Gopher Invitational 2019

SCIENCE OLYMPIAD

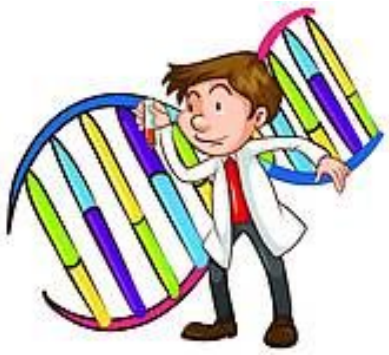
Exploring the World of Science

Heredity

Team Name: _____ Team Number: _____

This test will be divided into four parts:

- Part 1: Crosses, Pedigrees, & Karyotypes (30 pts)
- Part 2: DNA Structure & Replication (30 pts)
- Part 3: Mitosis & Meiosis (20 pts)
- Part 4: Protein Synthesis (20 pts)



Each part will be divided into two or three sections:

- General Knowledge
- Investigation (only in parts 1 and 2)
- Challenge Problems

This test has a total of 80 problems. All problems are worth 1 point each except the challenge problems which are worth 2 points each (unless stated otherwise). There are no penalties for wrong answers. Pre-selected questions will be used as tie breakers. A calculator will be helpful for some problems but none of the problems require the use of a calculator.

You may write on this test and take it apart as long as it is reassembled before you turn it in. Only the answer sheet will be graded. Feel free to raise your hand if you have any questions.

GOOD LUCK!

Part 1: Crosses, Pedigrees, & Karyotypes

General knowledge

1. A flying pig (FF) is crossed with a non-flying pig (ff). Assuming complete dominance, what percentage of their offspring will be able to fly?

2. Suppose that the two heterozygous flying pigs (Ff) had 3 progeny. What is the probability that all 3 progeny cannot fly?

3. Color-blindness is an X-linked recessive trait. A color-blind male pig mates with a normal, non-carrier female pig. Which of the following is most likely to happen?

a. All male offspring are colorblind
b. All female offspring are colorblind
c. All female offspring are carriers

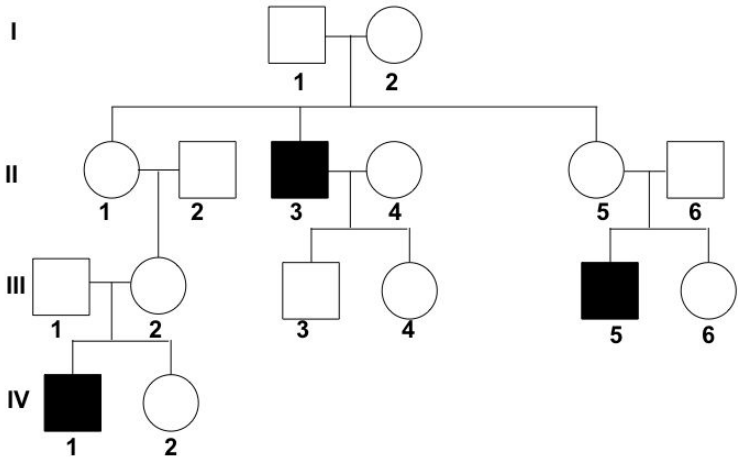
4. Roses often display incomplete dominance. If a true-breeding red rose is crossed with a white rose, all of the resulting offspring would look like

a. 
b. 
c. 
d. 

5. Which of the following are recessive genetic disorders? (choose all that apply)

a. Tay-Sachs disease
b. Down syndrome
c. Cystic fibrosis
d. Huntington's disease
e. Polydactyly

For questions 6-8, examine the pedigree shown below.



Credit: Khan Academy

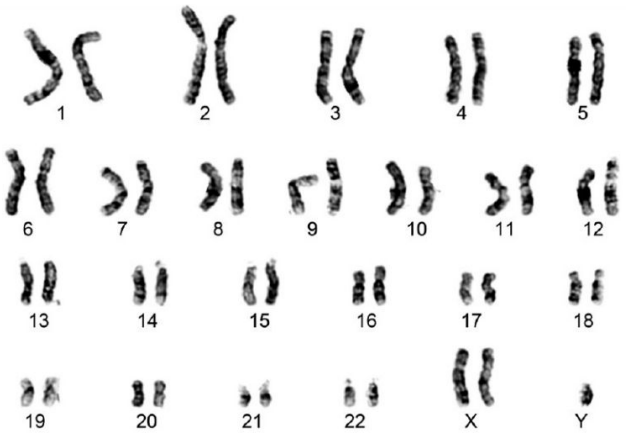
6. The trait in the pedigree exclusively affects
    a. Males
    b. Females
    c. Both males and females

