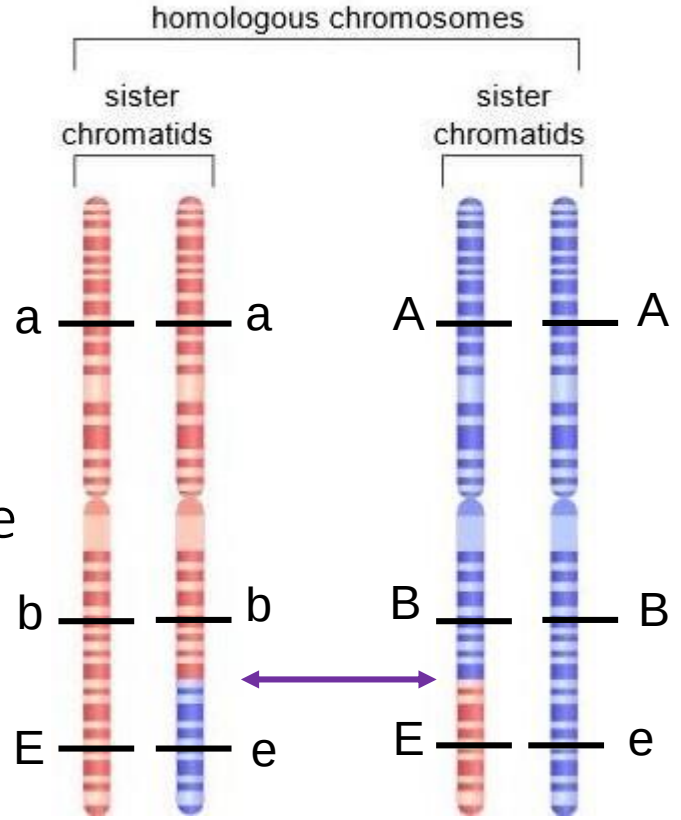
Late Prophase I – Crossing-over & Recombination

Crossing-over is a process - what happens:

- specialized proteins deliberately break the DNA molecules at the same location in 2 non-sister chromatids of homologous chromosomes.

- during DNA repair, rather the joining the broken segment back to the chromatid to which it was originally attached, the broken segment is joined to the chromatid of the other homolog (i.e., non-sister chromatid)

- Results in the exchange of genetic material between non-sister chromatids

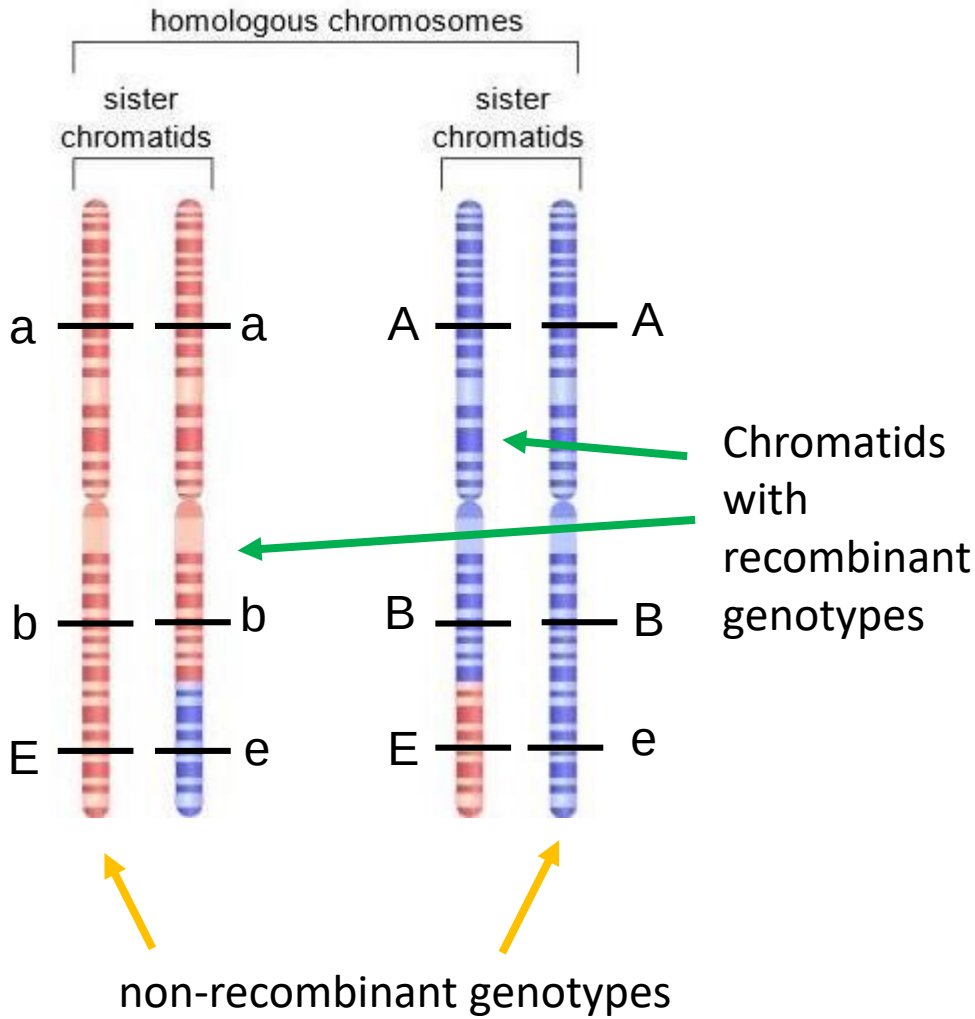


File:HR in meiosis.svg

Prophase I – Crossing-over & Recombination

- Crossing-over leads to **recombination** of genetic material (outcome)
  = the production of new combinations of alleles (maternal and paternal) on a chromatid.
  - sister chromatids are no longer identical
- In this example, before crossing-over and recombination chromosome genotypes of the chromatids = abE and Abe
- After crossing-over and recombination:
  - abE and ABe = **non-recombinant genotypes**
  - abe and ABE = **recombinant (new) genotypes**

- Crossing-over creates genetic variation amongst gametes (and offspring), i.e. because chromosomes have unique combinations of maternal and paternal alleles.



File:HR in meiosis.svg

Afew points about crossing-over

- Average of 1.6 cross-over events for any one chromosome during meiosis.
- Likelihood of a cross-over event occurring at any specific location on a chromosome is 0.000001% (not testable)
- So, scientists cannot predict where and when crossing-over will occur.

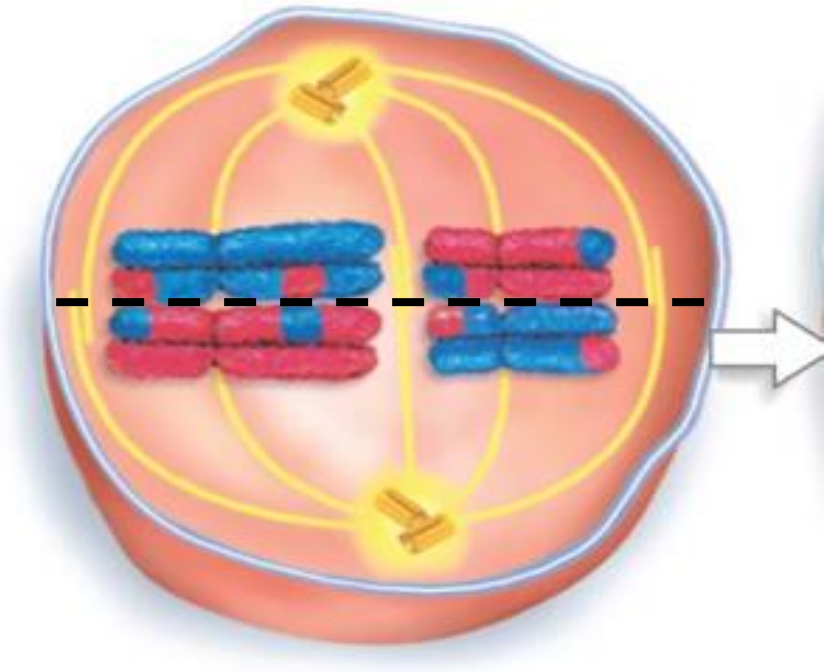
Metaphase I

M = chromosomes meet in the middle

Homologs on either side of the metaphase plate (unlike mitosis)

2nd source of genetic variation:
Independent Assortment of Homologous Chromosomes

- meaning homologous pairs align independently of each other, i.e. there is not a maternal side and paternal side

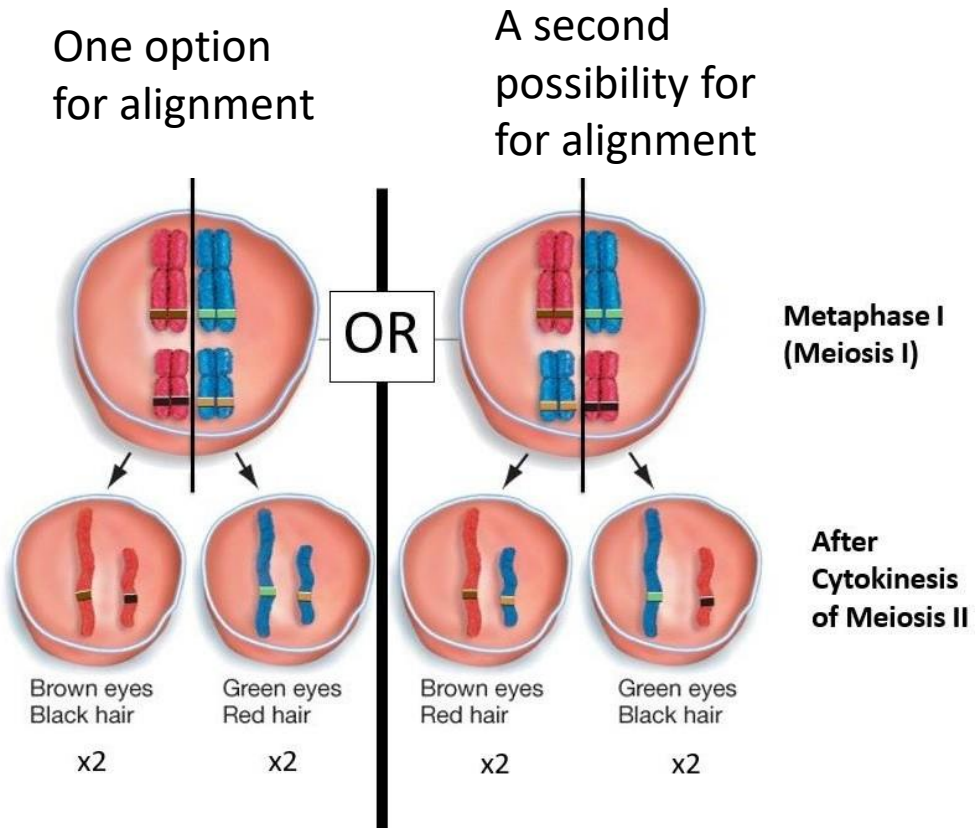


4. Metaphase I: Tetrads migrate to metaphase plate.

Independent assortment of homologs – second source of genetic variation

- Outcome of independent assortment:

Each gamete gets a random assortment of maternal and paternal chromosomes and their alleles



Independent assortment of homologous chromosomes

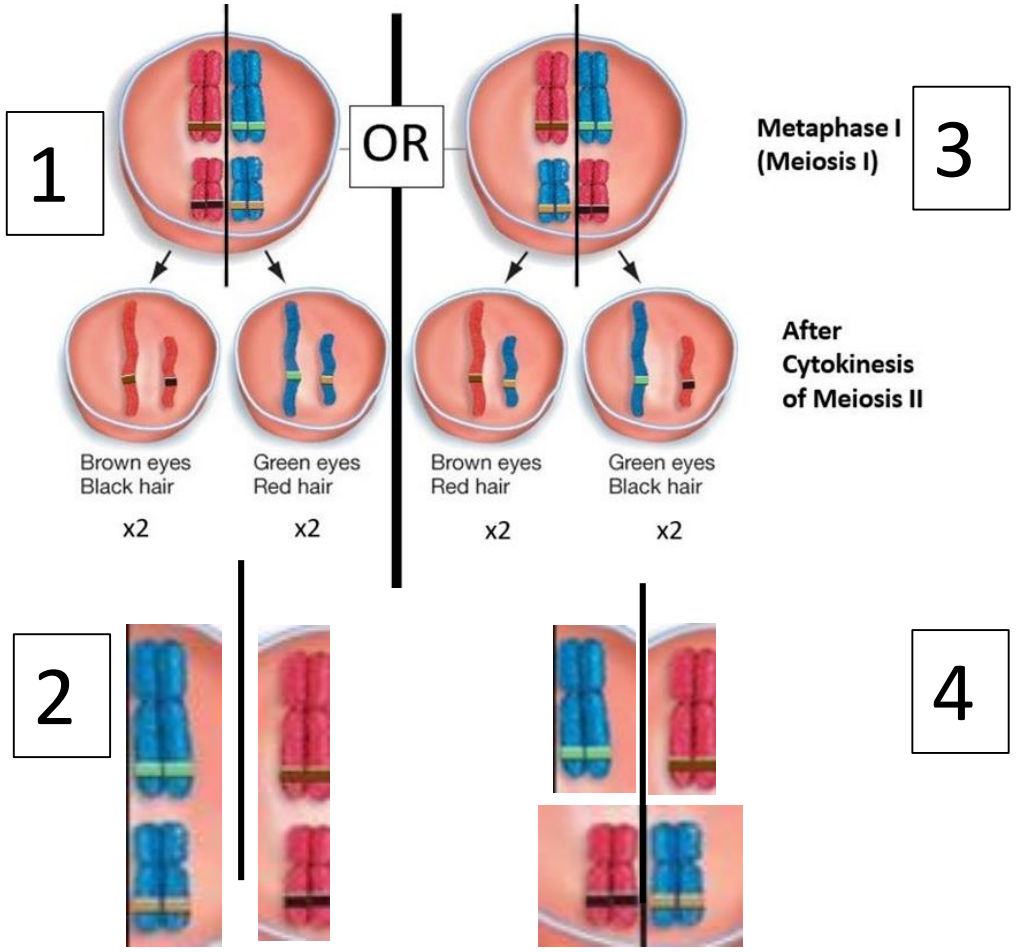
- The possible number of alignments at the metaphase plate = 2^n, where n = number of chromosomal /homologous pairs.

- In this example, there are two pairs of homologous chromosomes; so $2^n = 4$ ($2^2 = 4$)

- not a lot of variation in this figure

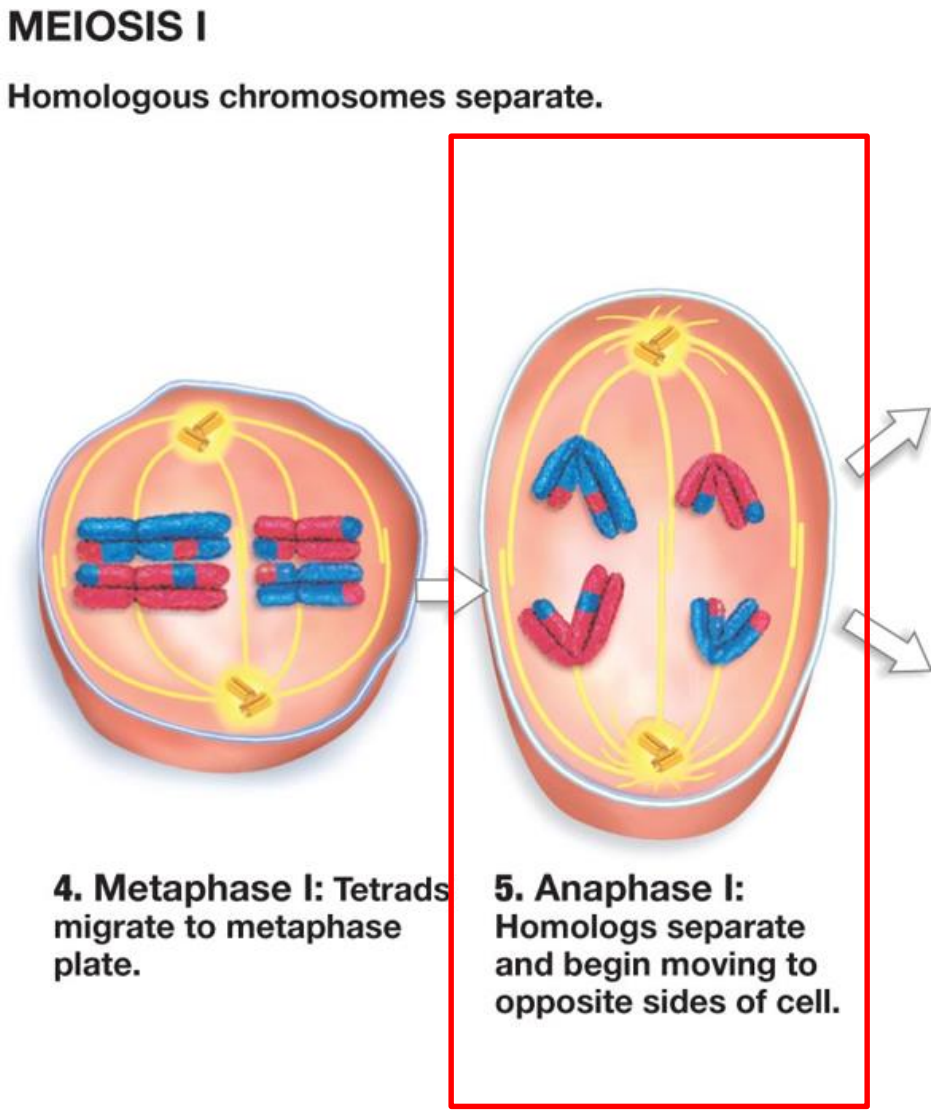
  - Humans = 2^{23} = potentially > 8,000,000 ways that chromosomes could independently orient themselves at the metaphase plate

  - This number does not include the genetic variability produced by crossing-over!



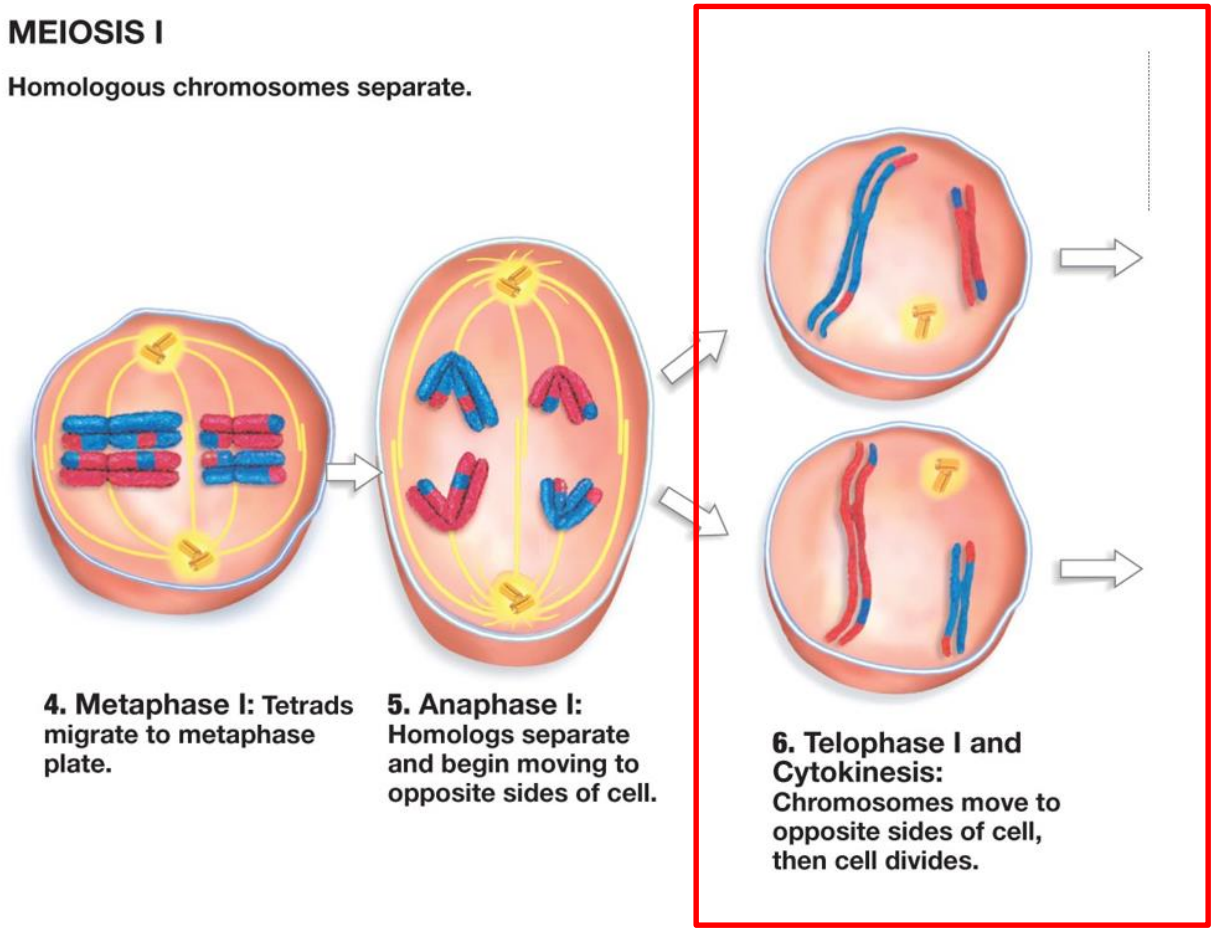
Anaphase I (A=apart)

- Spindle fibers (microtubules) contract
- <u>Homologous chromosomes separate</u> – move towards poles



Telophase I & Cytokinesis I

- Nuclear envelope may reform forming 2 nuclei.
- Cytokinesis – creates <u>two HAPLOID cells</u>
- <u>Sister chromatids still attached at centromere</u>



- At this point, Meiosis 1 is complete
- Daughter cells are haploid

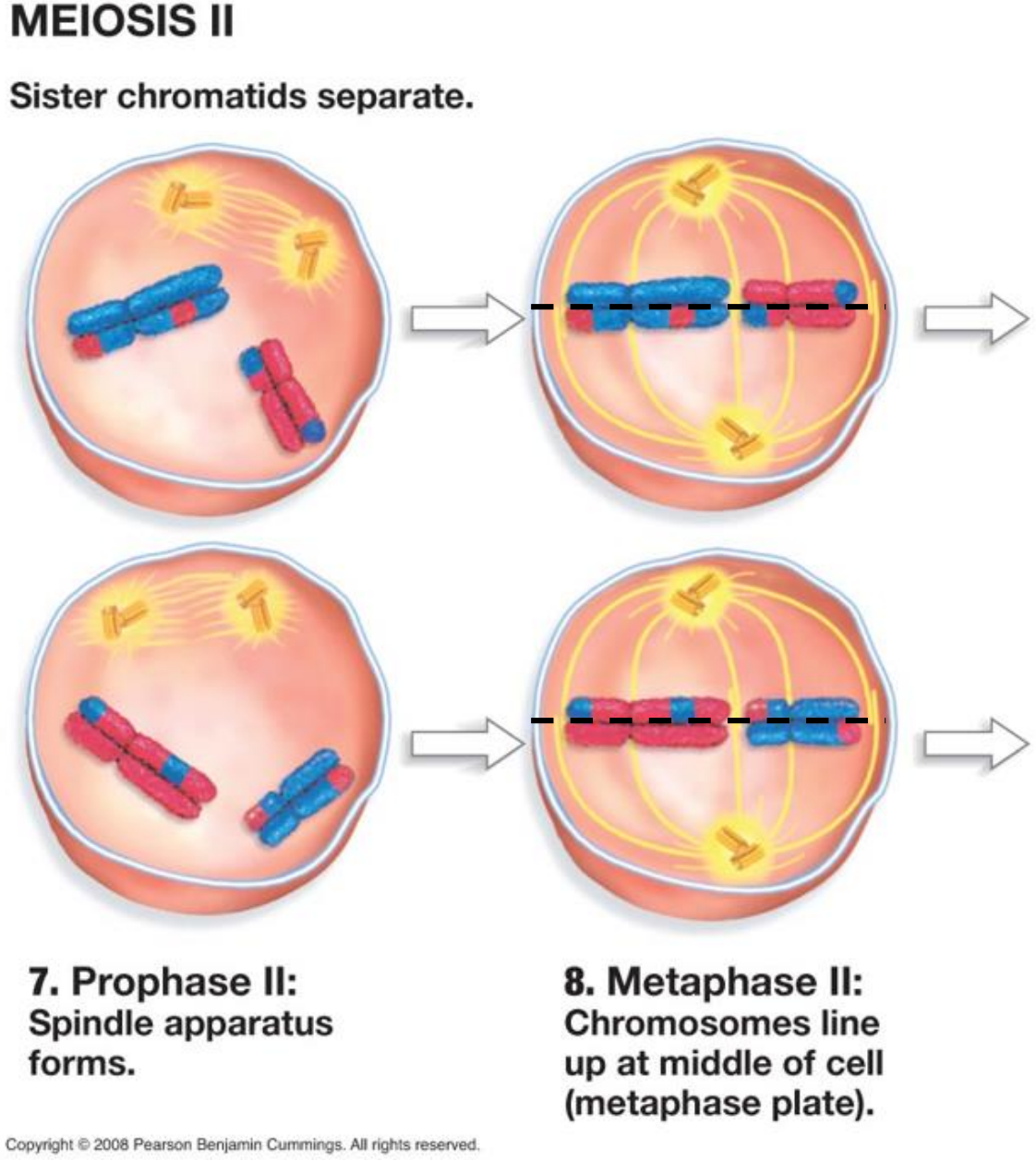
Interkinesis (not testable)