7. The pedigree's mode of inheritance is most likely
    a. Autosomal dominant
    b. Autosomal recessive
    c. X-linked dominant
    d. X-linked recessive

8. What is the genotype of person I-2? (Use A/a or X^A/X^a)

For questions 9-10, examine the karyotypes shown below

Karyotype 1



Karyotype 2

Credit: University of New South Wales

9. The individual with karyotype 1 has _____ syndrome and is considered _____.
    a. Klinefelter's, male
    b. Klinefelter's, female
    c. Fragile X, male
    d. Fragile X, female

10. The individual with karyotype 2 has _____ syndrome
    a. Patau's
    b. Edward's
    c. Down

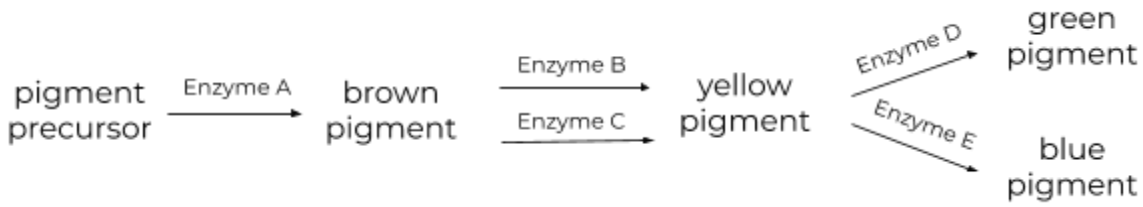
Investigation: Pass the Peas, Please

Happy belated holidays! Suppose that your mom decided to give you a pea plant for Christmas.

Initially, out of rage at this pathetic Christmas present, you decide to ignore your pea plant and it self-fertilizes. Even though your pea plant has yellow seeds, interestingly, some of its offspring have green seeds (assume that yellow seeds are dominant to green).

11. What is the seed color genotype of your pea plant? (use Y/y)
12. Your plant produced 384 offspring (a bit unrealistic). How many of the offspring are expected to have green seeds?
13. In the cross above how many of the offspring are expected to be heterozygous?

After some online research, you discover that the metabolic pathway for pea color pigment synthesis works like this:



(FYI: this is not real and completely made up)

14. If a pea plant has nonfunctional Enzyme B but every other enzyme in this pathway is functional, the plant will produce peas with which color(s)?

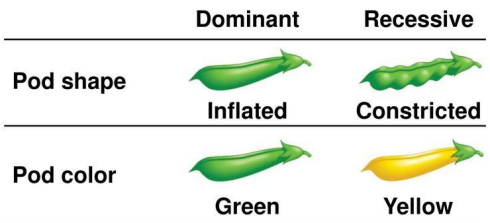
Now suppose you want blue peas to play pranks on your blueberry-loving mom. You may assume that the dominant allele for each enzyme codes for a functional enzyme while the recessive allele codes for a nonfunctional enzyme.

15. A plant with which of the following genotypes would only produce blue peas?
    a. AAbbccddEe
    b. aaBBccddEE
    c. AabbCcddEe
    d. AABbCCDdee
16. Suppose that the Y allele codes for an enzyme inhibitor. Given that yellow seed color is dominant to green, which enzyme(s) does Y inhibit?

Next, you notice that your pea plant has purple flowers. Since purple is a dominant allele, the plant's flower color genotype is either PP or Pp. Thus, you decide to perform a testcross.

17. In order to perform a testcross you would need to go a plant store and buy another pea plant with what genotype? (use P/p)
18. You perform the testcross and all of the offspring are purple. What is the flower color genotype of your Christmas present pea plant? (use P/p)

Lastly, you decide to investigate your pea plant's pod characteristics. Your pea plant is heterozygous for both pod shape and pod color. Once again, you observe the 384 offspring from your plant's self-fertilization but this time focusing on pod characteristics.



19. What fraction of the offspring are expected to have constricted green pods?
20. How many offspring are expected to have inflated yellow pods?