- At the end of Meiosis I, the two cells do not need to go through Interphase again.
- But, there may be a short rest phase called “Interkinesis”

Meiosis II

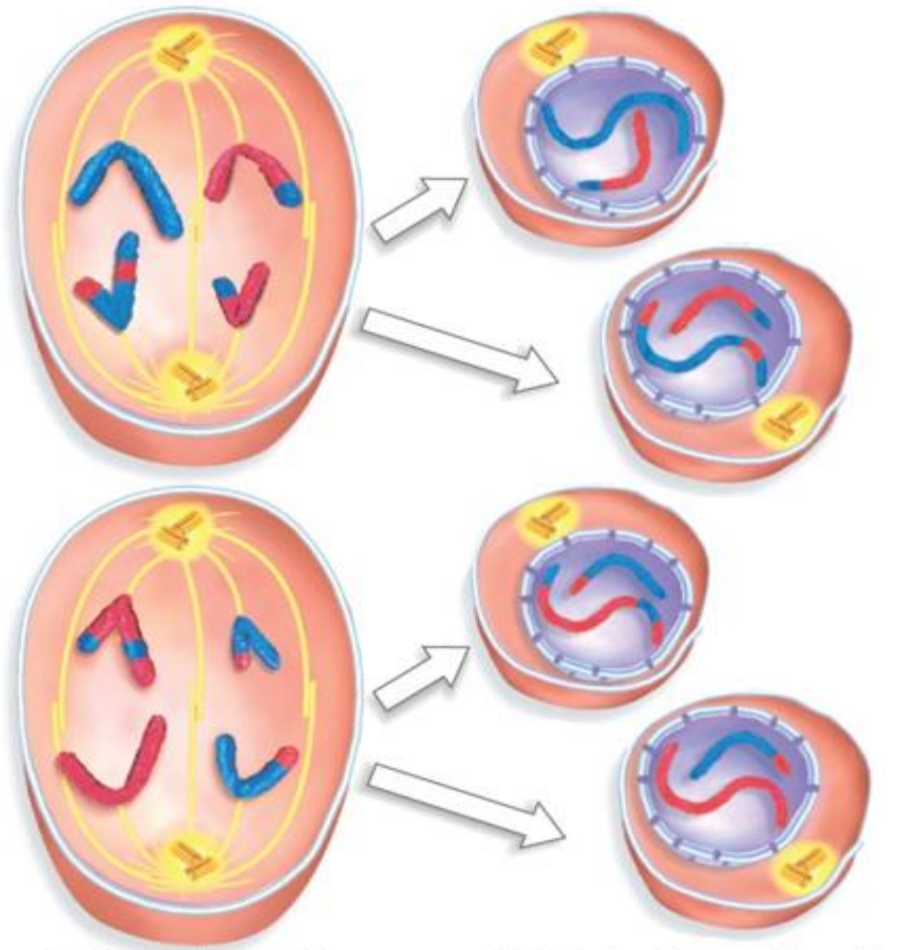
Very similar to mitosis – sister chromatids will separate.

But now the cell is haploid (if parent cell was diploid)



MEIOSIS II

Sister chromatids separate.

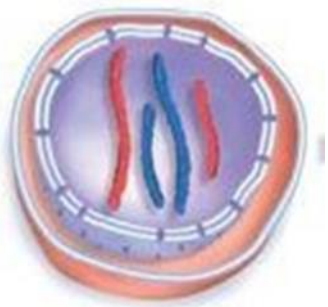


9. Anaphase II: Sister chromatids separate, begin moving to opposite sides of cell.

10. Telophase II and Cytokinesis: Chromosomes move to opposite sides of cell, then cell divides.

1n=2

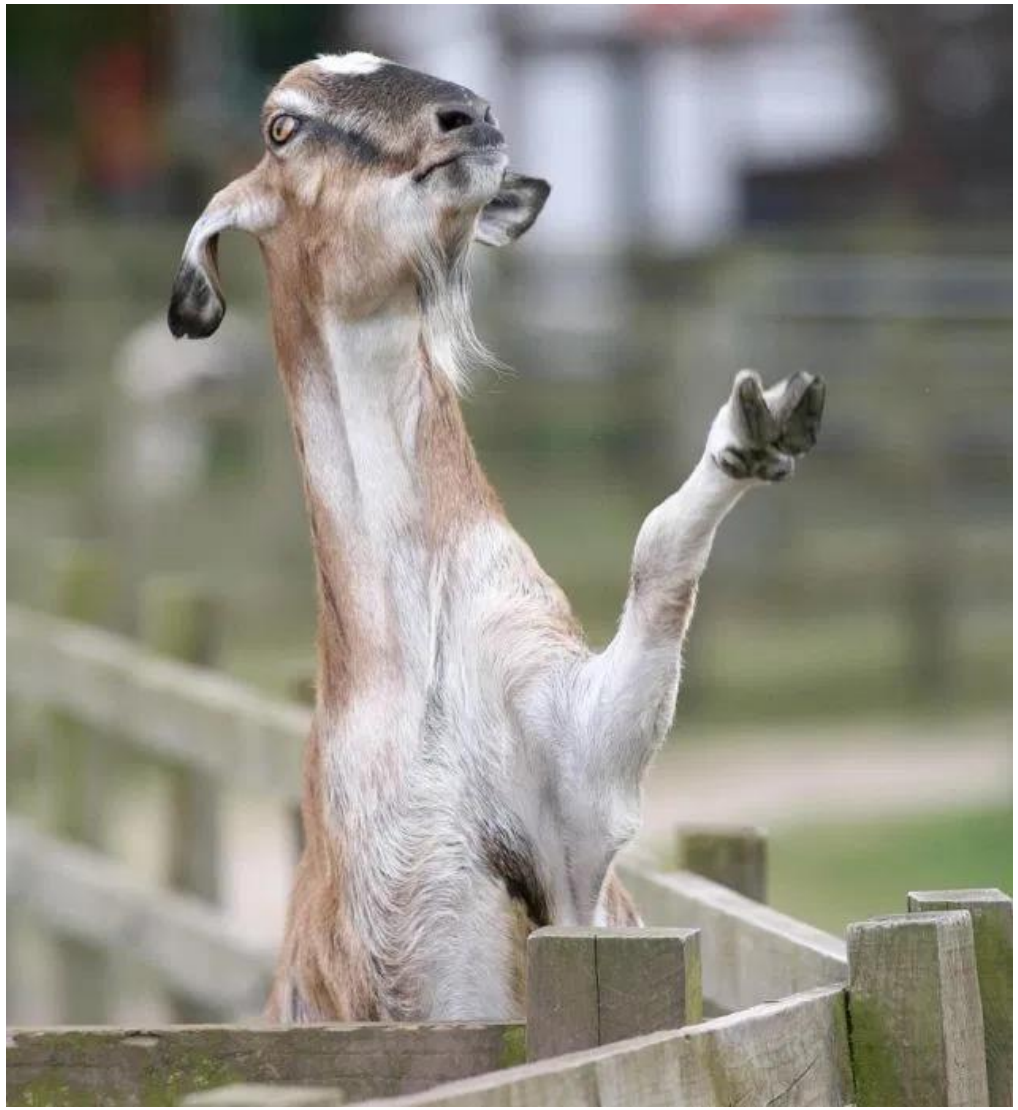
- End product is <u>4 haploid</u> daughter cells
- Half the genetic content of the parent cell
- Genetically different from each other



Original parent cell

2n=4

Meiosis fingers



Questions?

4-minute break

Predicting gamete genotypes, and their frequencies or ratios

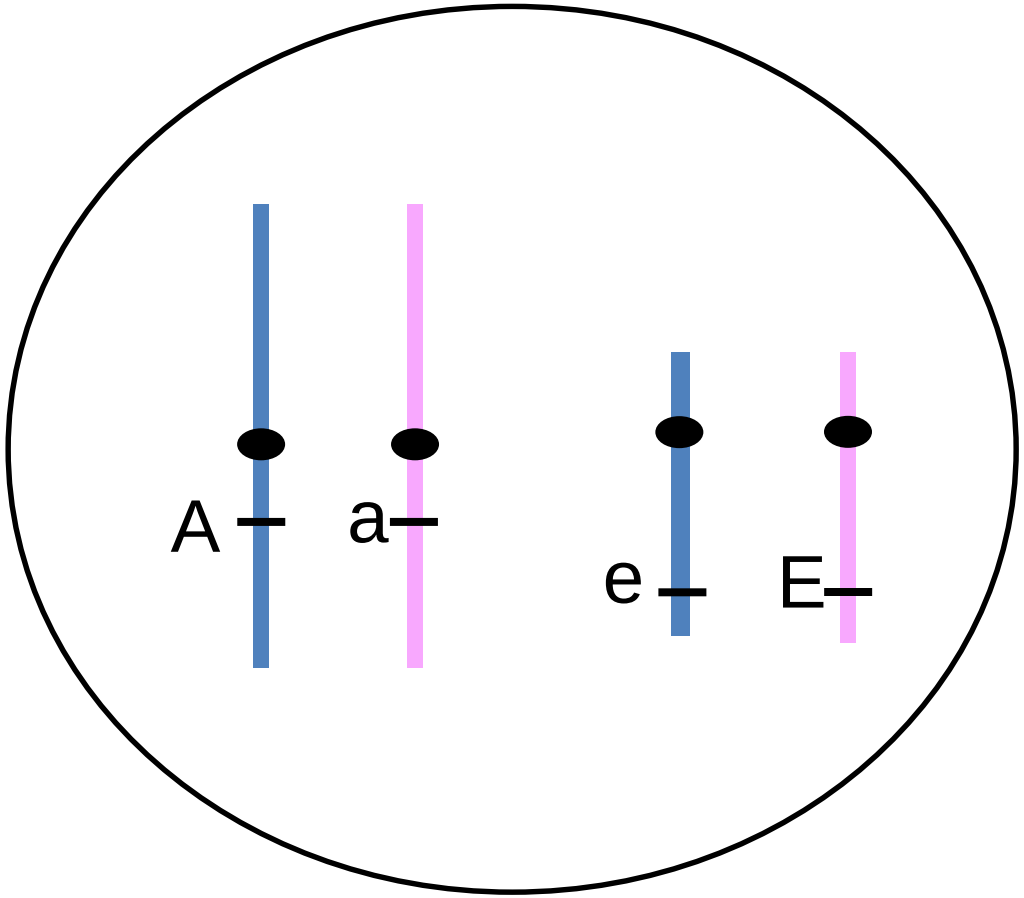
The gamete genotypes that can be produced (and their frequencies and/or ratios) depends upon whether:

1. The genes on different chromosomes (i.e. not physically linked);
   - so, the alleles can sort into gametes independently of each other; or

2. The genes are physically linked – with no crossing-over to break linkage (no recombination)
   - the alleles cannot sort independently from each other (i.e. they will travel together to the gametes); or

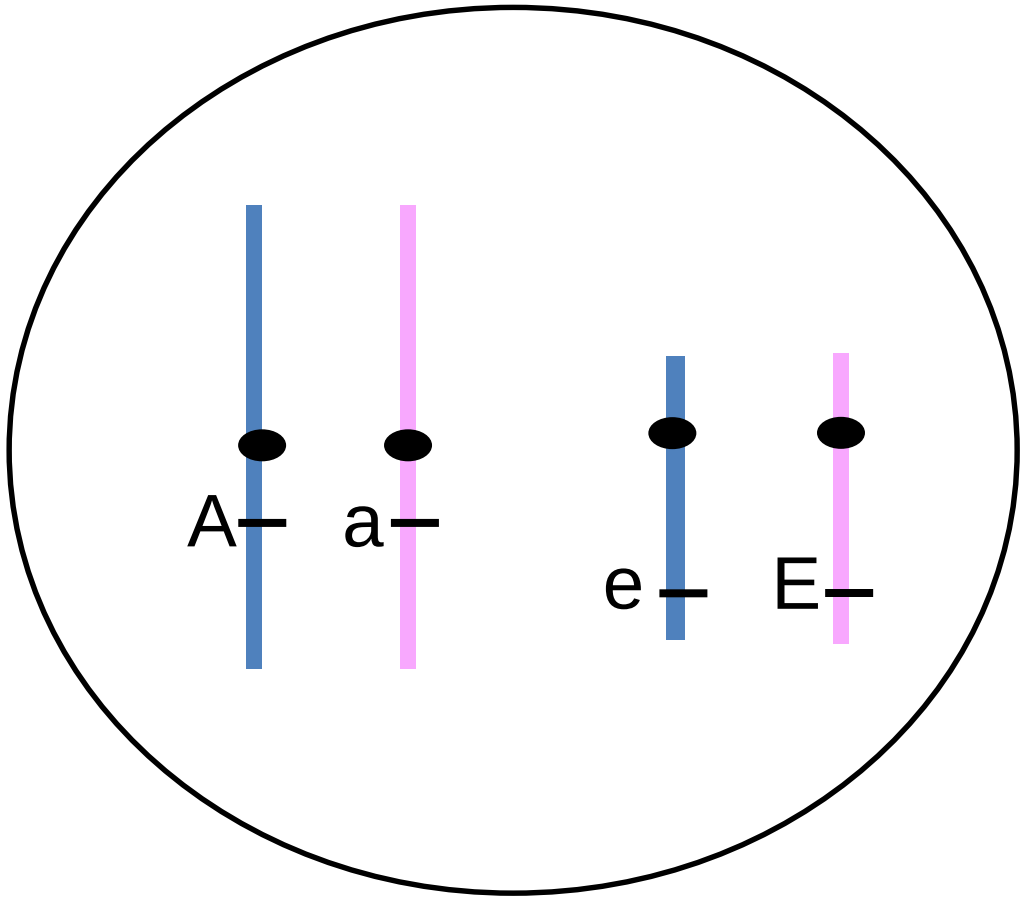
3. The genes are physically linked – but crossing-over and recombination will break linkage in at least some cells.

Predicting gamete genotypes (and their frequencies) if the genes are on separate chromosomes (so alleles can assort independently into gametes)



2n=4 cell with a genotype: A/a;E/e – in G1

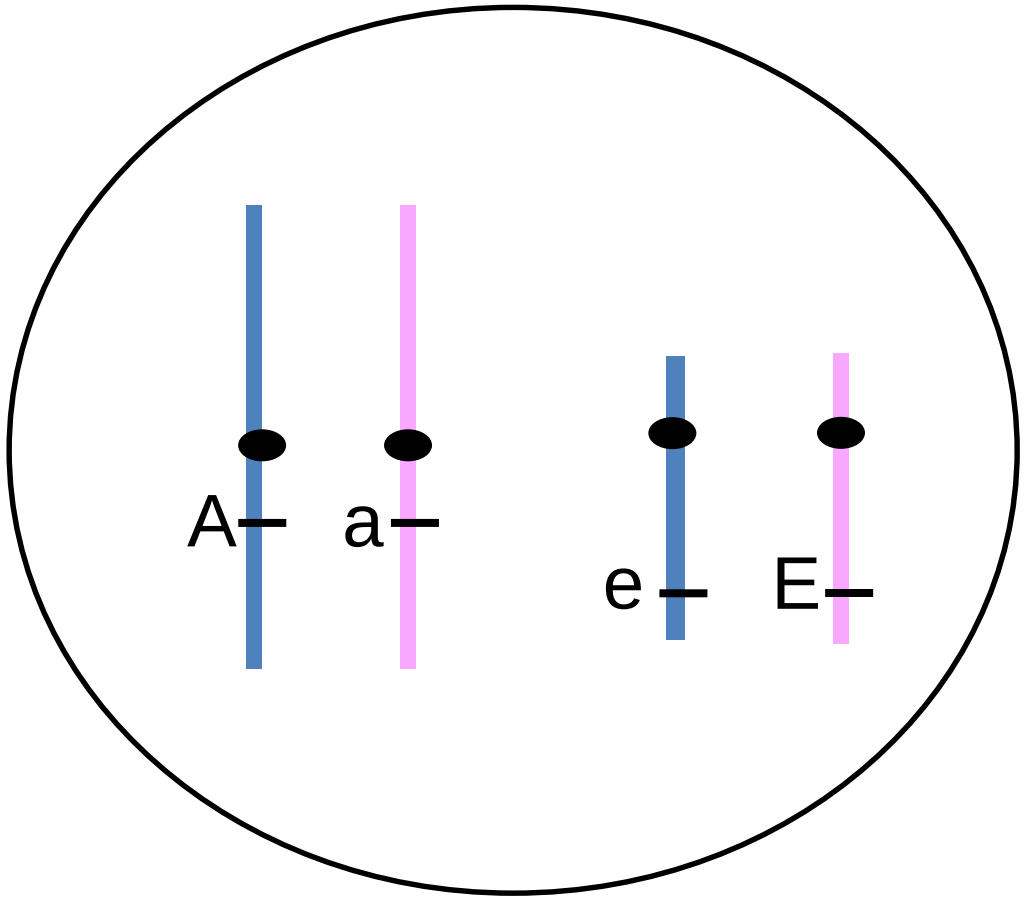
iClicker Question



If 1,000 cells with this genotype underwent meiosis, what gamete genotypes could be produced and with what frequency or ratio?

A. 2 Genotypes: Ae, aE
   Frequency: 50%, 50%, Ratio - 1:1
B. 4 Genotypes: Ae, aE, AE, ae
   Frequency: Ae = aE > AE = aE, Ratio - 0.4, 0.4, 0.1, 0.1
C. 4 Genotypes: Ae, aE, AE, ae
   Frequency: 25%, 25%, 25%, 25%, Ratio - 1:1:1:1
D. 4 Genotypes: A, a, E, e
   Frequency: 25%, 25%, 25%, 25
   Ratio - 1:1:1:1
E. Not sure

Answer



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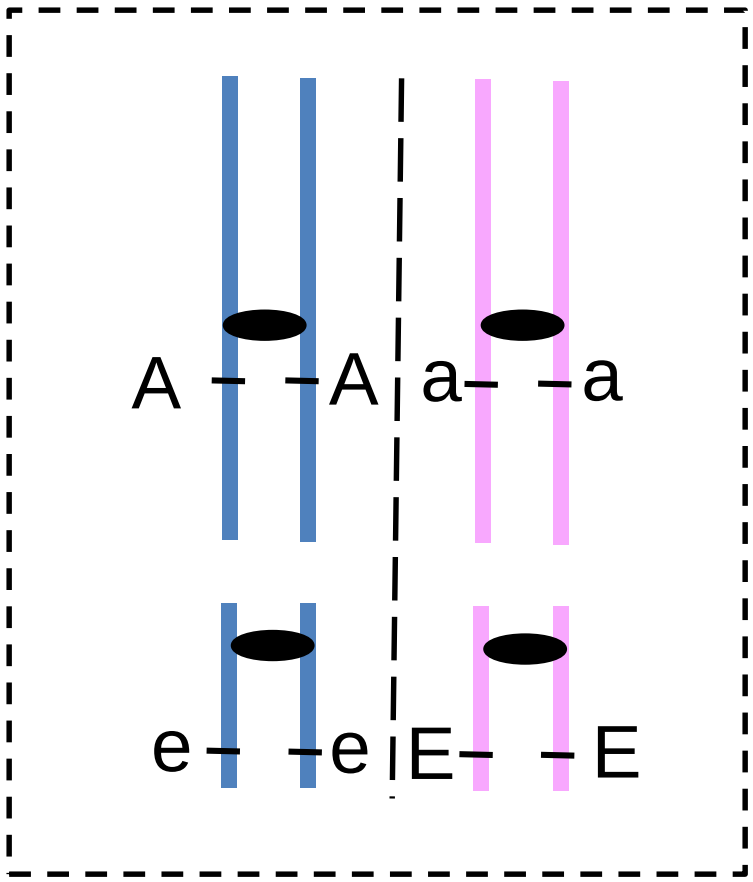
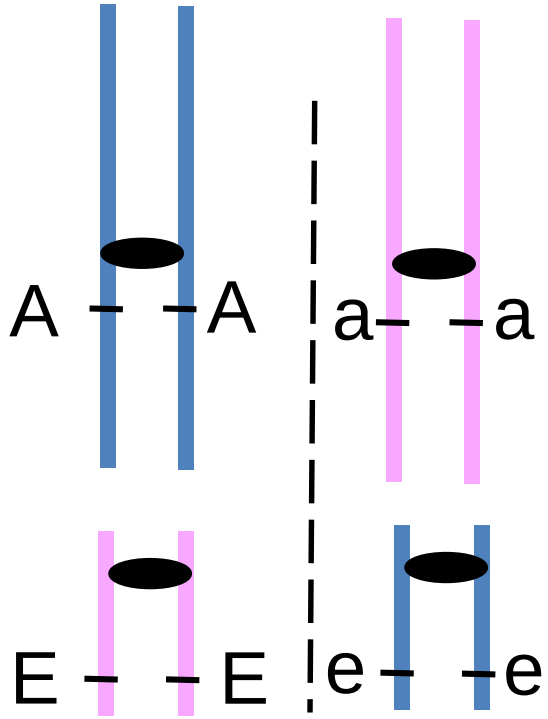
A. 2 Genotypes: Ae, aE
   Frequency: 50%, 50%, Ratio - 1:1
B. 4 Genotypes: Ae, aE, AE, ae
   Frequency: Ae = aE > AE = aE, Ratio - 0.4, 0.4, 0.1, 0.1
C. 4 Genotypes: Ae, aE, AE, ae
   Frequency: 25%, 25%, 25%, 25%,
   Ratio - 1:1:1:1
D. 4 Genotypes: A, a, E, e
   Frequency: 25%, 25%, 25%, 25
   Ratio - 1:1:1:1
E. Not sure

If genes are on different chromosomes (and multiple cells under meiosis)

Independent Assortment of Homologs @ Metaphase I

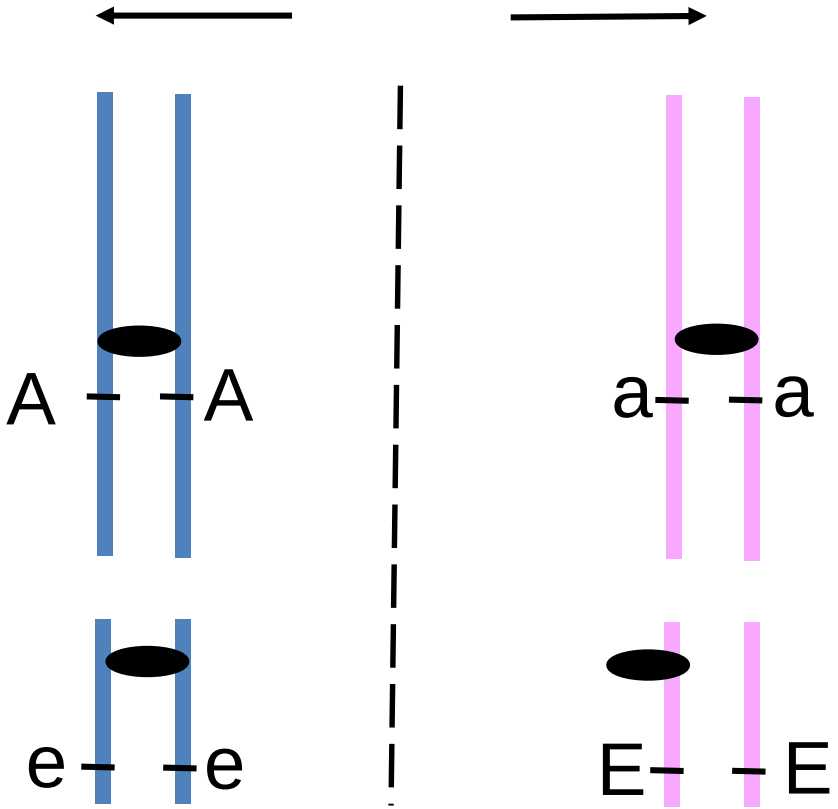


OR

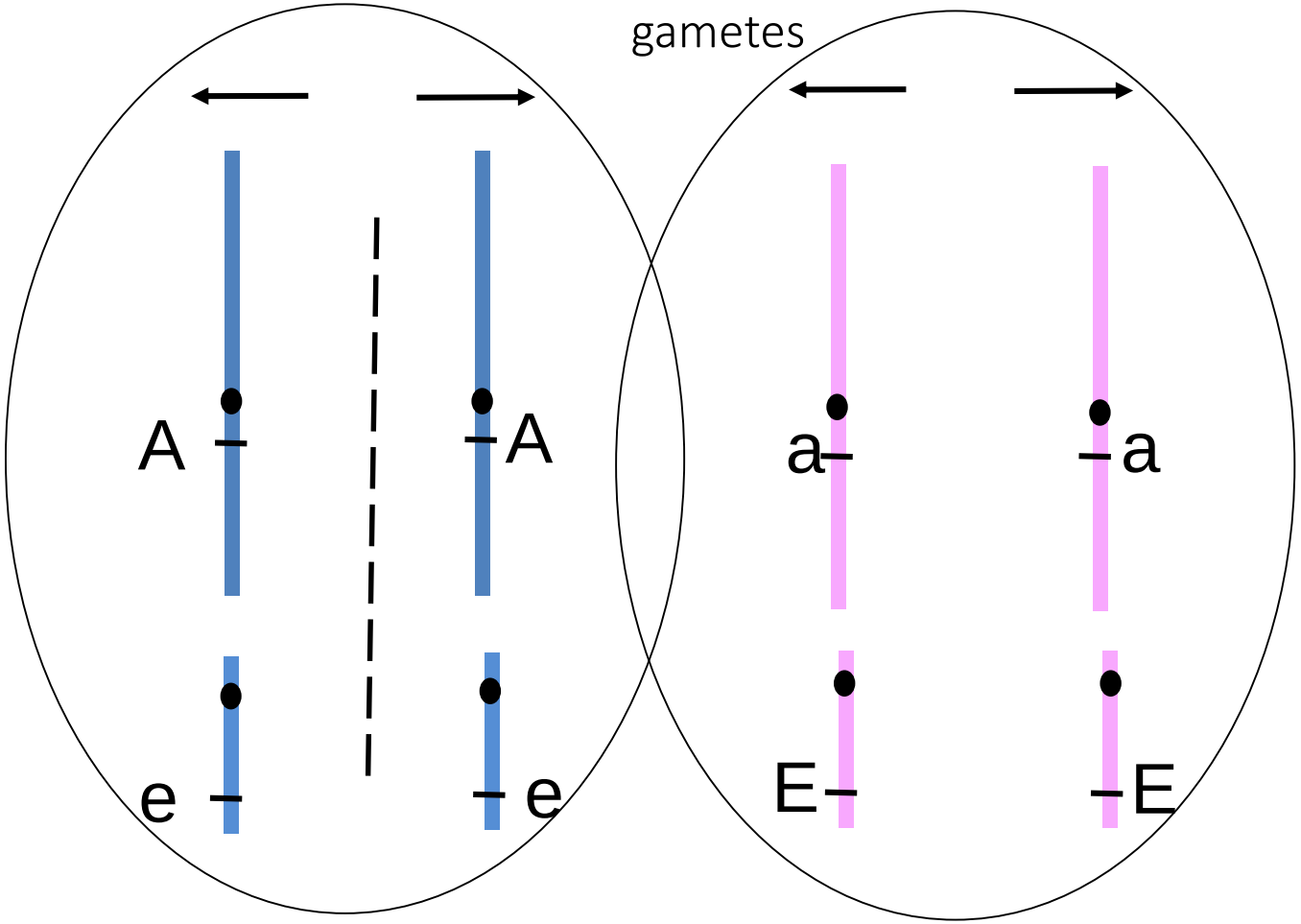


Anaphase I and II

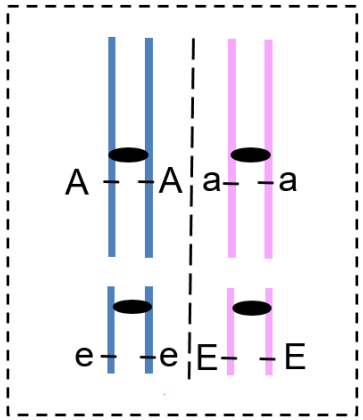
Anaphase 1- Homologs separate and end up in different cells

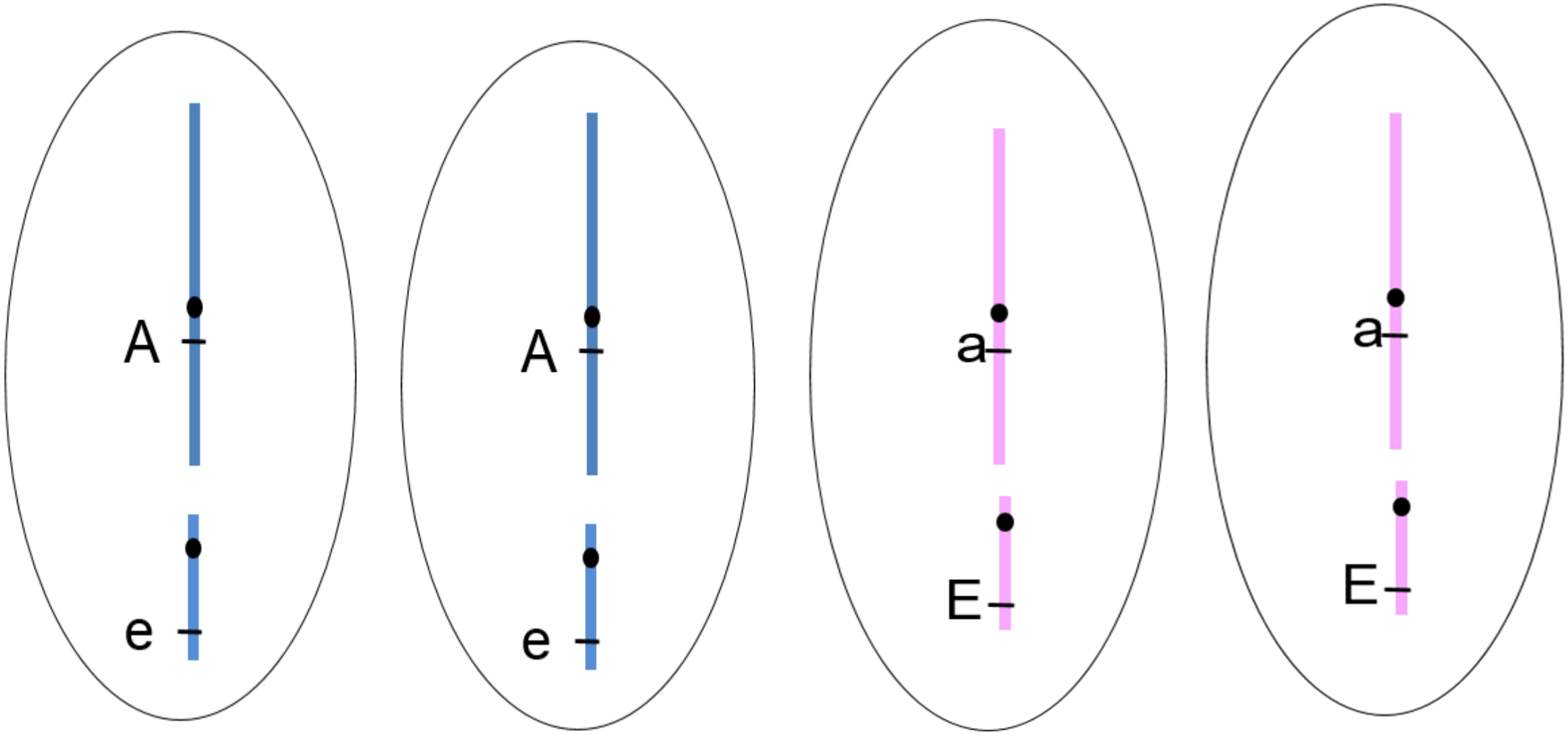


Anaphase 2- Sister chromatids separate and end up in different gametes



Gametes produced for one possible alignment of homologous chromosomes

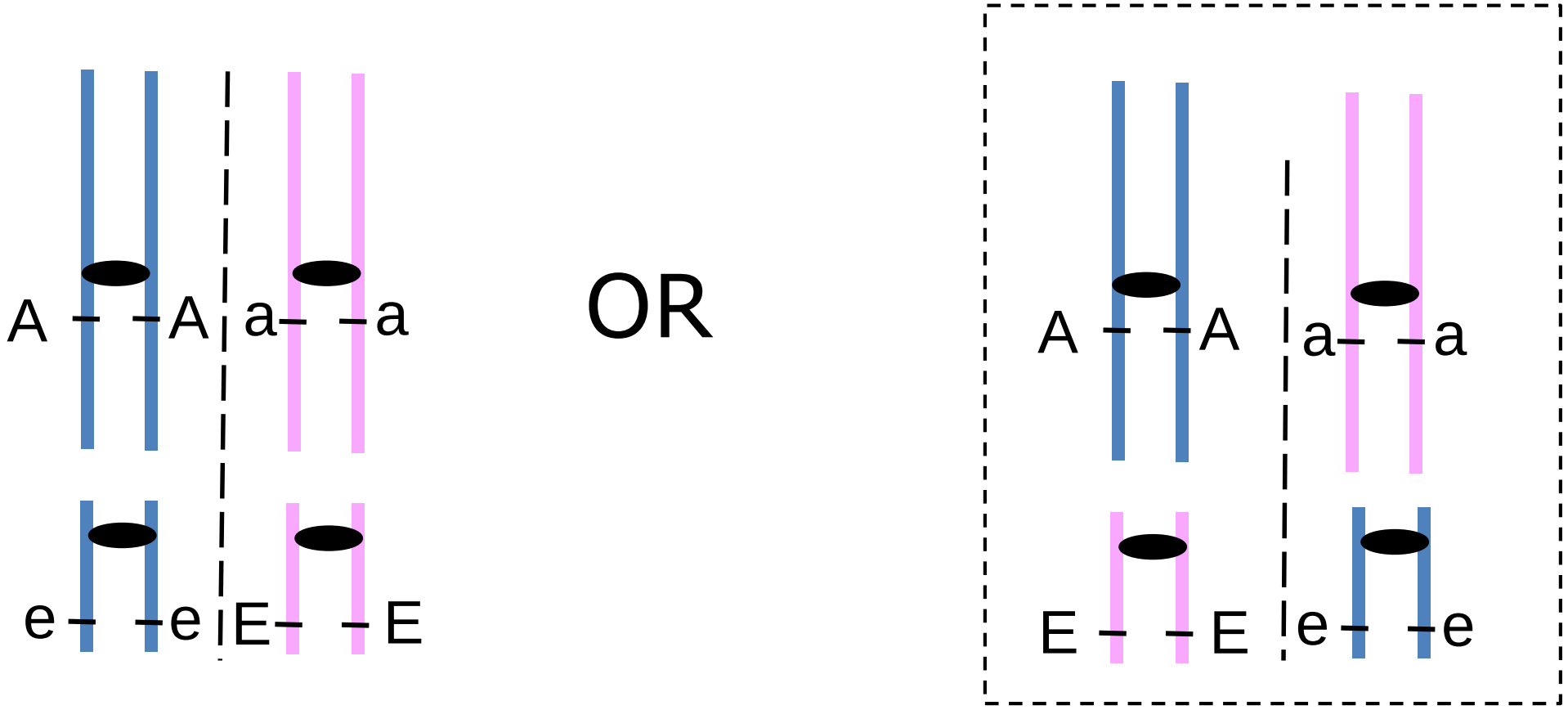




With this alignment – two gamete genotypes: Ae and aE. Frequency = 50%, 50% or ratio: 1:1

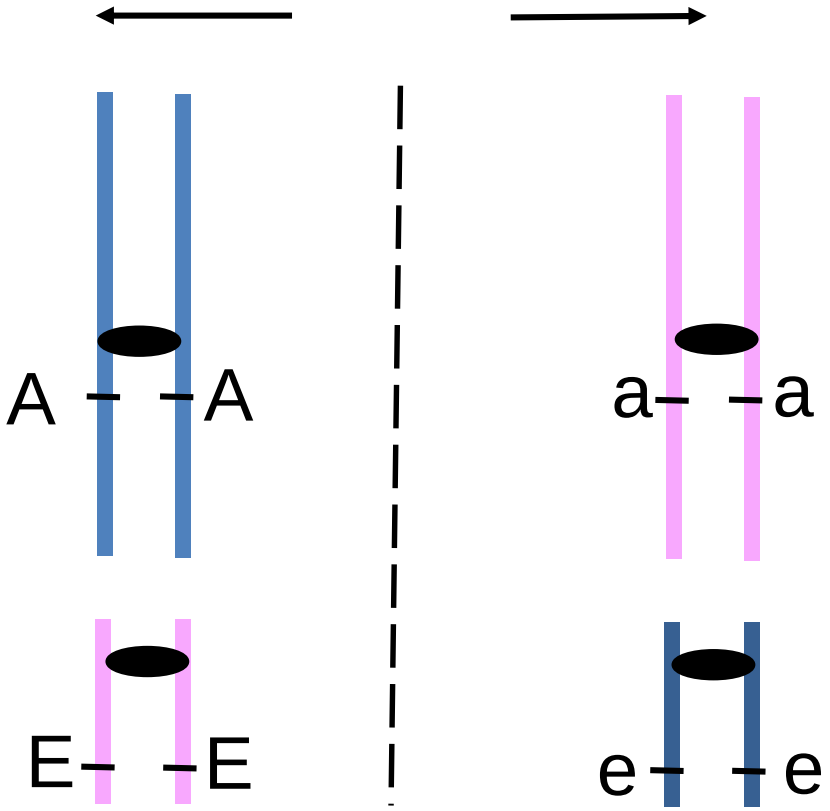
Different alignment of homologous chromosomes

Metaphase 1 – Independent Assortment of Homologs

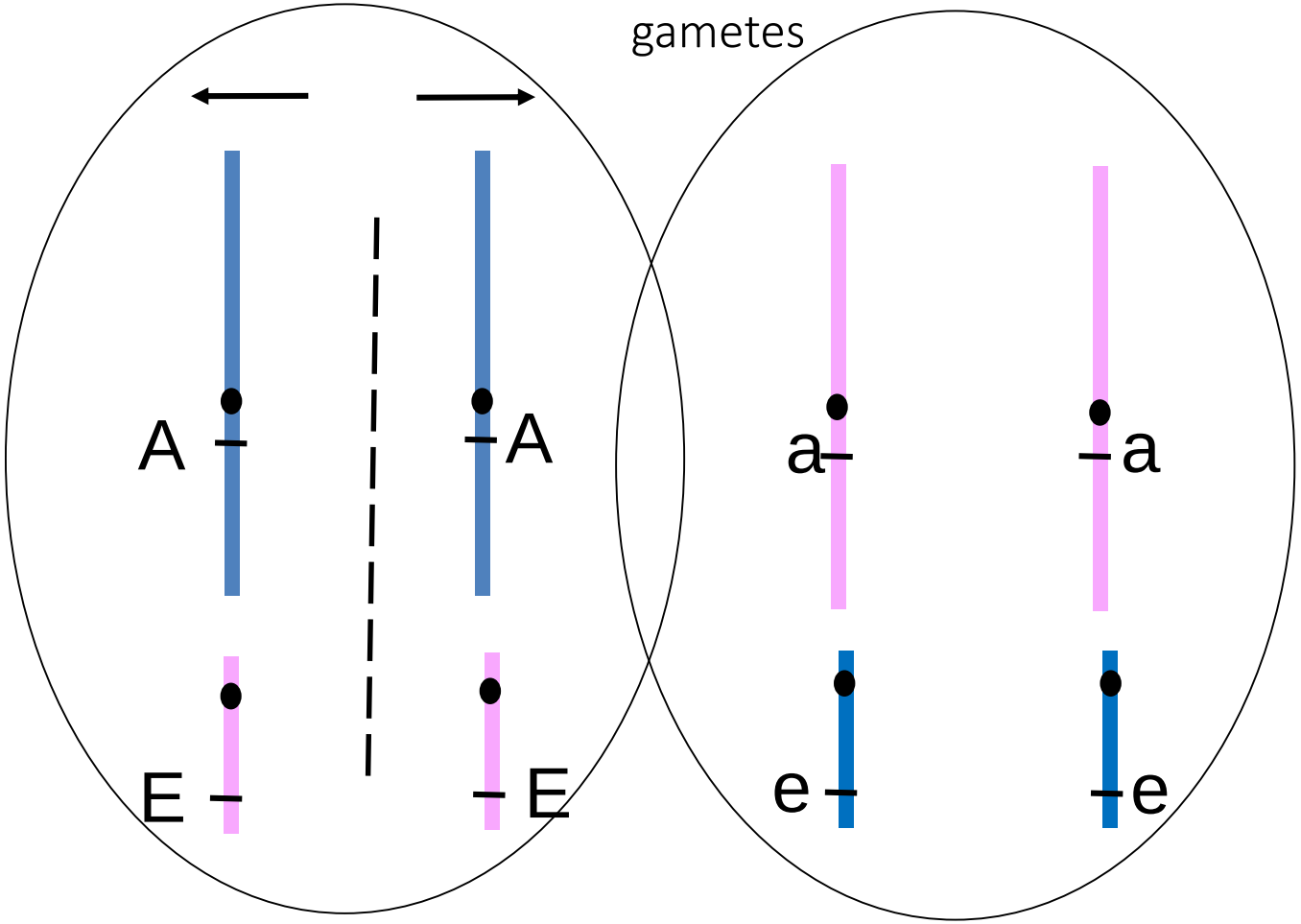


Anaphase I and Anaphase II

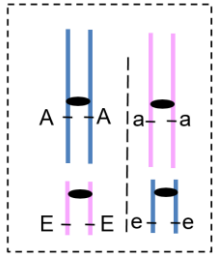
Anaphase 1- Homologs separate and end up in different cells

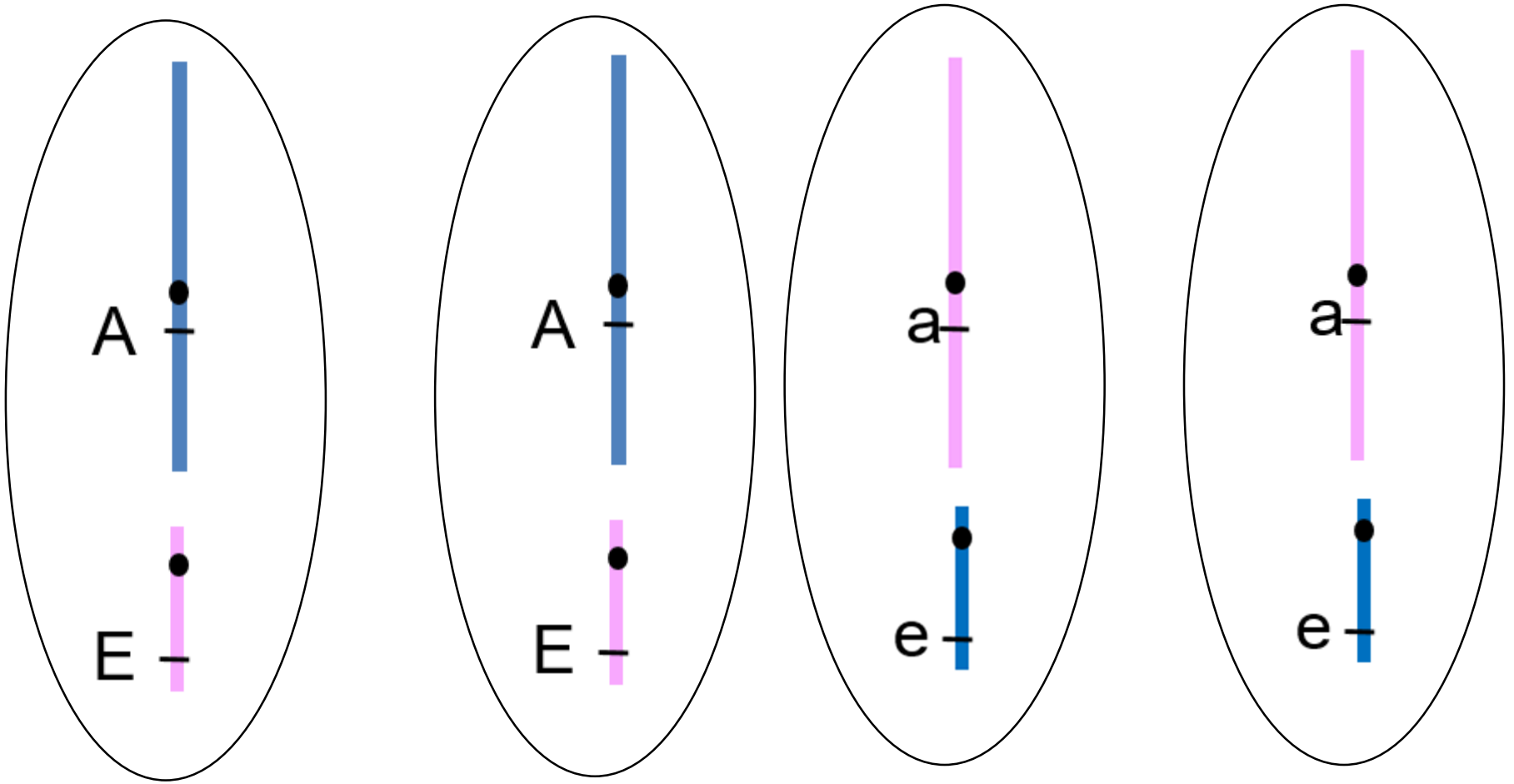


Anaphase 2- Sister chromatids separate and end up in different gametes



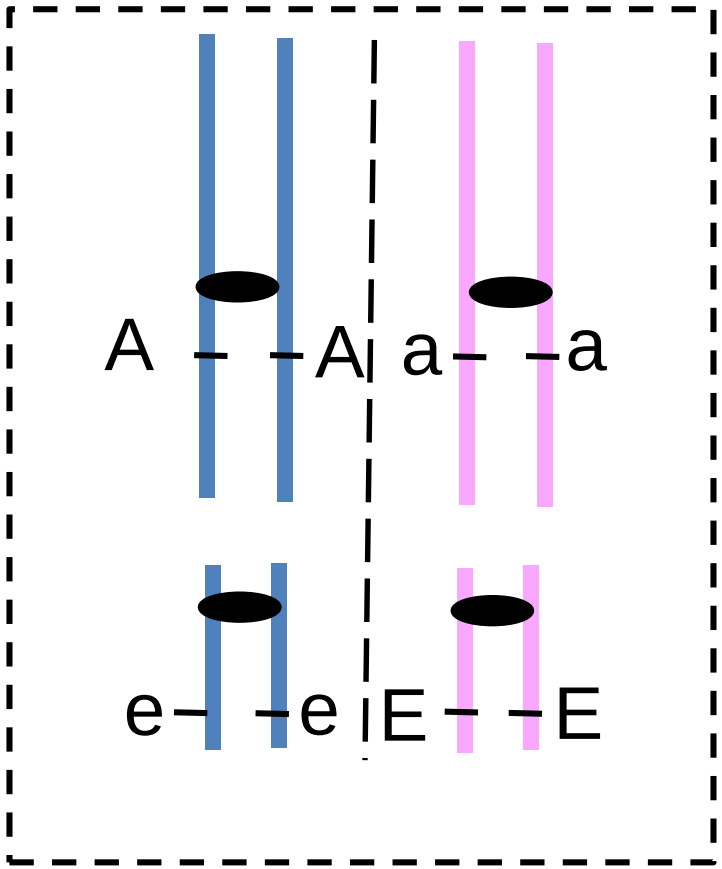
Gamete genotypes that can be produced with different assortment of homologs