Challenge problems

21. Incomplete penetrance (Minions)

Suppose that minion eye number is controlled by a dominant allele (D) where two eyes is dominant to one eye. A cross between a heterozygous double-eyed minion with a single-eyed minion produced 100 offspring. The phenotype and genotype data are presented below:

By phenotype	By genotype
Double-eyed minions: 36 Single-eyed minions: 64	Heterozygous: 50 Homozygous: 50

You suspect incomplete penetrance may have caused these peculiar results. Incomplete penetrance means that not all offspring with the double-eye allele have double-eyes (usually due to interactions with other factors). We define the penetrance of a gene as

Penetrance = (# of offspring with trait) / (# of offspring with allele)

Calculate the penetrance of the double-eye allele.

22. Polygenic genes (Minions again)

Welcome to the Clash Royale universe where minions are blue and have sharp claws. Claw length is controlled by three different genes (A, B, and C) and each dominant allele (in any of the three genes) contributes 1 cm to the minion's claw length. For example, an AaBBCc minion has claws that are 4 cm longer than an aabbcc minion.

How many different claw lengths are possible in the minion population?

23. Lethal alleles

Manx cats have a very short or non-exist tail. This short tail allele (S/s) is dominant. However, a cat homozygous for the short tail allele typically does not survive past early fetal development. Thus all manx cats are heterozygous.

What is the ratio of short-tailed offspring to long-tailed offspring in a cross between two short-tailed Manx cats?

24. Sex-influenced traits

Some traits can be present in both sexes but are only expressed in one sex. An example is the beard growth allele. The beard growth allele is autosomal dominant and also requires interaction with significant amounts of testosterone in order to produce phenotypic effects. Thus, it is typically only expressed in males who have much higher testosterone levels than females.

Bob, who is heterozygous for the beard allele mates with Beth who is homozygous recessive. They have a daughter named Bonnie. Unfortunately, Bonnie has a tumor in her adrenal gland that causes abnormally high testosterone secretion. What is the probability that Bonnie will grow a beard?

25. Temperature sensitive alleles

The albino allele codes for a non-functional tyrosinase, an enzyme that catalyzes the first reaction in the synthesis of melanin (a dark pigment) from the amino acid tyrosine. Some animals with a himalayan coat color have a mutation in the albino allele that causes them to produce a temperature-sensitive tyrosinase. In other words, the tyrosinase enzyme only works at certain temperatures.

Model of tyrosinase
(shamelessly stolen from *Wikipedia*)

Consider the coloration of the himalayan kitten shown above. You'd expect that tyrosinase extracted from this kitten's cells would have the greatest activity at which temperature?

a. Above 37 °C
b. At exactly 37 °C
c. Below 37 °C

Part 2: DNA Structure & Replication

General Knowledge

1. What does DNA stand for?

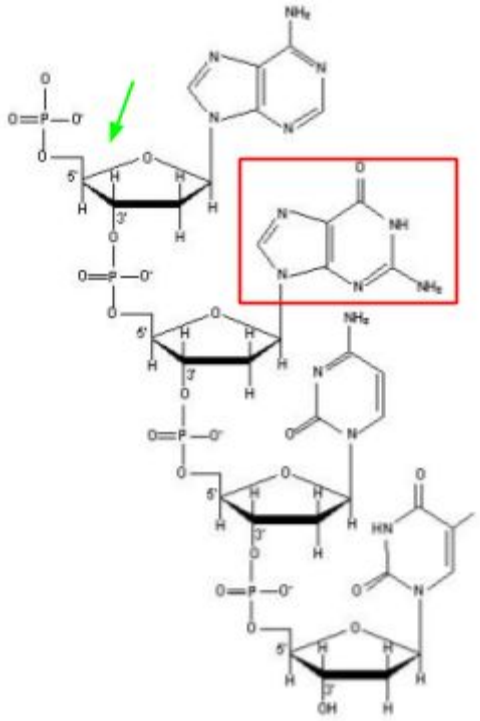
2. DNA is a polymer of many monomers called:
    a. Nucleosides
    b. Nucleotides
    c. Ribonucleotides
    d. Ribonucleosides
    e. None of the above

3. In which direction(s) can DNA polymerase replicate DNA?
    a. 5' to 3'
    b. 3' to 5'
    c. Either direction
    d. Neither direction

4. Which nitrogenous base is found in RNA but not in DNA?

5. The backbone of a DNA double helix contains
    a. Sugars and nitrogenous bases
    b. Sugars and phosphates
    c. Nitrogenous bases and phosphates

For questions 6-8, consider the following short nucleic acid:



Credit: University of Queensland

6. Is the green arrow pointing to the 3' end or the 5' end?

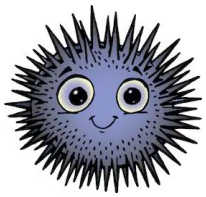
7. Name the nitrogenous base that is boxed in red.