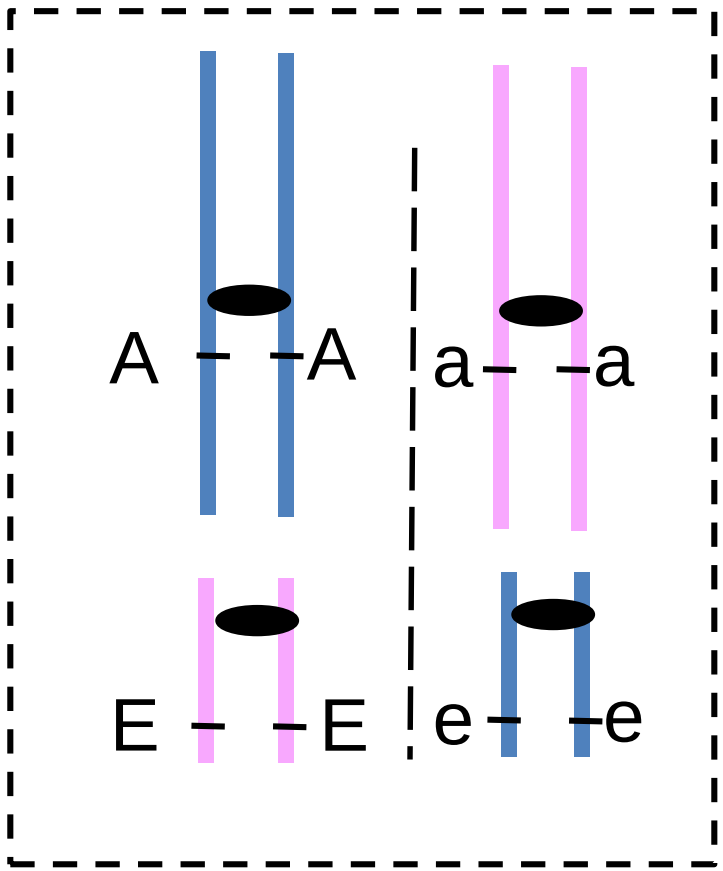


With this alignment – two gamete genotypes: AE and ae. Frequency = 50%, 50% or ratio: 1:1:1:1

If genes are on different chromosomes (and multiple cells under meiosis)



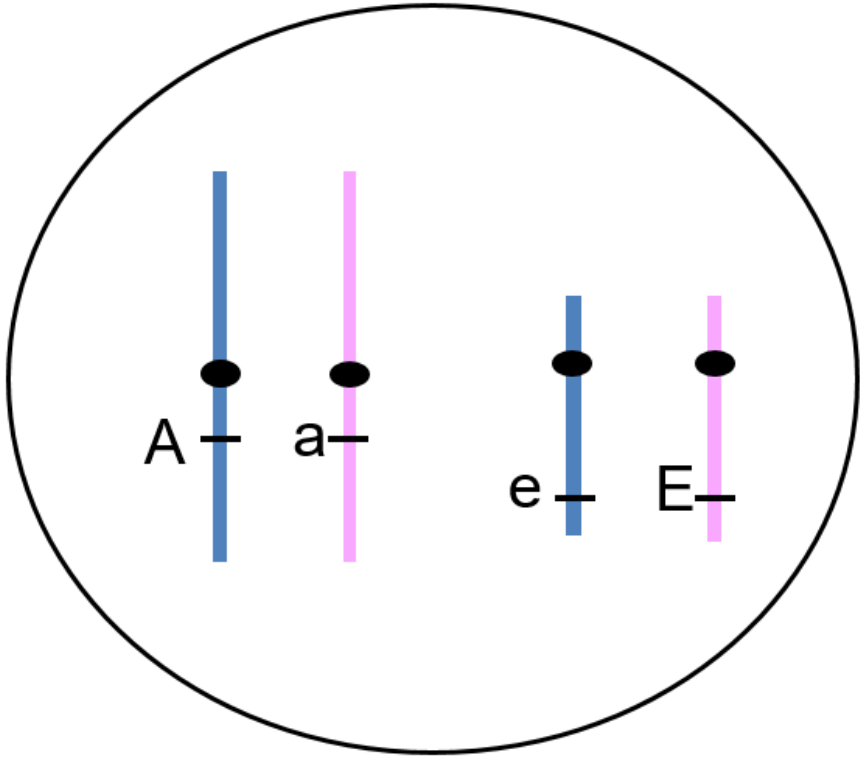
AND



If many cells undergoing meiosis, both alignments will occur with equal frequencies

Genotypes produced: Ae = aE = AE = ae; with frequencies of 25%, 25%, 25%, 25%, or ratios of: 1:1:1:1

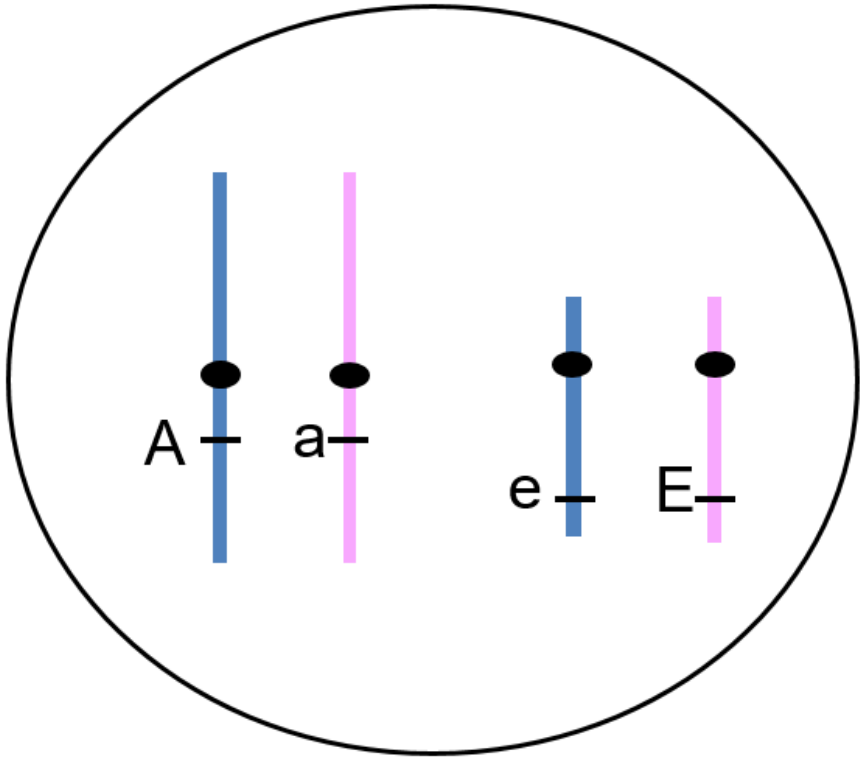
iClicker Question



If the genes are not physically linked (i.e. they are on separate chromosomes), would crossing-over and recombination affect the gamete genotypes that were produced (assuming more than one cell is undergoing meiosis)?

A. Yes
B. No
C. Not sure

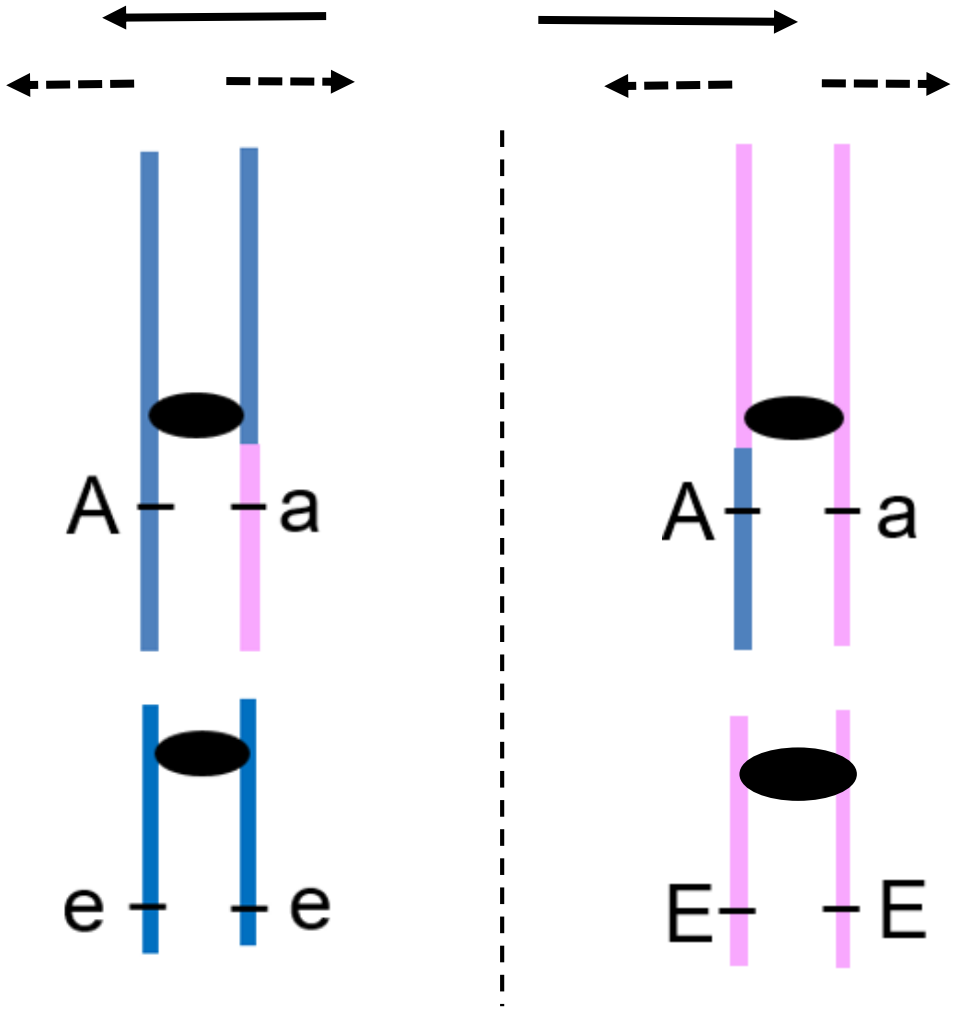
Answer



If there genes are not physically linked, would crossing-over and recombination affect the gamete genotypes that were produced (assuming more than one cell is undergoing meiosis)?

A. Yes
B. No
C. Not sure

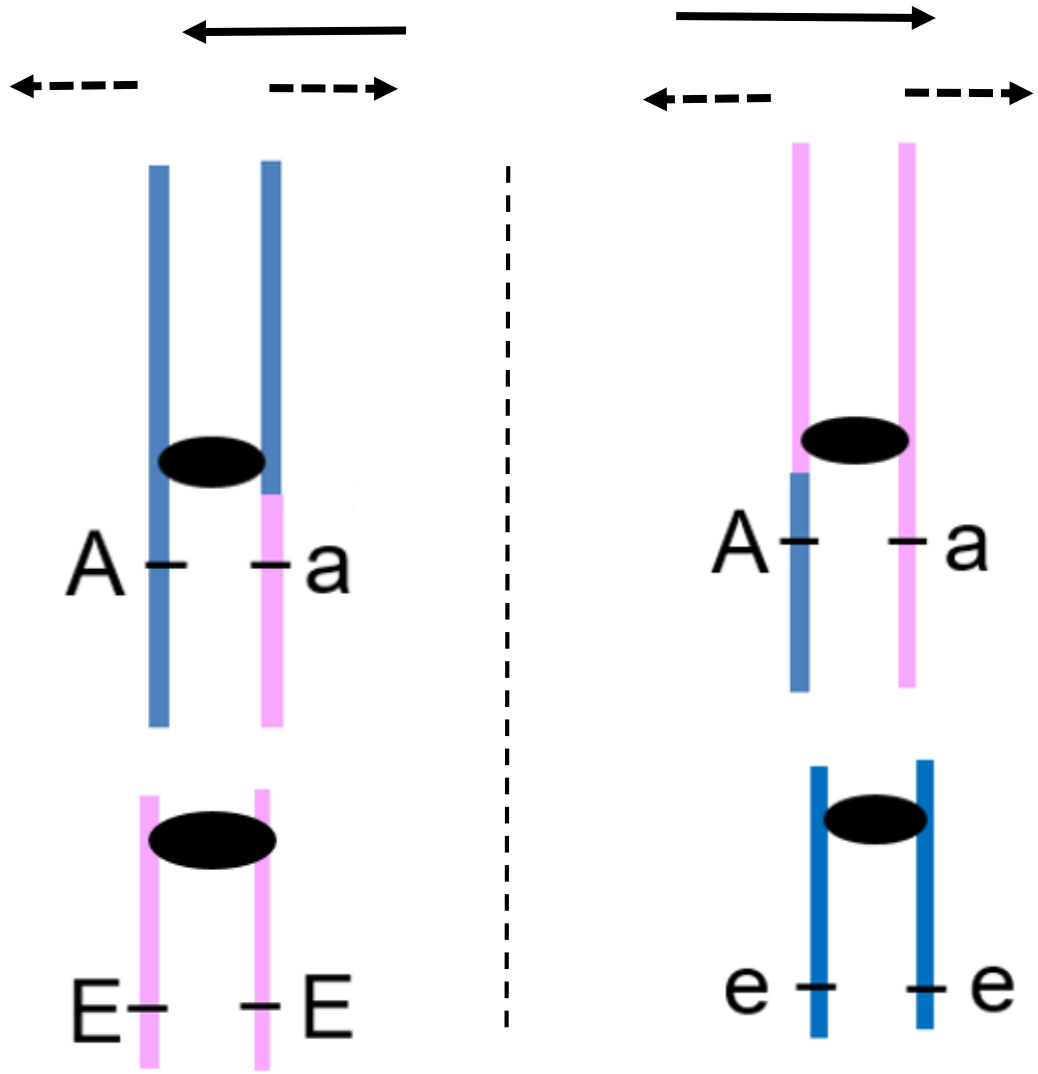
One alignment for homologs



If crossing-over occurred between centromere and A gene

OR

Another alignment for homologs



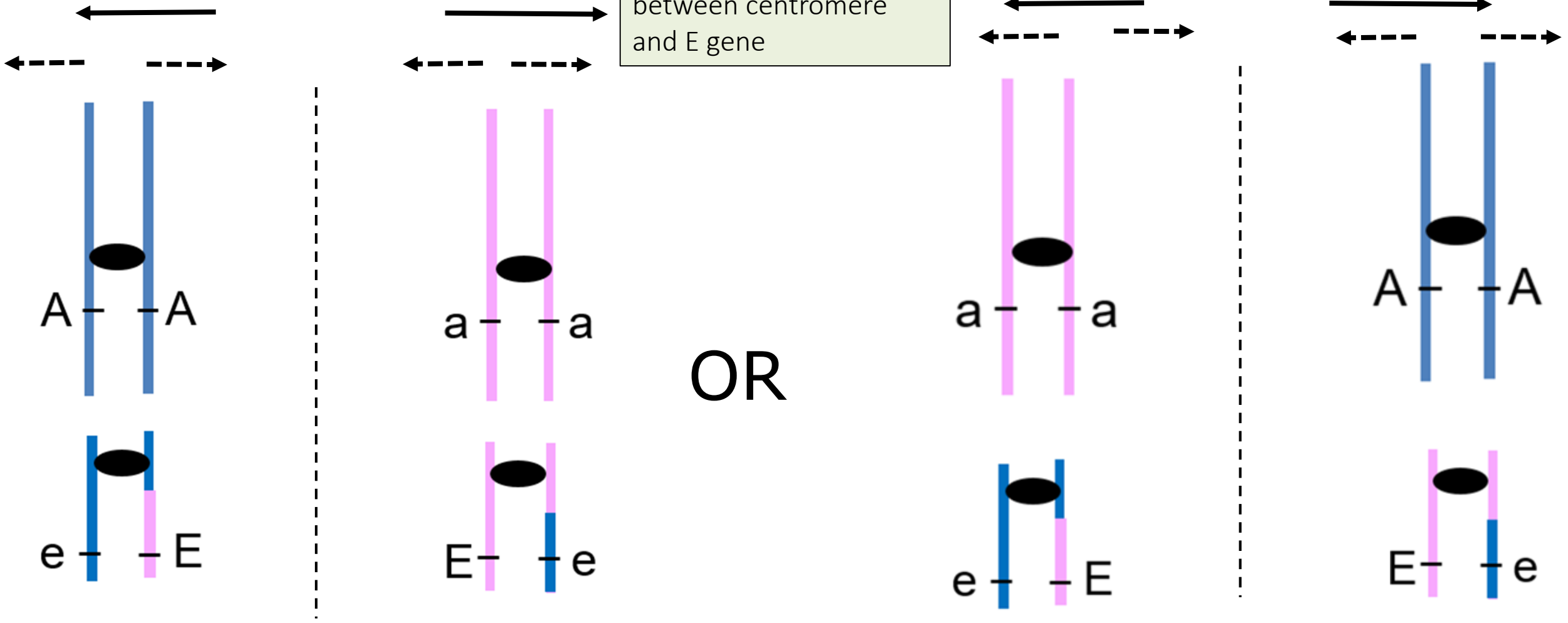
Would result in gametes with the following genotypes: Ae, ae, AE, aE
Equal frequencies, ratios

Would result in gametes with the following genotypes: AE, aE, Ae, ae
Equal frequencies, ratios

One alignment for homologs

If crossing-over occurred between centromere and E gene

Another alignment for homologs

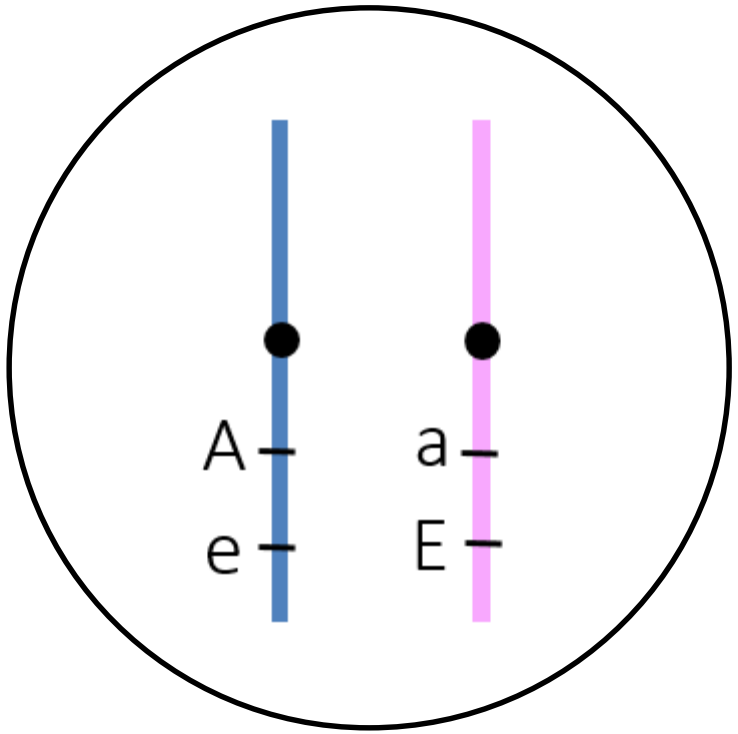


4 gamete genotypes & ratio: Ae = AE = AE = ae
Equal frequencies/ratios

4 gamete genotypes & ratio: ae = aE = AE = Ae
Equal frequencies/ratios

iClicker Question – genes physically linked, no crossing-over between the two genes

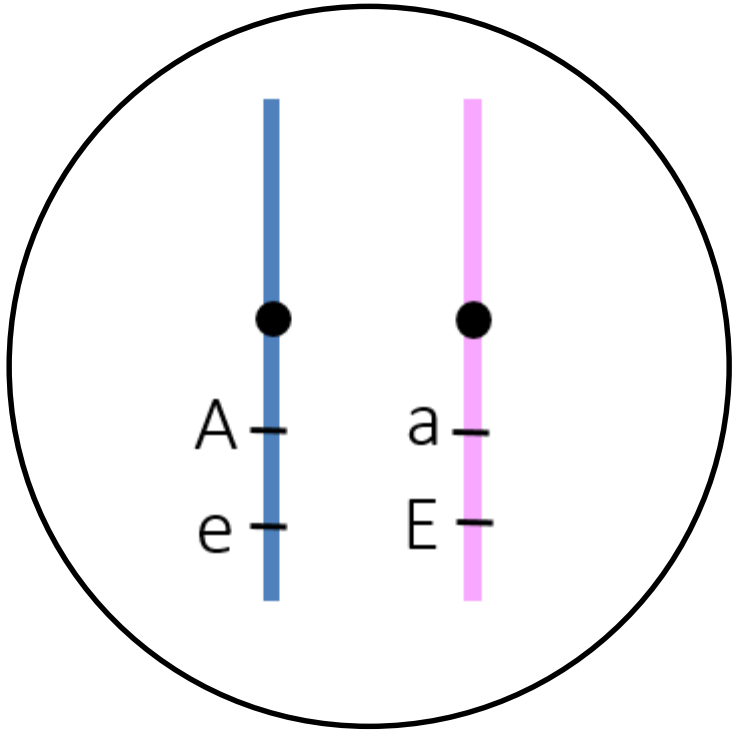
What gamete genotypes would be produced if the genes were linked, and there was no crossing over that resulted in recombination of the alleles?



A. Ae aE AE ae
B. Ae aE
C. A E a e
D. I am not sure

Answer

What gamete genotypes would be produced, if the genes were linked, and there was no crossing over that resulted in recombination of alleles?



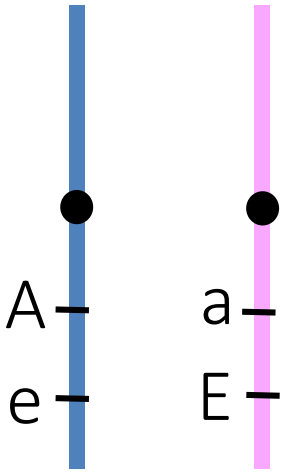
A. Ae aE AE ae
B. Ae aE
C. A E a e
D. I am not sure

Only parental genotypes – no recombinant genotypes (AE or ae)

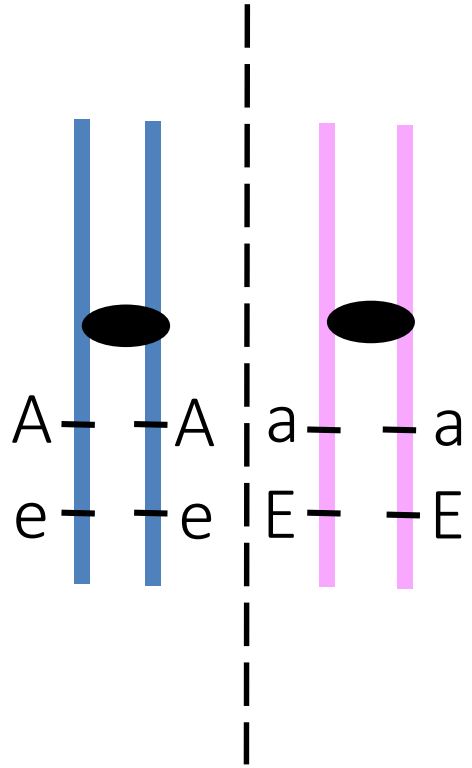
If the two genes were physically linked (no crossing-over that breaks linkage)

- Linked genes travel together unless crossing-over breaks that linkage

Parent cell

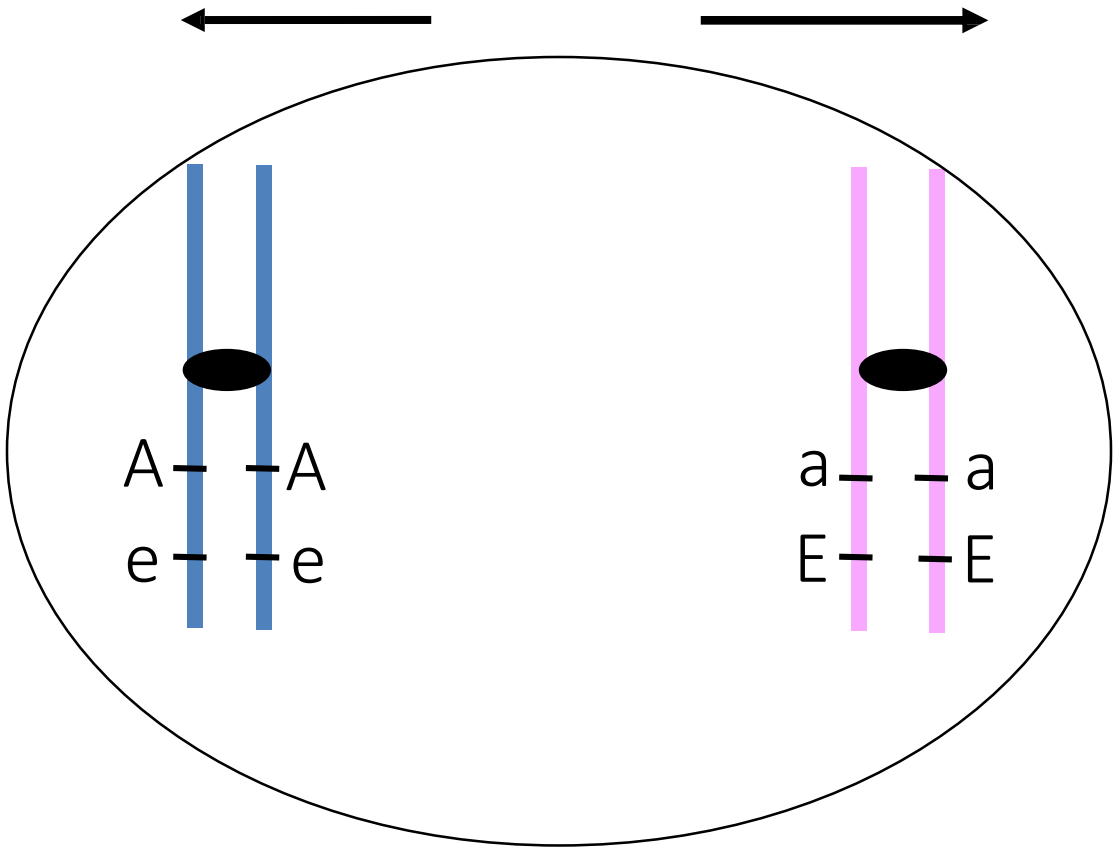


Metaphase

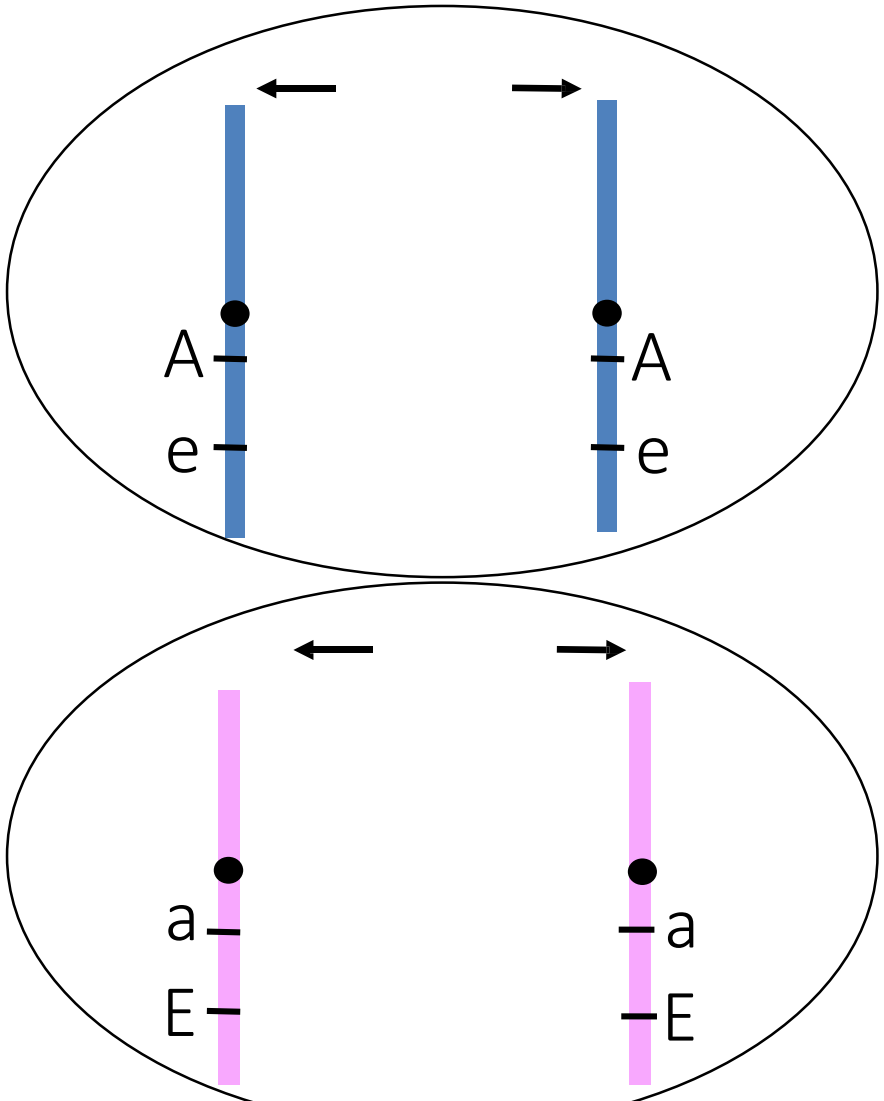


If genes are linked and crossing-over does not result in recombination

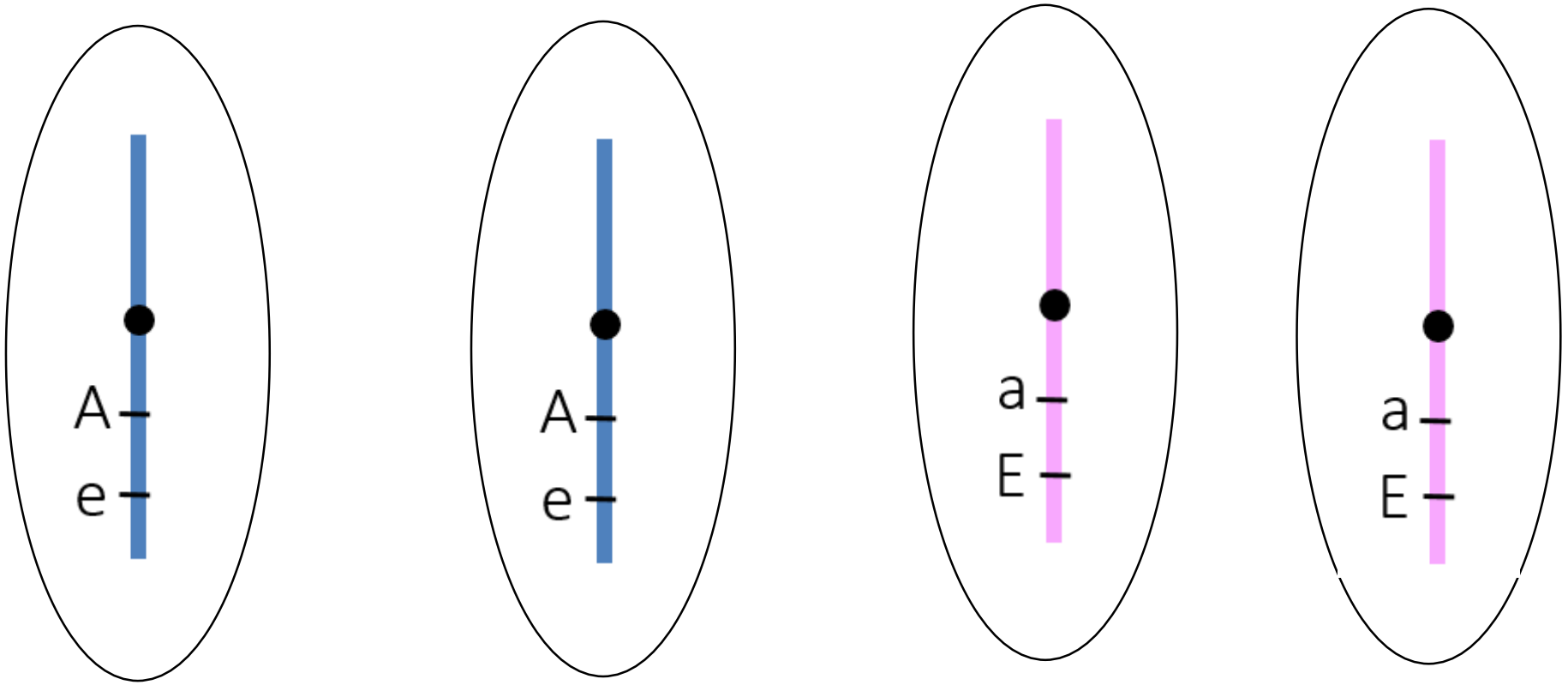
Anaphase 1 (homologs separating)



Anaphase 2 (sister chromatids separating)



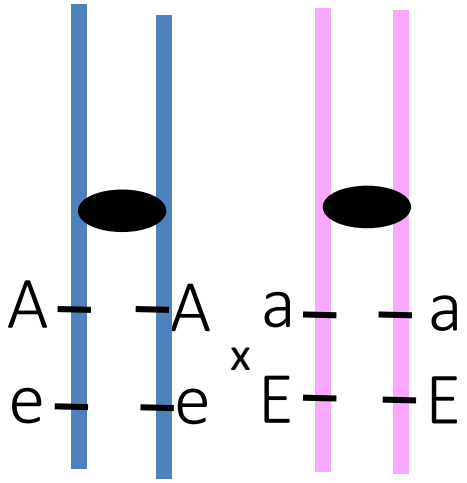
If genes are linked and linkage not broken



If no crossing-over/recombination, 50% Ae and 50% aE genotypes (= only <u>parental genotypes</u>) . No recombinants (AE or ae gametes)

iClicker Question

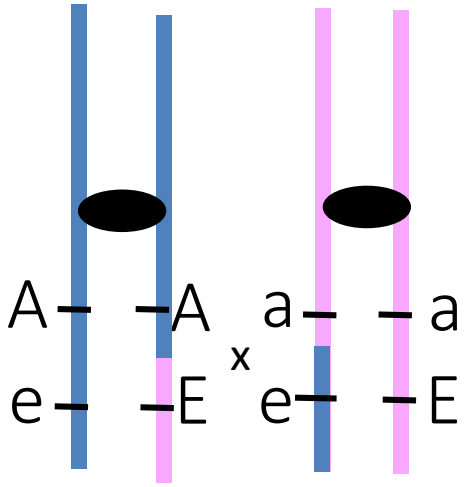
If the 2 genes were linked, but there was crossing over at "X", what gamete genotypes would be produced by this one cell?



A. Ae, AE, ae, aE
B. Ae, aE
C. A, a, E, e
D. I am not sure

Answer

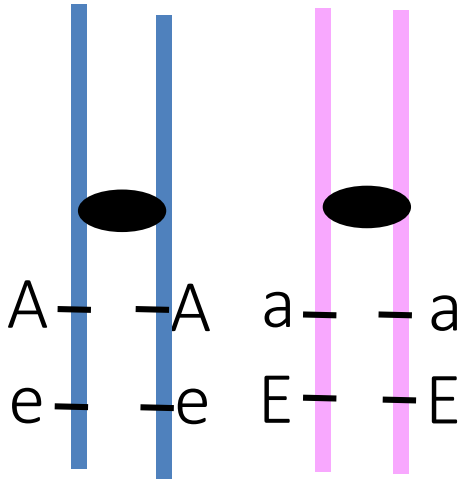
If the 2 genes were linked, but there was crossing over at "X", what gamete genotypes would be produced by this one cell?



A. Ae, AE, ae, aE
B. Ae, aE
C. A, a, E, e
D. I am not sure

iClicker Question

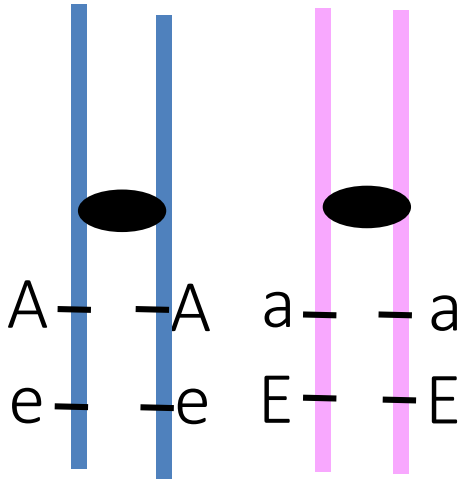
If 1,000 cells with the genotype below underwent meiosis, and crossing-over could occur, would all four genotypes (Ae, aE, AE and ae) be produced with equal frequency?



A. Yes
B. No
C. I am not sure

Answer

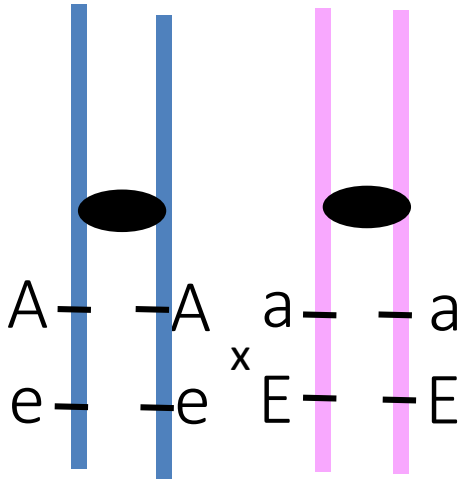
If 1,000 cells with the genotype below underwent meiosis, and crossing-over could occur, would all four genotypes (Ae, aE, AE and ae) be produced with equal frequency?



A. Yes
B. No
C. I am not sure

iClicker Question

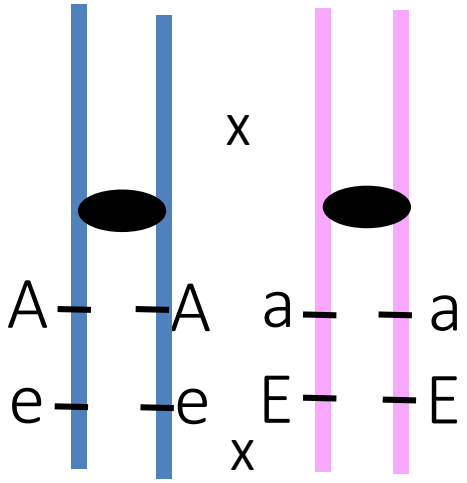
If 1,000 cells were undergoing meiosis and the genes were linked as shown below, would the DNA always break between the A and E genes?



A. Yes
B. No
C. I am not sure

Answer

If 1,000 cells were undergoing meiosis and the genes were linked as shown below, would the DNA always break between the A and E genes?



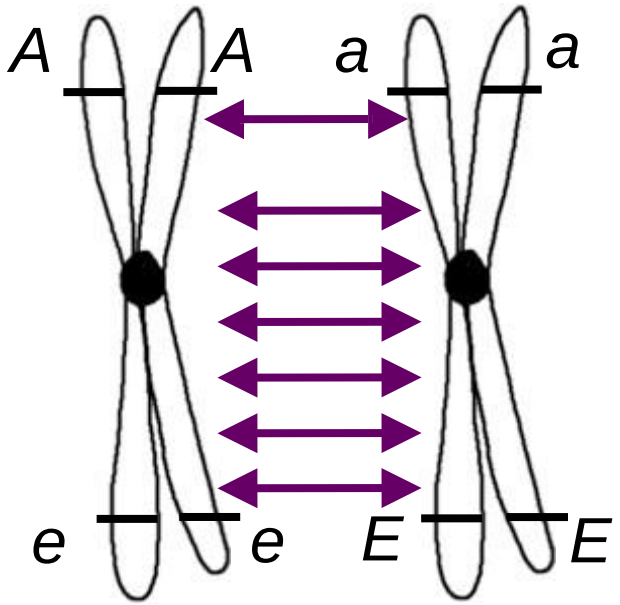
A. Yes
B. No
C. I am not sure

Sometimes the DNA will break above the A gene or below the E gene. If that happens, what gamete genotypes would be produced by those cells?

Ae and aE (parental) only

So, with recombination: Ae, aE, AE, ae - parental and recombinant genotypes
Without recombination: Ae, and aE (parental only)
So, overall expect more parental than recombinant genotypes

The physical distance between genes affects the probability that crossing over will result in recombination



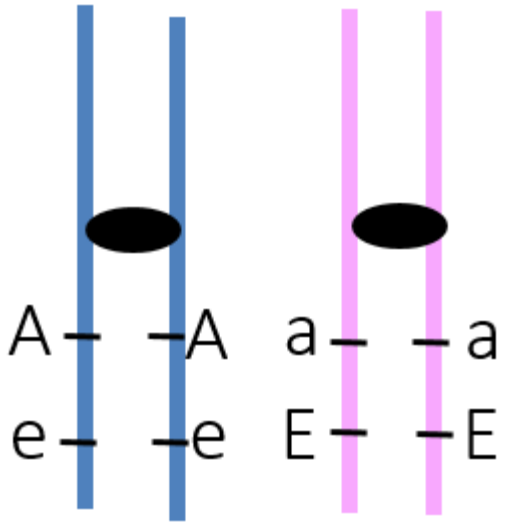
Genes that are far apart = lots of opportunities for crossing-over and recombination

Genes that are close together are less likely to cross-over

- In this example, I would expect to see 4 gamete genotypes: Ae, aE, AE, ae
- I would still expect parental genotypes (Ae, aE) to be more frequent than the recombinant genotypes (AE, ae)
- But I would expect their frequencies to be very close.

iClicker Question

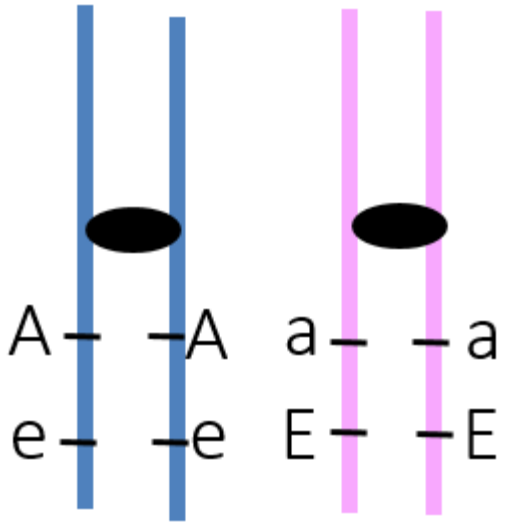
If 1,000 cells were undergoing meiosis and the genes were linked as shown below, and crossing-over could occur, which genotypes would be produced most frequently?



A. Ae and aE
B. AE and ae
C. Ae and ae
D. AE and aE
E. Not sure

Answer

If 1,000 cells were undergoing meiosis and the genes were linked as shown below, and crossing-over could occur, which genotypes would be produced most frequently?



A. Ae and aE (parental)
B. AE and ae (recombinant, new)
C. Ae and ae
D. AE and aE
E. Not sure

Calculating number of possible gamete genotypes

- if genes are not linked, or if they are linked, but crossing-over can occur

- You can calculate the number of possible gamete genotypes using the equation:

$$2^n$$

n = number of genes that are heterozygous

Note - this formula looks the same as the formula that you used to calculate the number of possible alignments of homologous chromosomes. BUT, n = different.

iClicker Question – genes not physically linked

- If a parent cell had the genotype A1/A2;B1/B2;C1/C1 (assuming the genes are not physically linked); how many gamete genotypes are possible.

$$2^n$$

A: 2

B: 4

C: 8

D: 16

E: 32

What would those possible genotypes be?

Answer

- If a parent cell had the genotype A1/A2;B1/B2;C1/C1 (assuming the genes are not physically linked); how many gamete genotypes are possible.

$$2^n$$

A: 2

B: 4

C: 8

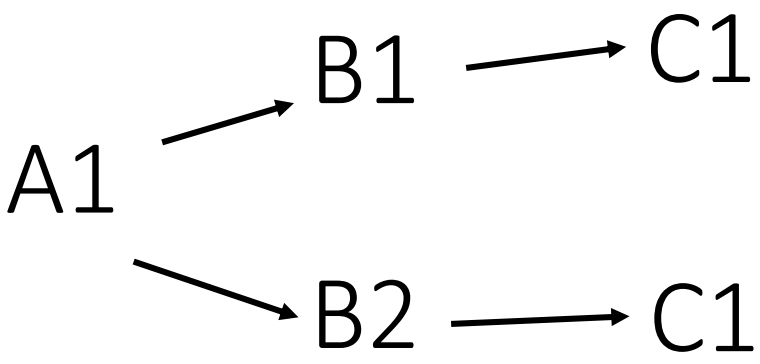
D: 16

E: 32

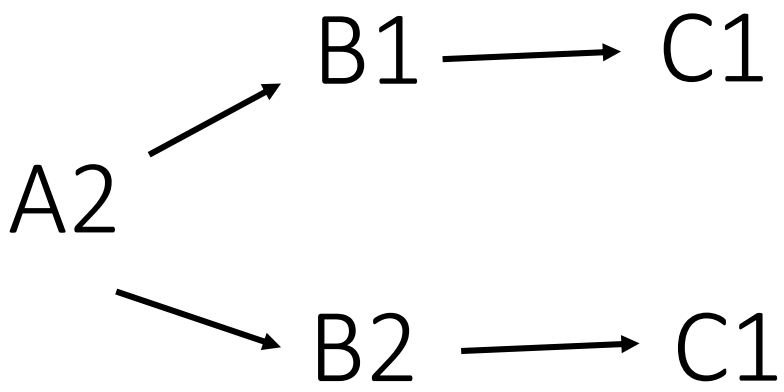
What would those possible genotypes be?

A1B1C1, A1B2C1, A2B1C1, A2B2C1

A1/A2;B1/B2;C1/C1



A1B1C1
A1B2C1



A2B1C1
A2B2C1

You should now:

Understand/know:

- The stages of meiosis:
  - How ploidy, number of chromatids and number of DNA molecules change throughout meiosis.
  - Identify genes, alleles, homologous chromosomes, sister and non-sister chromatids.
  - Similarities and differences with mitosis

Be able to:

- Interpret and/or draw diagrams of chromosomes at different stages of meiosis.
- Work forwards and backwards through meiosis

Understand/know:

- How genetic variation amongst individuals arises and the cellular mechanisms responsible:
  - Crossing over & genetic recombination (Prophase I)
  - Independent assortment of homologous chromosomes (Metaphase I).
  - Random fusion of gametes

Be able to predict the gamete genotypes that can be produced via meiosis (if genes are not linked, linked with no crossing-over; or linked with crossing-over

Sunday assignments

You should now be able to complete Quiz #2 and Worksheet #2

- Meiosis & Genotypes – 3 hypotheses – due Sunday @ 11:59 pm (change)

You should also be able to complete worksheet #3 (Sally scenario). But, this worksheet is not due until the following Sunday.