8. Is nucleotide in the previous question a purine or a pyrimidine?

9. During DNA replication, which enzyme unwinds the DNA helix into single strands?
    a. Topoisomerase
    b. Single-strand binding proteins
    c. Primase
    d. Helicase

10. During DNA replication, which enzyme stabilizes single-stranded DNA?
    a. Topoisomerase
    b. Single-strand binding proteins
    c. Primase
    d. Helicase

Investigation: *C. urchinis*



Suppose you have decided to run away from MinneSNOWta to California, where the weather is always nice. You go scuba diving in the Pacific Ocean and discover a new species of sea urchin! You assign it to the binomial *C. urchinis*.

The genome of *C. urchinis* is sequenced.

11. You found that 18% of *C. urchinis*'s genome is adenine. What percent is thymine?
12. What percent is cytosine?
13. Who first discovered the base pairing rules for DNA?

Later, you make a groundbreaking discovery that *C. urchinis* contains 2 novel nitrogenous bases in its DNA! In addition to the usual adenine, cytosine, guanine, and thymine, it also has seanine and urchinine which pair together (Hmmm... *C. urchinis* might be an alien from another planet). During the initial sequencing of the *C. urchinis* genome, urchinine was mistaken to be adenine.

14. Given that 4% of the *C. urchinis* genome is urchinine, now what percent is adenine?
15. Now what percent is cytosine?

Later, you find that each somatic cell in *C. urchinis* has 8 chromosomes. Each chromosome has an average of 2 million DNA base pairs. The longest chromosome has 4 million base pairs while the shortest chromosome has 1 million base pairs

16. How many total base pairs does each somatic cell of *C. urchinis* have?
17. Assume the *C. urchinis* can replicate its DNA at 100 nucleotides per second. How long will it take to duplicate the shortest chromosome in hours?
18. Assuming that all chromosomes in a *C. urchinis* cell can be duplicated at the same time (each at 100 nucleotides per second), how long will it take one somatic cell to duplicate all of its DNA in hours?

Unfortunately, you later discover that seanine and urchinine are rare nucleotides and thus it takes longer to replicate DNA sequences that contain these bases. Based on laboratory experiments, you found that a sequence of only seanine and urchinine is duplicated at 20 nucleotides per second. Assume that all chromosomes have the same composition of seanine and urchinine.

19. How many seanine bases does the shortest chromosome of *C. urchinis* have?
20. How long will it take to duplicate the shortest chromosome?

Challenge Questions

21. Melting temperature

First of all, DNA melting does not mean turning DNA into a liquid from a solid, it simply means separating the two strands of the double helix (very important for lots of experiments involving DNA!). The temperature at which this occurs varies based on the composition of the DNA strand. The adenine-thymine pair bond involves two hydrogen bonds while the cytosine-guanine pair has three. More hydrogen bonds require higher temperatures to melt.

Arrange the following nucleotide sequences in order of increasing melting temperature

a. 3'-TATATATATATA-5'
b. 3'-CTAGCTAGCTAG-5'
c. 3'-CCGGCCGGCCGG-5'
d. 3'-AATTCCGGAATT-5'