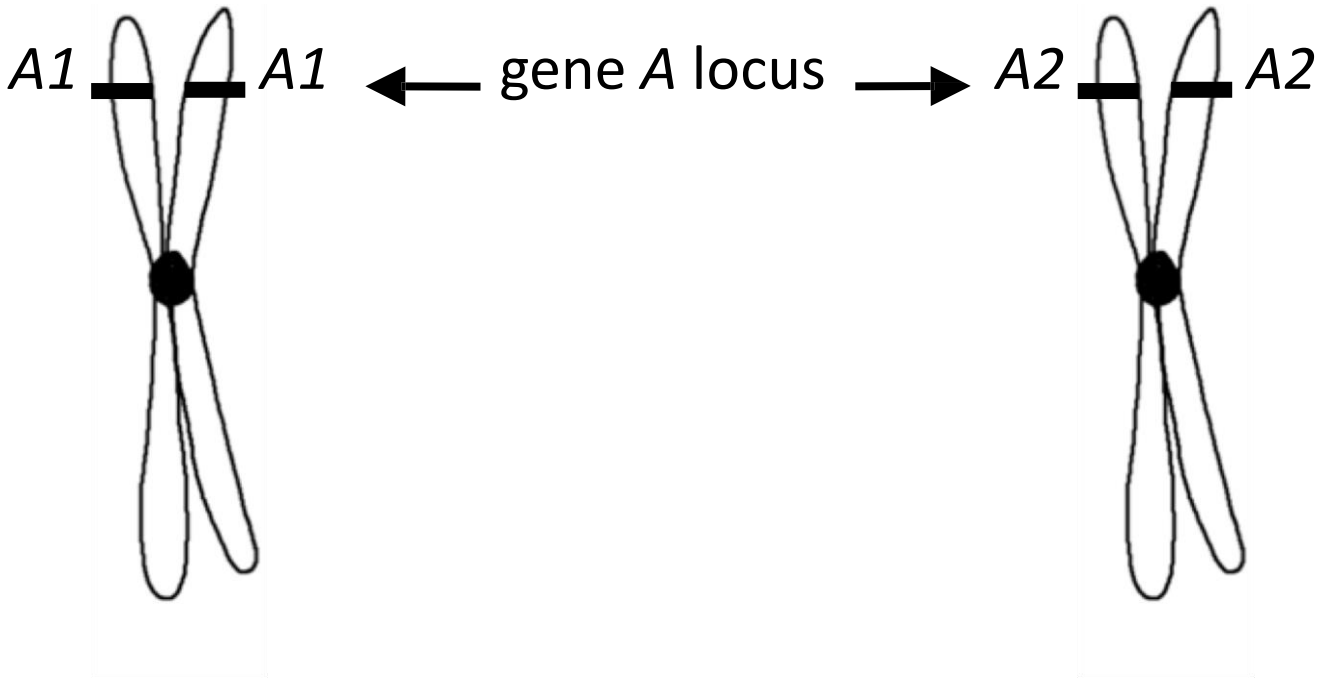
Next class

- Finish mitosis and meiosis

- Start Patterns of Inheritance – Mendelian Inheritance

Meiosis Worksheet (#2)

Premise: A man has the genotype *A1*/*A2*; *B1*/*B2*. He inherited the *A1* and *B1* alleles from his mother, and the *A2* and *B2* alleles from his father.



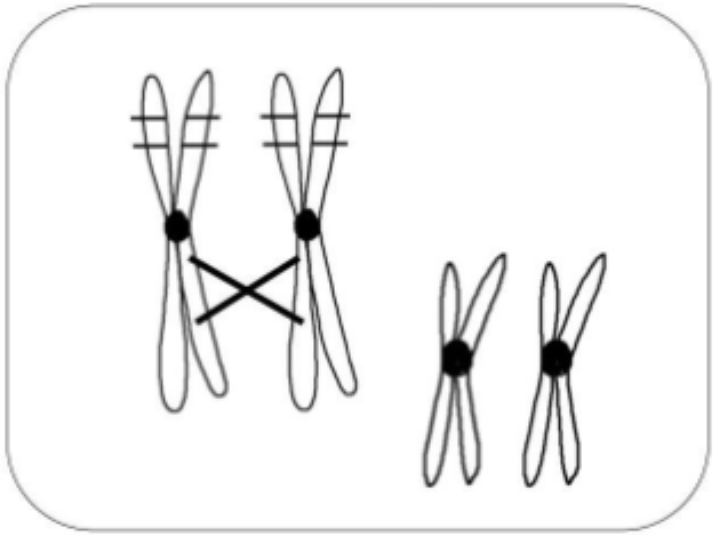
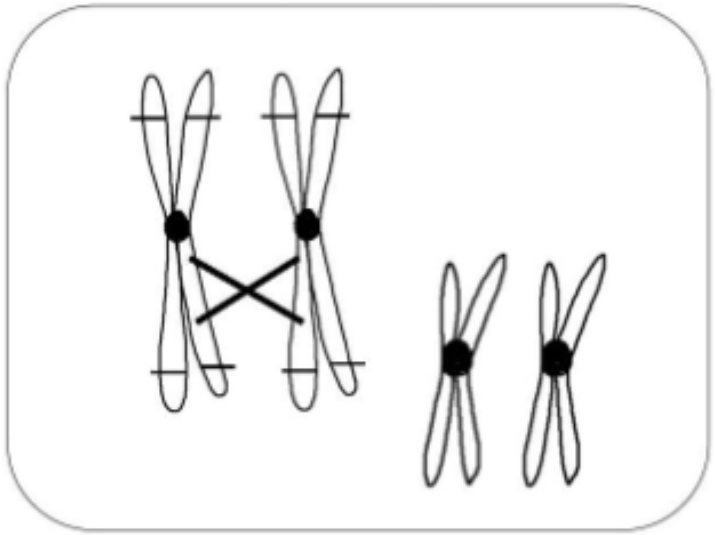
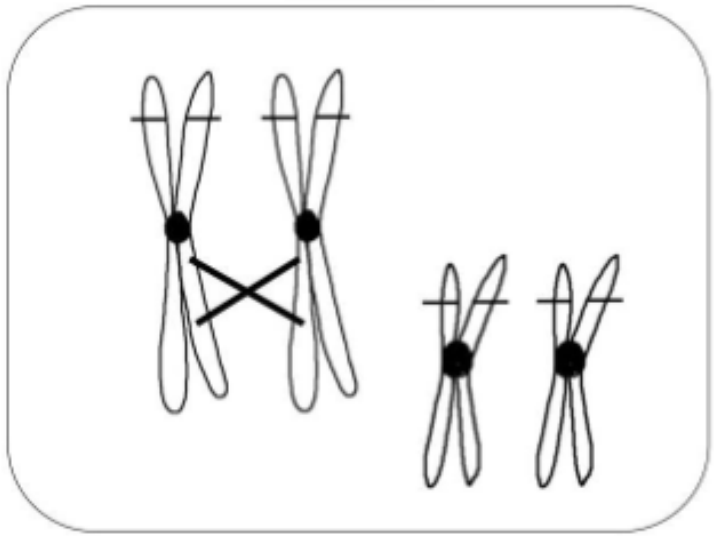
We provide you with location of gene A (above).
The worksheet looks at 3 different hypotheses in which the *location* of gene B varies.

Worksheet #2 -3 hypotheses (meiosis)

WORKSHEET #2 - MEIOSIS & GENOTYPES – 3 Hypotheses

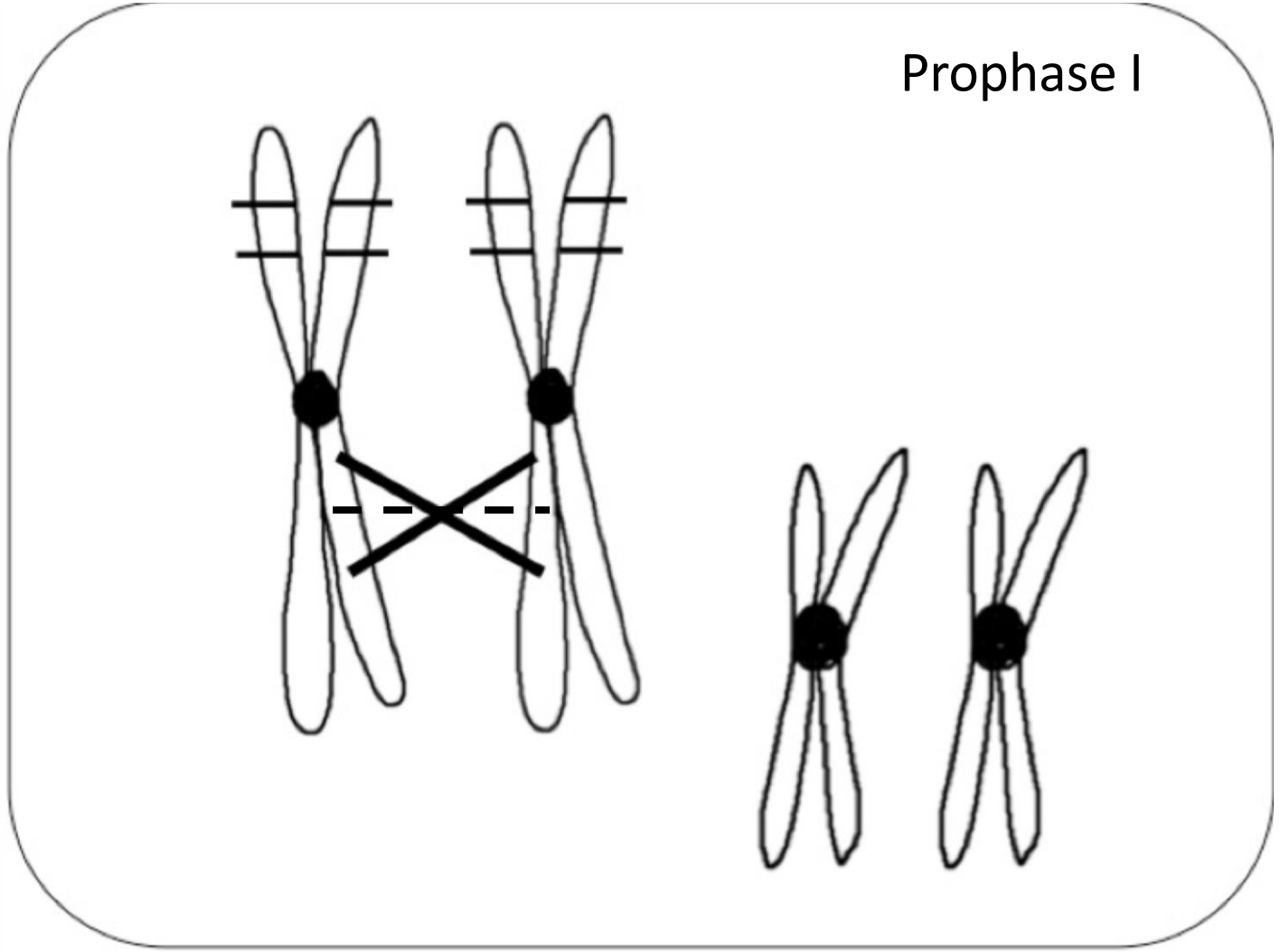
A man has the genotype *A1*/*A2*; *B1*/*B2*. He inherited the *A1* and *B1* alleles from his mother, and the *A2* and *B2* alleles from his father. The diagrams below show one of the man's sex cells undergoing meiosis to form gametes (sperm), under three possible hypotheses. The location of gene *A* is known; we do not currently know the location of gene *B*. The approximate location of a crossover event is marked with an "X"; you can assume this crossover happens 100% of the time.

Please complete each of the diagrams (and formulate predictions for each hypothesis) by labelling the location of the alleles:

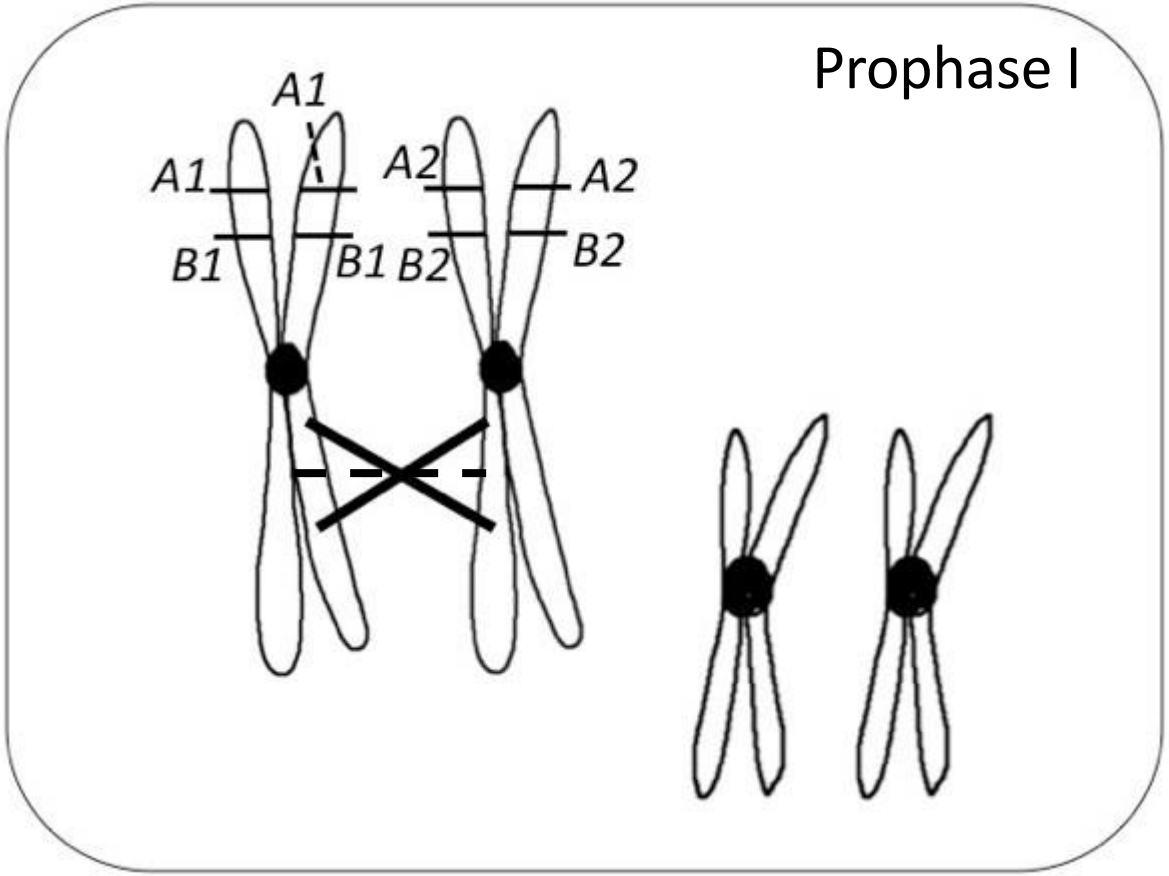
Hypothesis 1:	Hypothesis 2:	Hypothesis 3:
Both genes are physically linked, and they are close together.	Both genes are physically linked, but they are far apart.	Gene *A* is found on one pair of homologs, and gene *B* is on a different pair of homologs.
Prophase I	Prophase I	Prophase I
		

Premise: A man has the genotype *A1*/*A2*; *B1*/*B2*. He inherited the *A1* and *B1* alleles from his mother, and the *A2* and *B2* alleles from his father.

Hypothesis 1: Loci A and B are physically linked (they are located on the **same** chromosome)



Hypothesis 1: Loci A and B are physically linked (they are located on the **same** chromosome)



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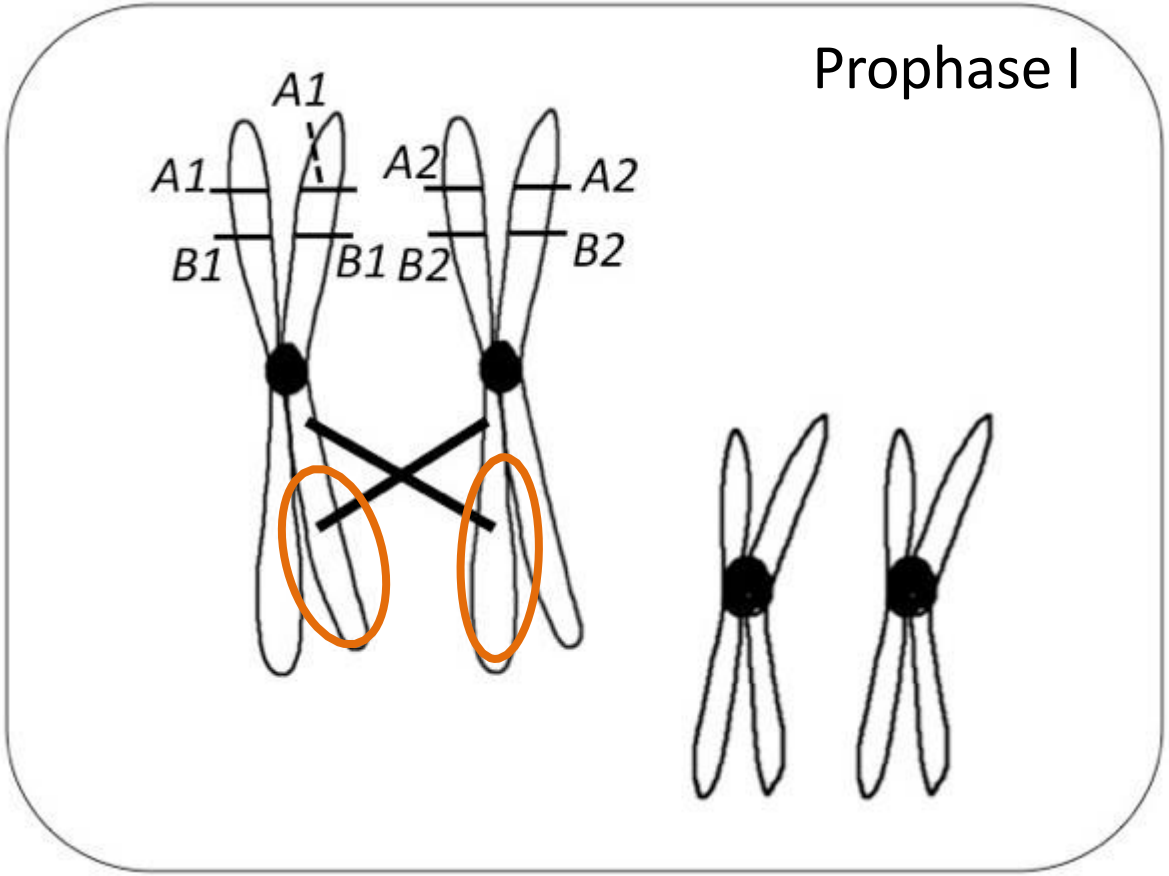
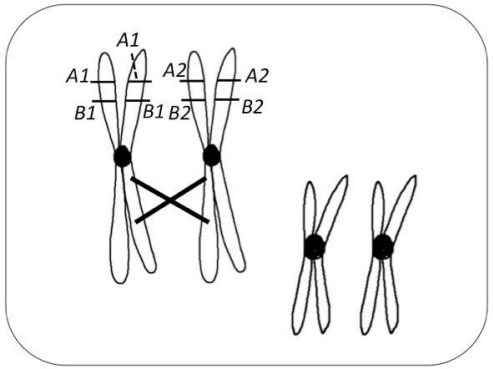
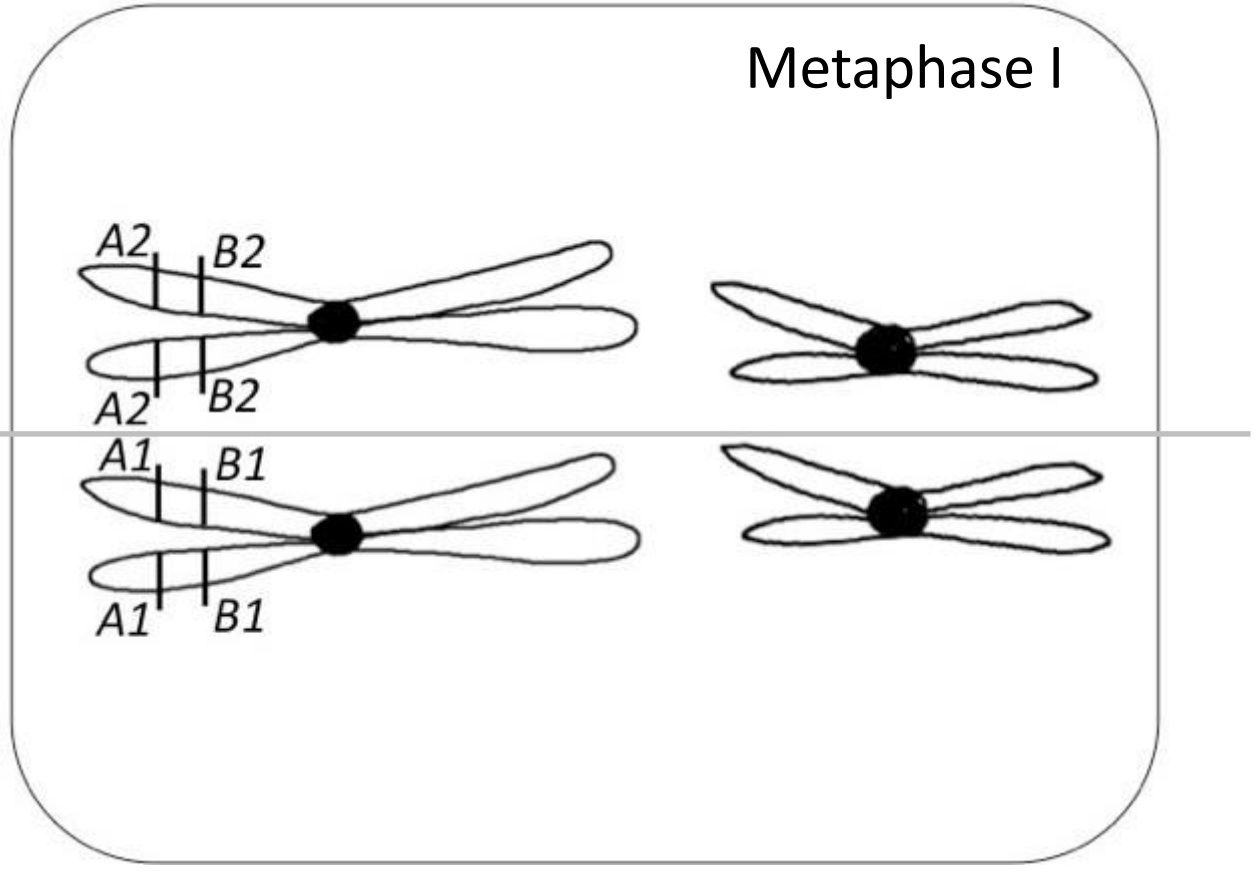


- The crossover swaps the **lower** portion of these chromatids
- Under this hypothesis, both loci (= the location of both genes) are above the crossover, so the alleles we are interested in are not impacted.

Hypothesis 1: Loci A and B are physically linked (they are located on the same chromosome)

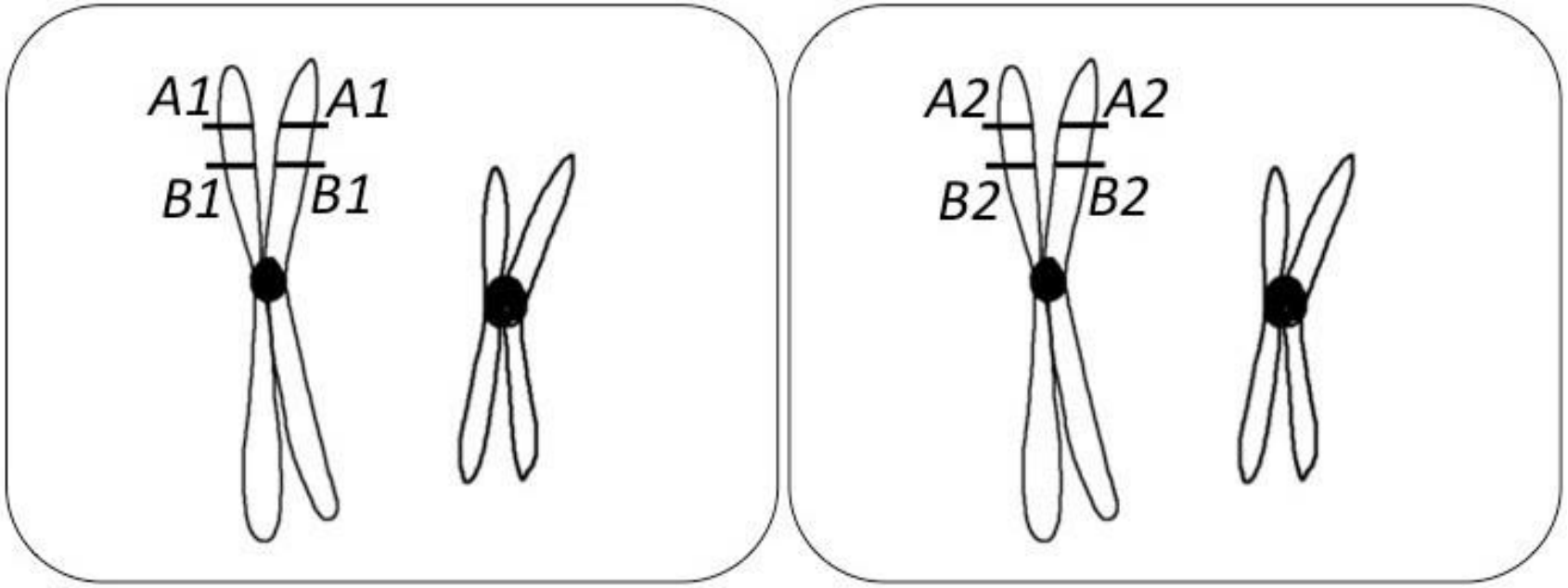


Prophase I



Hypothesis 1: Loci A and B are physically linked (they are located on the **same** chromosome)

End of Telophase I and cytokinesis

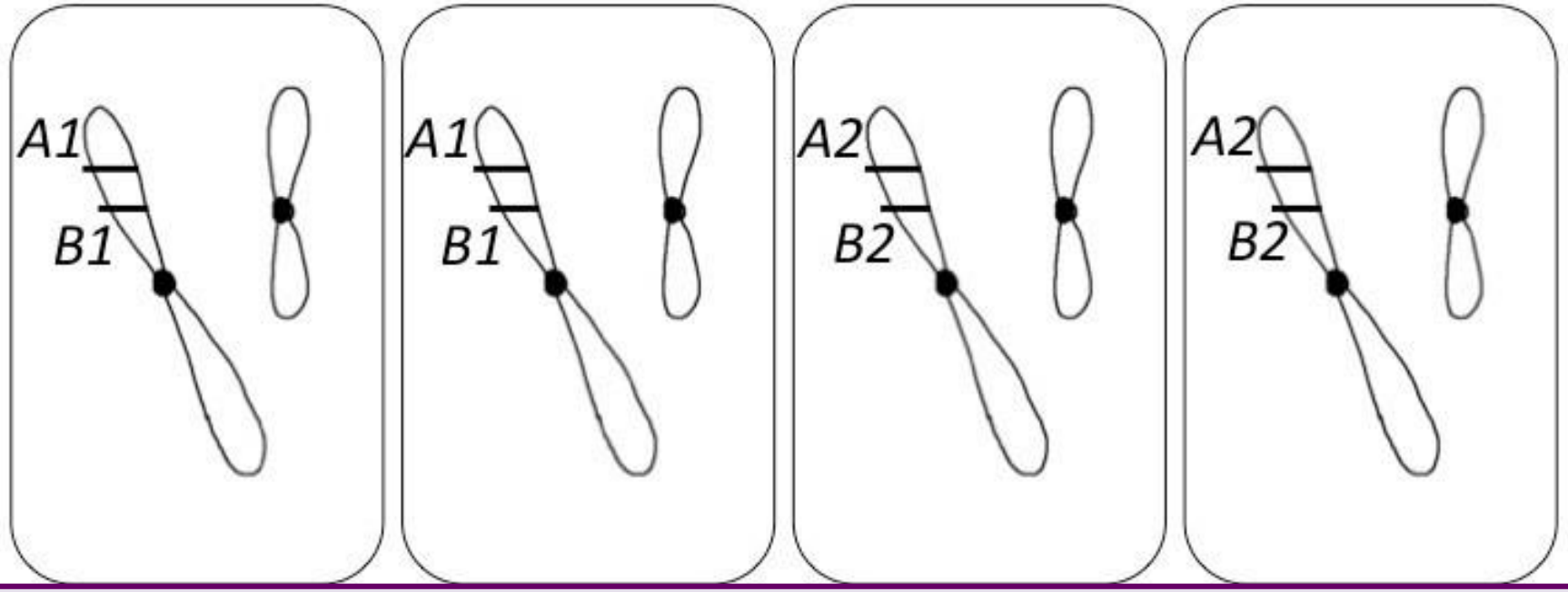


Hypothesis 1: Loci A and B are physically linked (they are located on the same chromosome)

End of Telophase II and cytokinesis

Maternal allele combination:

Paternal allele combination:



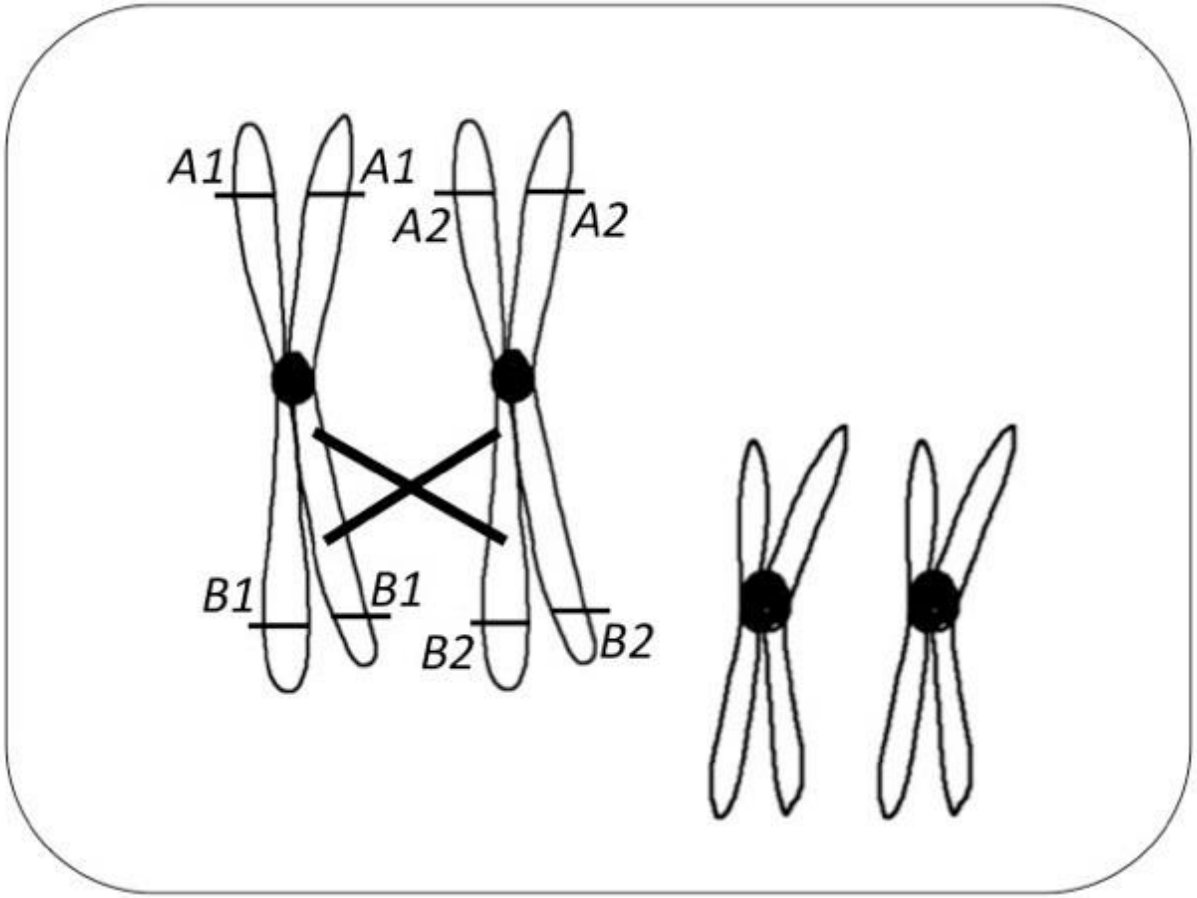
Only parental (non-recombinant) genotypes –

A1;B1 (0.5 or 50%) & A2;B2 (0.5 or 50%)

no recombinant genotypes (or new gentoypes) under this hypothesis.

Premise: A man has the genotype *A1*/*A2*; *B1*/*B2*. He inherited the *A1* and *B1* alleles from his mother, and the *A2* and *B2* alleles from his father.

Hypothesis 2: Loci A and B are also physically linked, but just further apart this time. Assume crossing over occurs 100% of the time.



Premise: A man has the genotype *A1*/*A2*; *B1*/*B2*. He inherited the *A1* and *B1* alleles from his mother, and the *A2* and *B2* alleles from his father.

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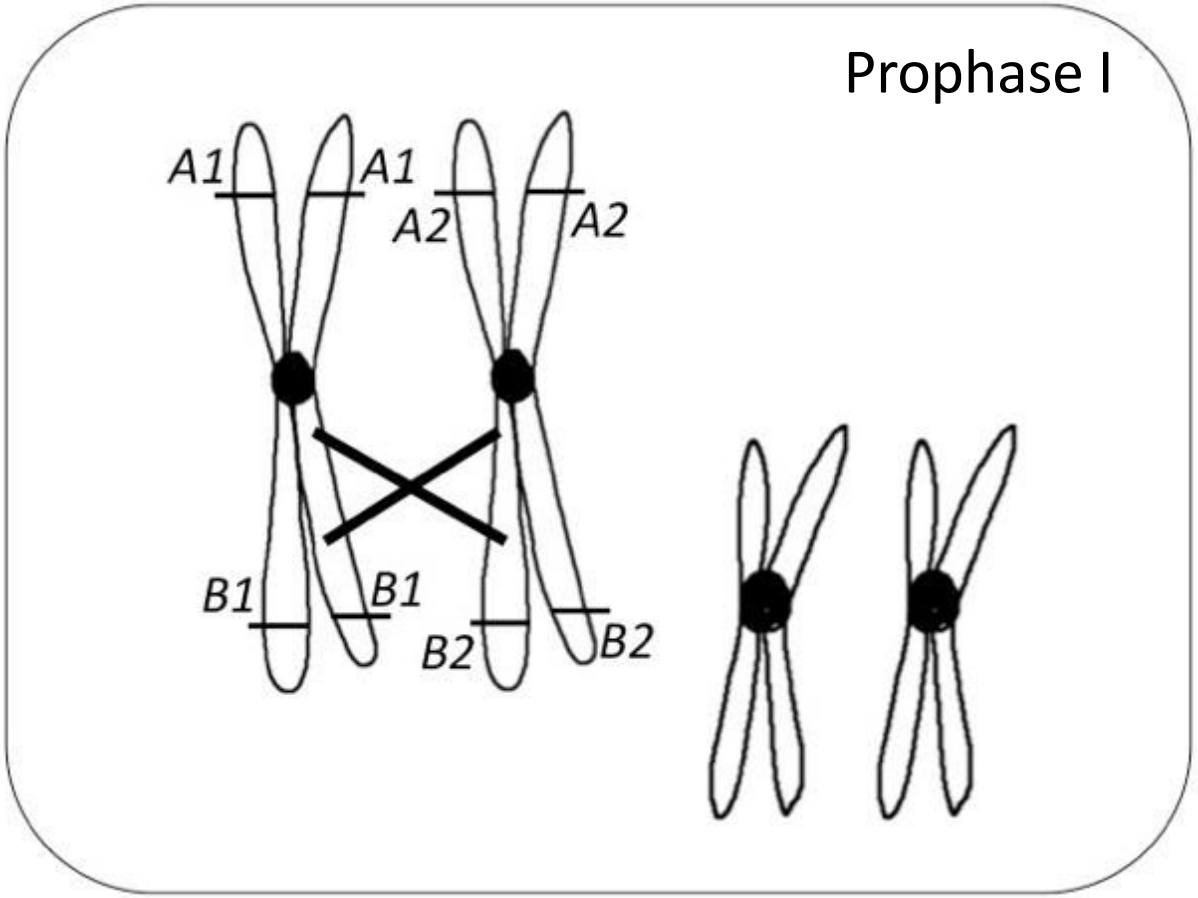
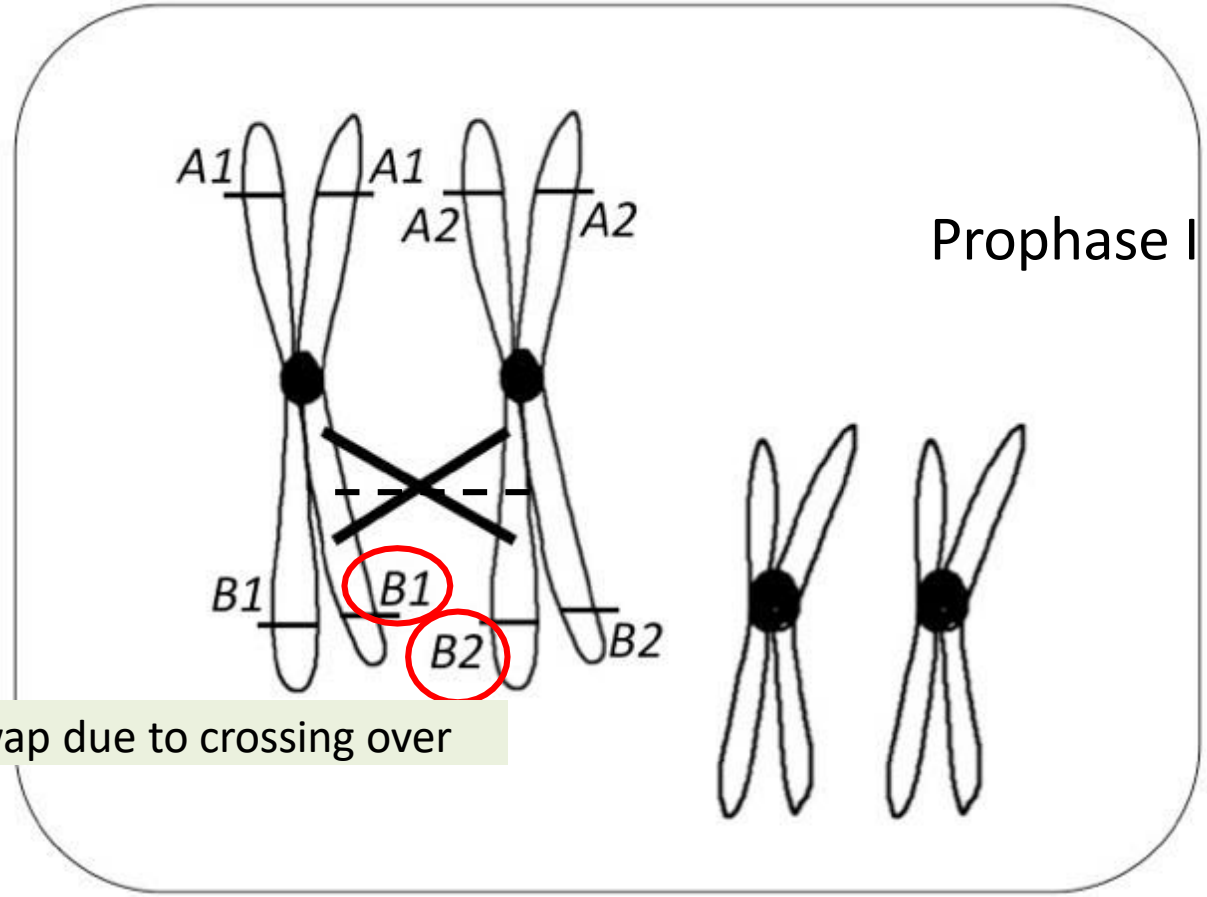


Will the alleles here be affected by crossing over in this scenario?

A: Yes

B: No

Hypothesis 2: **Loci A and B are also physically linked, but just further apart this time. Assume crossing over occurs 100% of the time.**



These will swap due to crossing over

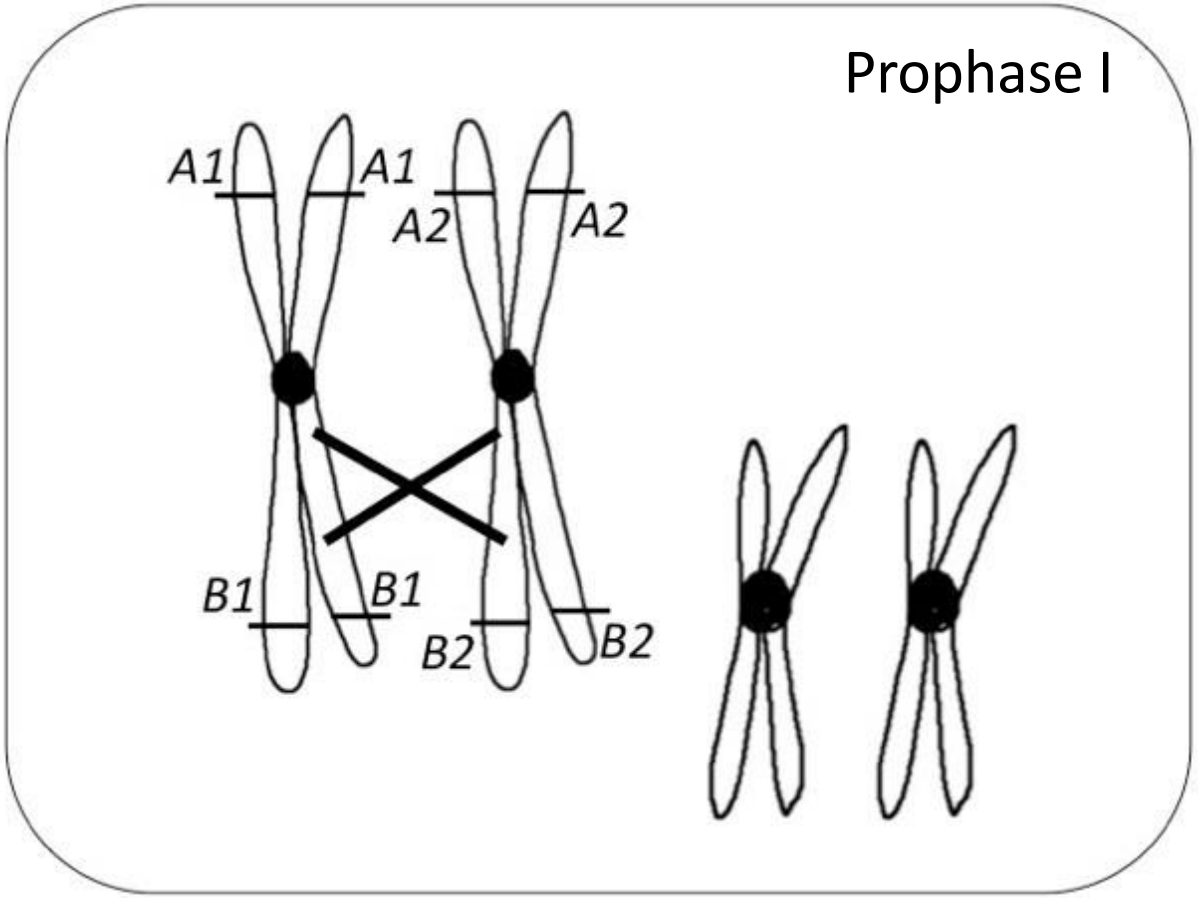
Will the alleles here be affected by crossing over in this scenario?

A: Yes

B: No

Premise: A man has the genotype *A1*/*A2*; *B1*/*B2*. He inherited the *A1* and *B1* alleles from his mother, and the *A2* and *B2* alleles from his father.

Hypothesis 2: Loci A and B are also physically linked, but just further apart this time. Assume crossing over occurs 100% of the time.

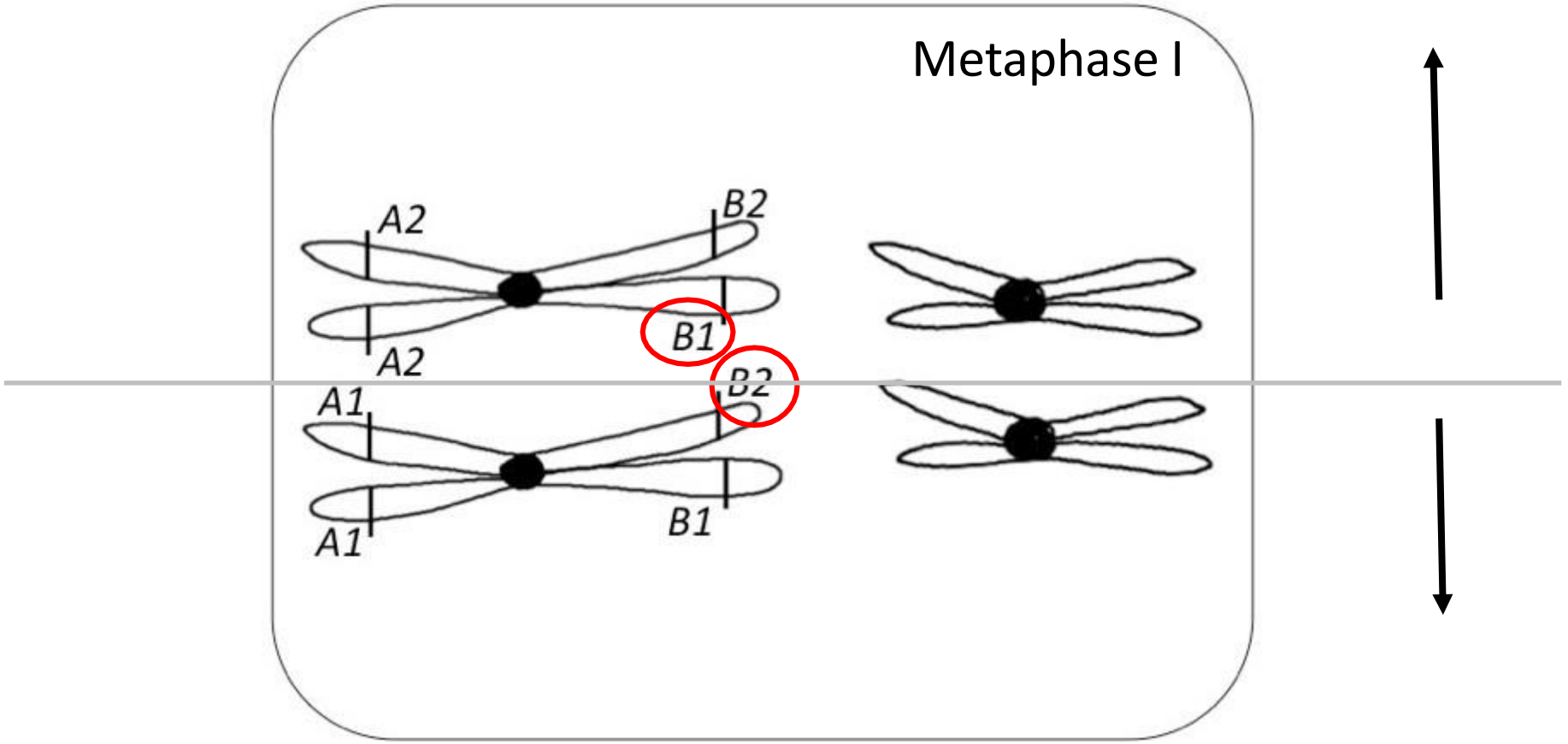


Will the alleles here be affected by crossing over in this scenario?

A: Yes

B: No

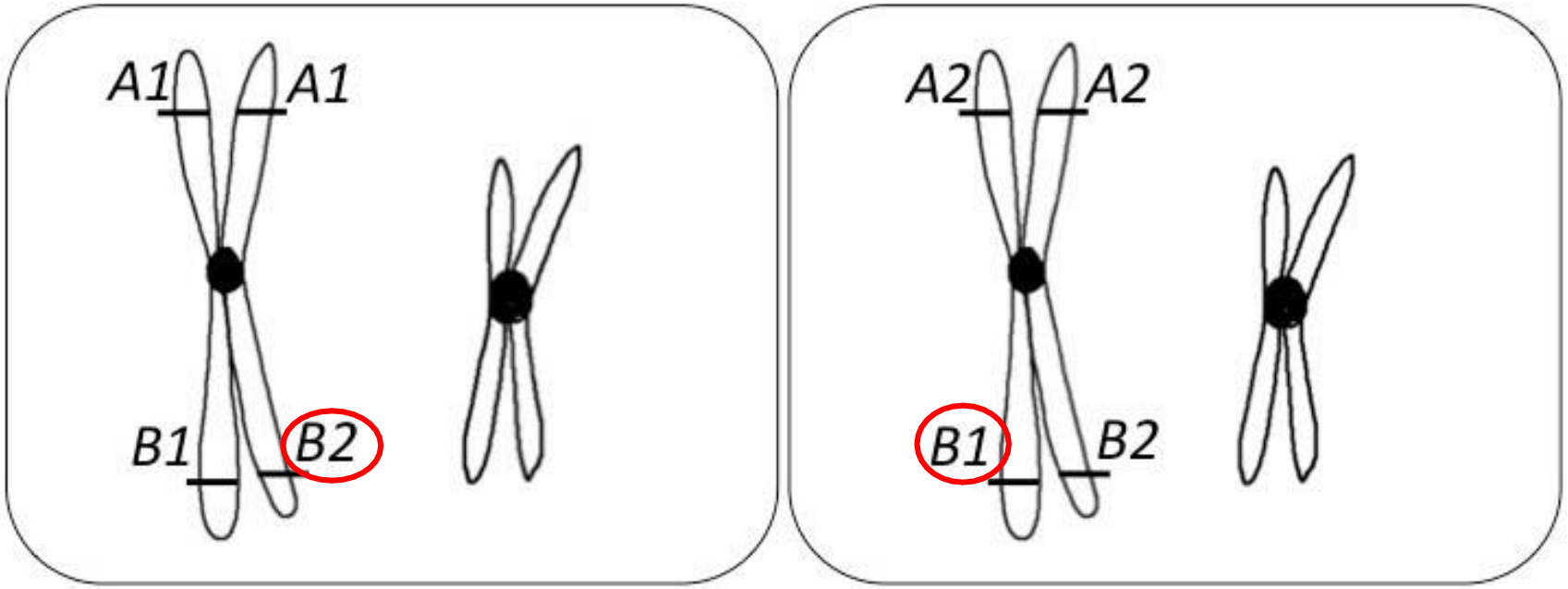
Hypothesis 2: **Loci A and B are also physically linked, but just further apart this time. Assume crossing over occurs 100% of the time.**



The inner DNA segments containing the *B1* and *B2* alleles were swapped during prophase, so those alleles are now on different chromosomes.

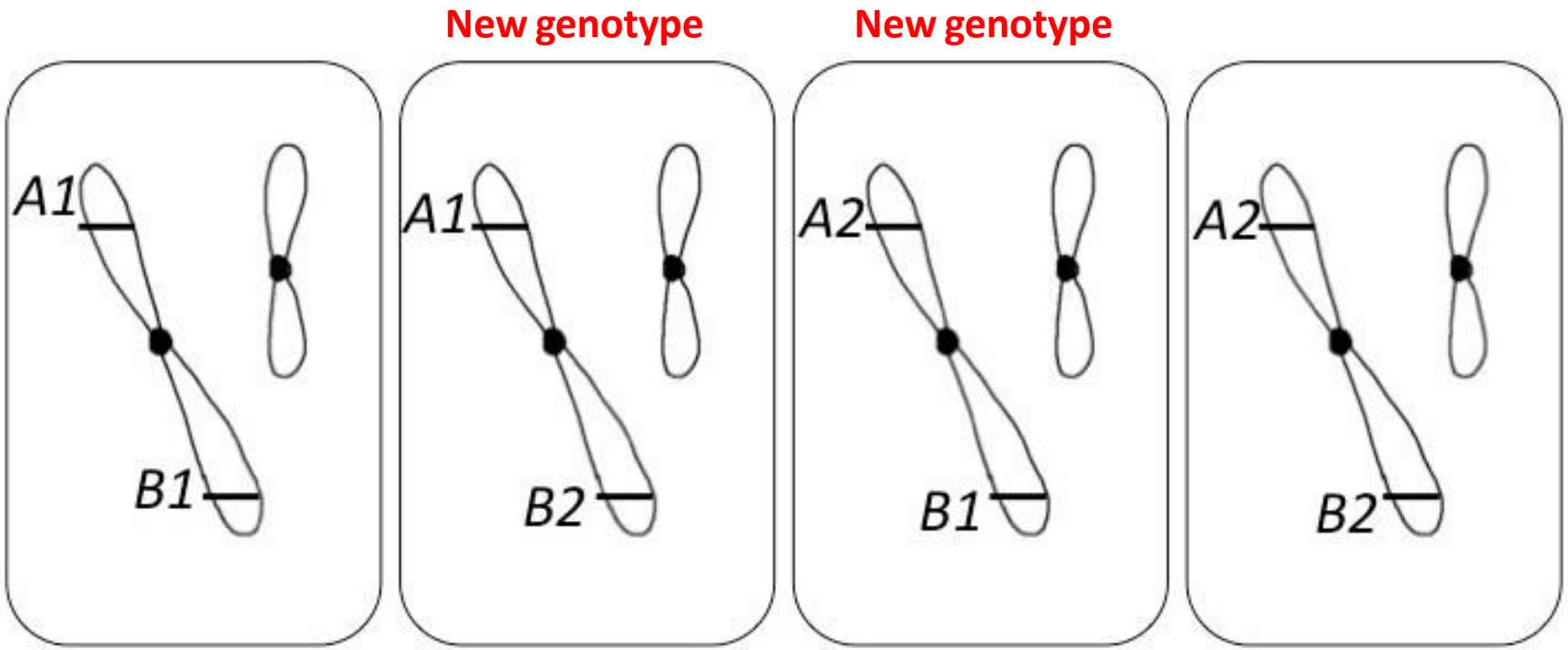
Hypothesis 2: Loci A and B are also physically linked, but just further apart this time. Assume crossing over occurs 100% of the time.

End of Telophase I



Hypothesis 2: **Loci A and B are also physically linked, but just further apart this time. Assume crossing over occurs 100% of the time.**

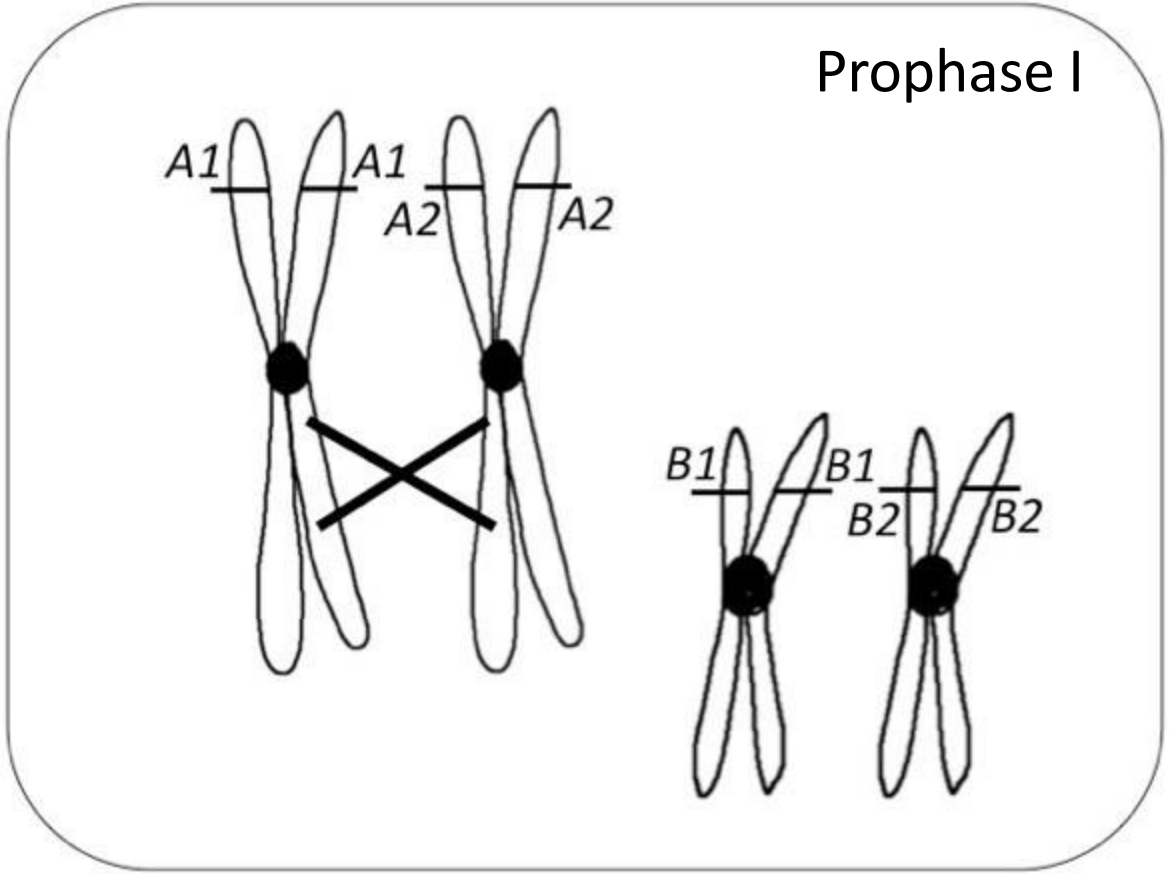
End of Telophase II



Under this hypothesis we now have both the **parental genotypes** (*A1;B1* and *A2;B2*) and **new recombinant genotypes** (*A1;B2* and *A2;B1*).

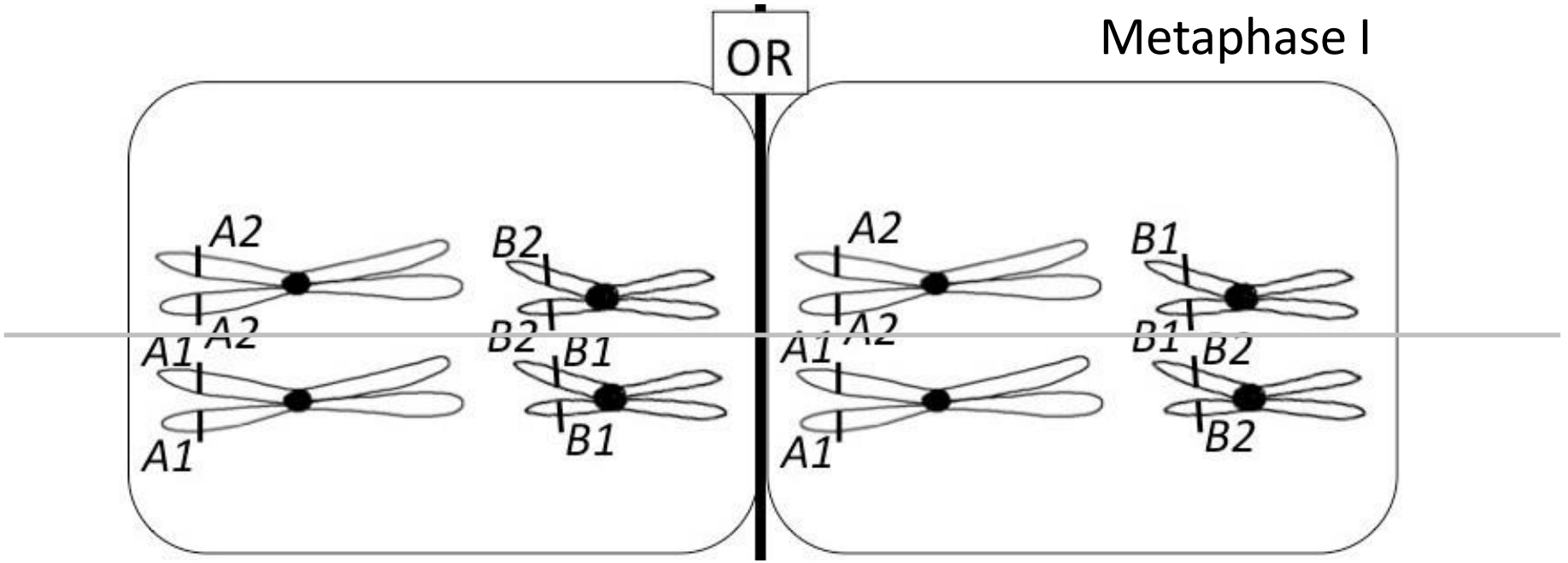
Premise: A man has the genotype *A1*/*A2*; *B1*/*B2*. He inherited the *A1* and *B1* alleles from his mother, and the *A2* and *B2* alleles from his father.

Hypothesis 3: Loci A and B are not physically linked (i.e., they are on separate non-homologous chromosomes). Assume crossing over occurs 100% of the time.



Hypothesis 3: **Loci A and B are not** physically linked **(i.e. they are on separate non-homologous chromosomes). Assume crossing over occurs 100% of the time.**

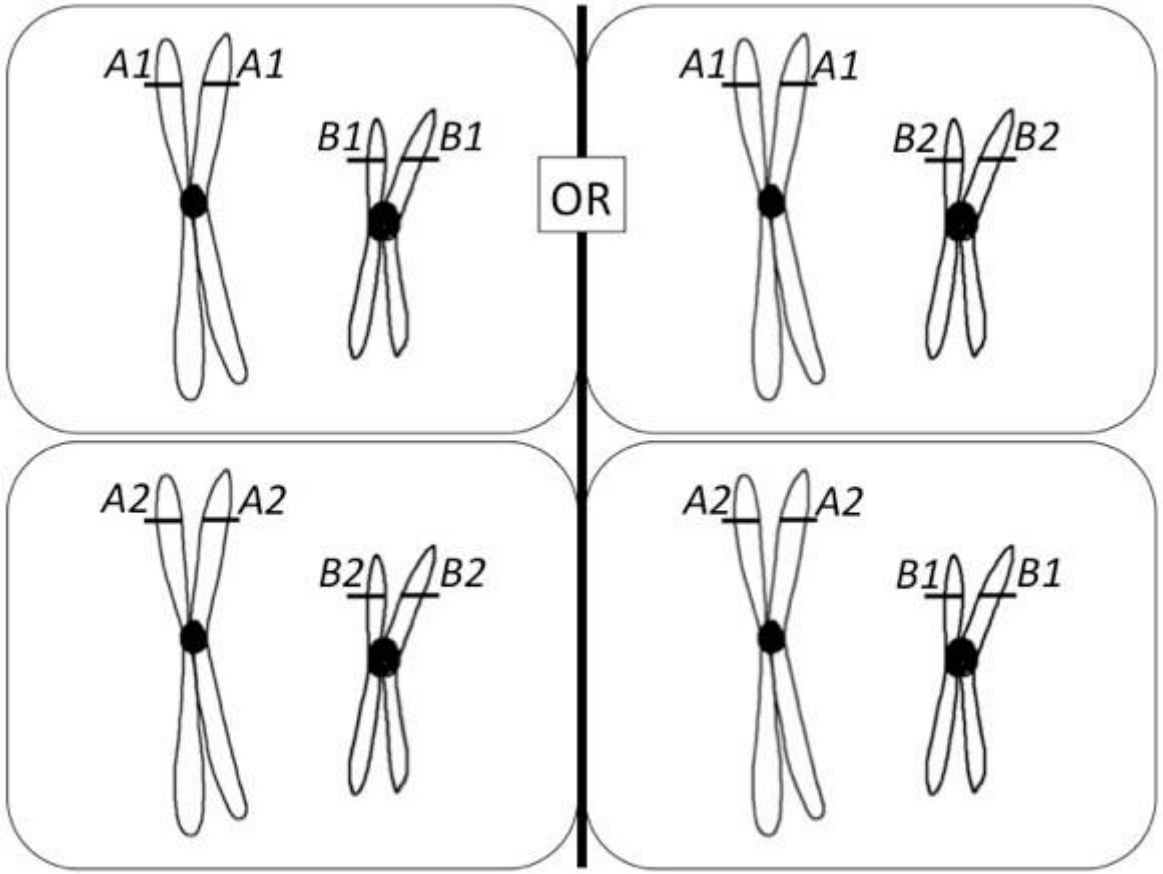
Independent assortment of chromosomes can occur as these genes (A and B) are **physically not linked.**



Hypothesis 3: **Loci A and B are not** physically linked **(i.e. they are on separate non-homologous chromosomes). Assume crossing over occurs 100% of the time.**

End of Telophase I

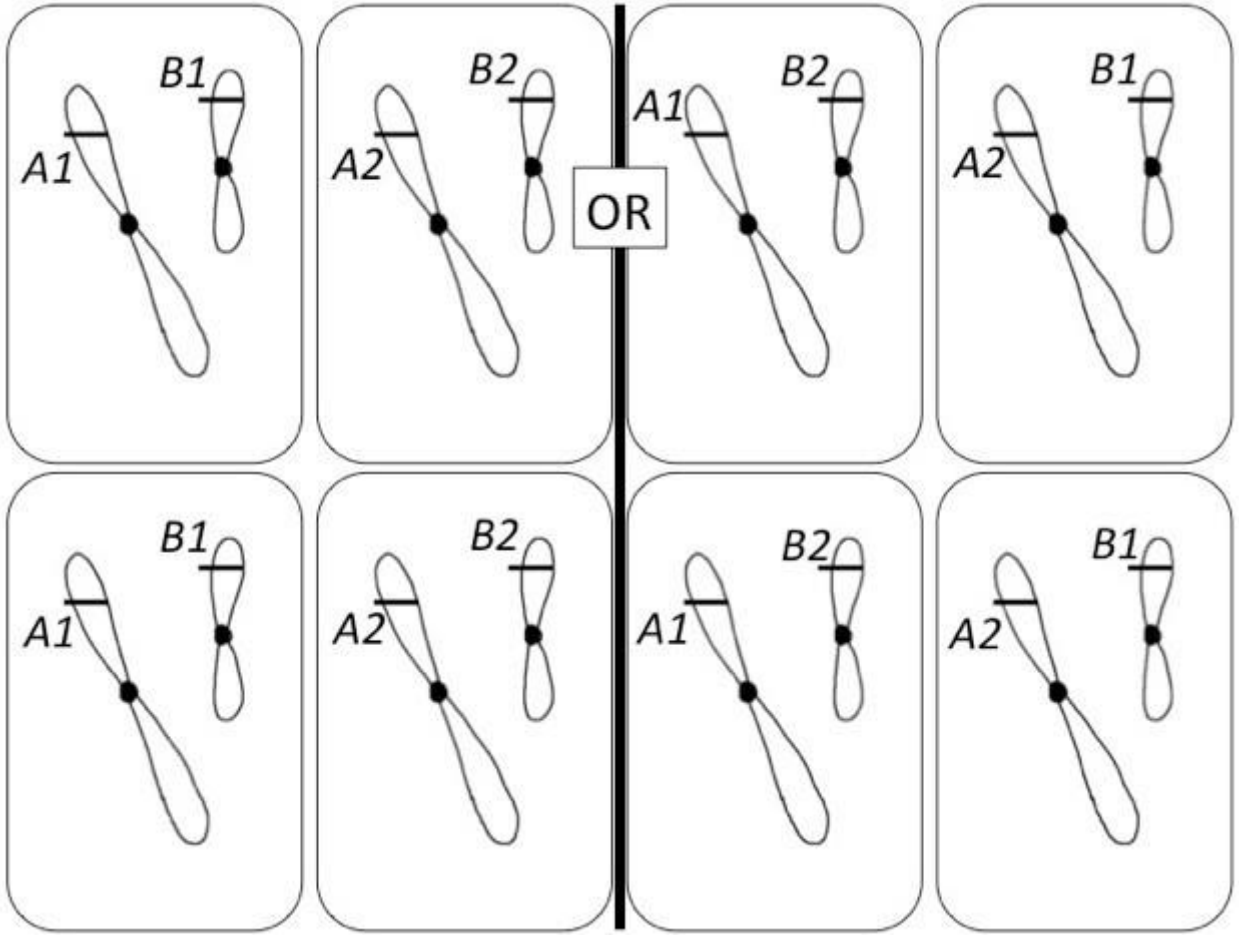
Maternal chromosomes in one daughter cell, and paternal chromosomes in the other:



OR one maternal chromosome and one paternal chromosome in each cell.

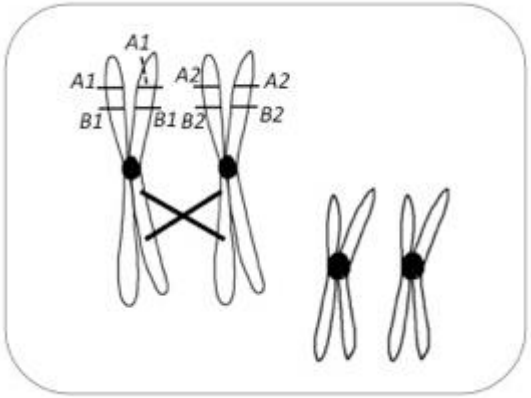
Hypothesis 3: **Loci A and B are not** physically linked **(i.e. they rae on separate non-homologous chromosomes). Assume crossing over occurs 100% of the time.**

End of Telophase II



Expected Genotype Ratios

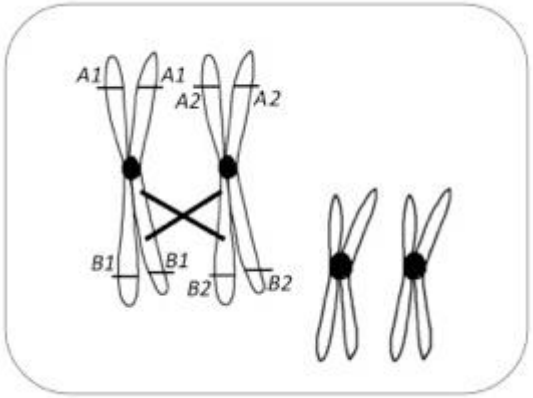
Hypothesis 1



A1; B1: 50%
A2; B2: 50%

Or a 1:1 ratio

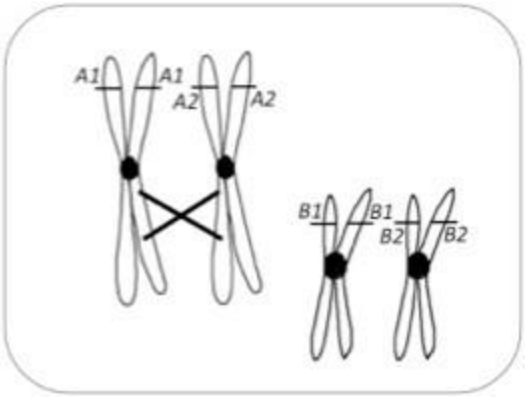
Hypothesis 2



A1; B1: 25%
A1; B2: 25%
A2; B1: 25%
A2: B2: 25%

Or 1:1:1:1 ratio

Hypothesis 3



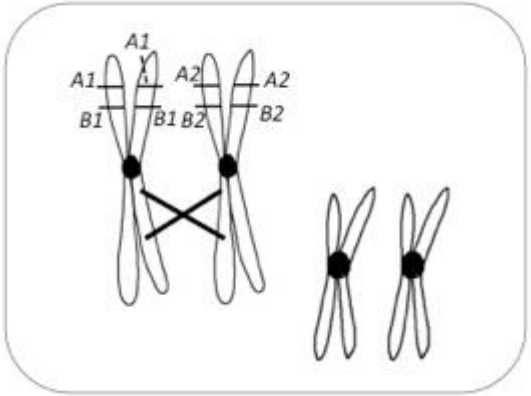
A1; B1: 25%
A1; B2: 25%
A2; B1: 25%
A2; B2: 25%

Or 1:1:1:1 ratio

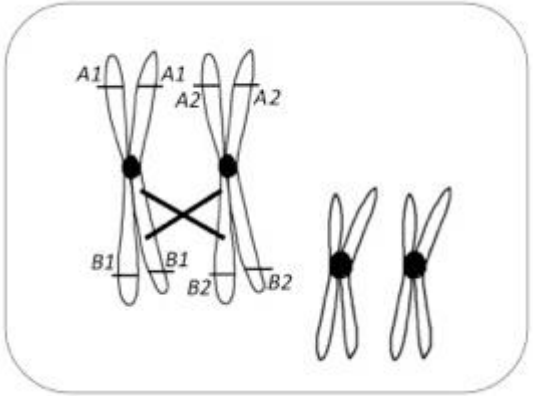
Assuming multiple cells undergo meiosis

Expected Genotype Ratios

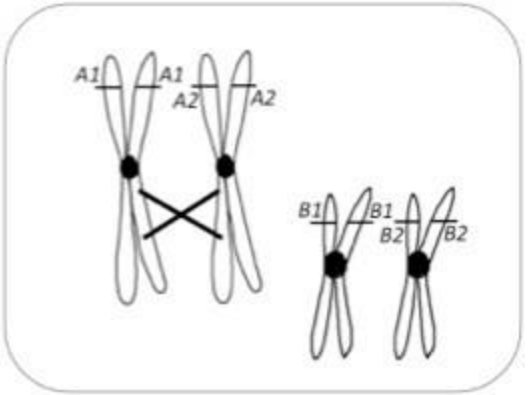
Hypothesis 1



Hypothesis 2



Hypothesis 3



Key points:

1. Physically linked alleles can be broken up by crossing over (resulting in genetic recombination) during Prophase I (Hypothesis 2)

2. Independent assortment of chromosomes can result in gametes receiving a random combination of maternal and paternal chromosomes and their alleles (Hypothesis 3)

This means that all combinations of the *A* and *B* alleles are possible with Hypotheses 2 & 3