22. Technical details

I. DNA is composed of a phosphate group, a sugar, and a nitrogenous base. What type of sugar is found in DNA? (1 point)

a. Glucose
b. Ribose
c. Deoxyribose
d. Deoxyglucose
e. Dextrose

II. What type of bond is found in the DNA backbone? (1 point)

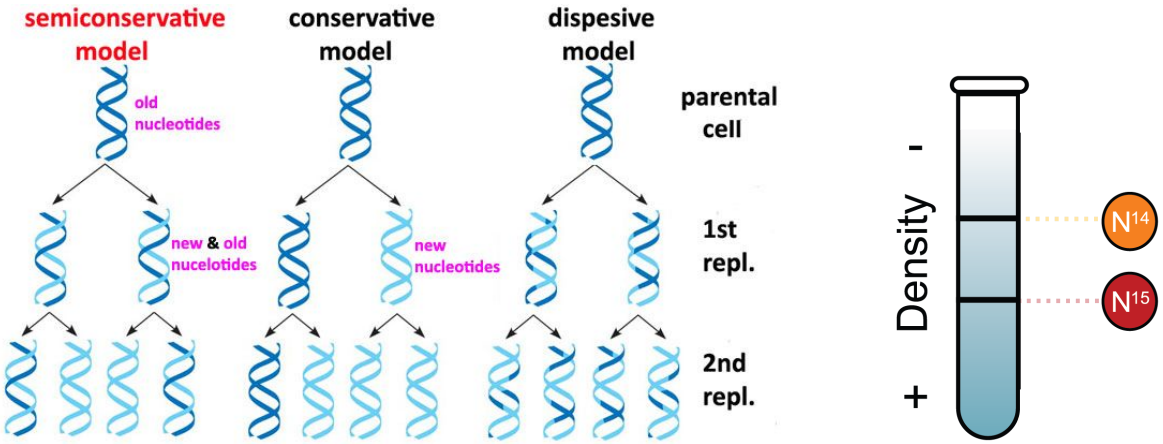
a. Hydrogen bond
b. Ionic bond
c. Phosphoester bond
d. Phosphodiester bond

23-24. Meselson-Stahl experiment

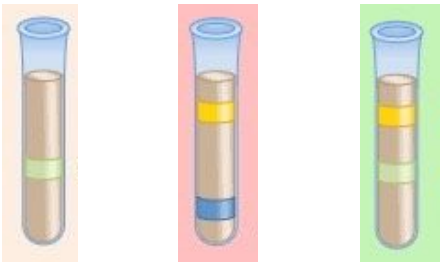
The three models of DNA replication are illustrated on the next page. DNA replication is known to follow the semiconservative model but initially, scientists had to rule out other models such as the conservative and dispersive models. In the Meselson-Stahl experiment, often considered "the most beautiful experiment in biology", the semiconservative model of DNA replication was confirmed.

The experiment started by growing *E. coli* on a medium containing a heavy isotope of nitrogen (^{15}N). Thus, the *E. coli* contained "heavy" DNA. The *E. coli* were then transferred to a medium containing the normal isotope of nitrogen (^{14}N) so that newly replicated DNA would be "light".

After one or two rounds of DNA replication, Meselson



and Stahl isolated DNA from *E. coli* and used density gradient centrifugation to separate the DNA strands by weight. Density gradient centrifugation involves spinning the DNA sample in a test tube containing a gradient of cesium chloride. Heavier DNA will sink further down the test tube while lighter DNA remains near the top. The results of a density gradient centrifugation after one round of DNA replication are shown in Test Tube A.



Test Tube A | Test Tube B | Test Tube C

23. Which model of DNA replication is not consistent with the results shown in Test Tube A?

24. Since DNA replication is semiconservative we would expect that DNA extracted from E. coli after two rounds of DNA replication would produce the results shown in which test tube?

25. Okazaki fragments

Bob the biochemist is trying to synthesize DNA *in vitro* (in a test tube). He adds every enzyme and molecule involved in DNA replication that he can remember. Bob adds some DNA and replication did occur. However, the replicated DNA contained a normal strand paired with numerous fragments of DNA. Which enzyme did Bob forget to add?

Credit: Campbell Biology

Part 3: Mitosis & Meiosis

General Knowledge

1. Mitosis results in _____ cells
    a. 2 genetically identical
    b. 2 genetically unique
    c. 4 genetically identical
    d. 4 genetically unique

2. During which phase of mitosis do sister chromatids separate?
    a. Prophase
    b. Metaphase
    c. Anaphase
    d. Telophase

3. Which stage of mitosis is the shortest?
    a. Prophase
    b. Metaphase
    c. Anaphase
    d. Telophase

4. Which of the following proteins is involved cleavage furrow formation?
    a. Actin
    b. Dynein
    c. Kinesin
    d. Tubulin

5. *S. aureus*, a type of prokaryote, reproduces using
    a. Mitosis
    b. Meiosis
    c. Duplication
    d. Binary fission

6. The three phases of interphase (in order) are
    a. G_1 G_2 S
    b. S G_1 G_2
    c. G_1 S G_2

7. During which phase of meiosis does crossing over occur?
    a. Prophase I
    b. Prophase II
    c. Metaphase I
    d. Metaphase II

8. Through a microscope, you observe a cell plate beginning to develop across the middle of a cell and nuclei forming on either side. This cell is mostly likely
    a. An animal cell in cytokinesis
    b. An animal cell in metaphase
    c. A plant cell in cytokinesis
    d. A plant cell in metaphase

Credit: Campbell Biology

9. Homologous chromosomes pair up during
    a. Mitosis
    b. Meiosis I
    c. Meiosis II

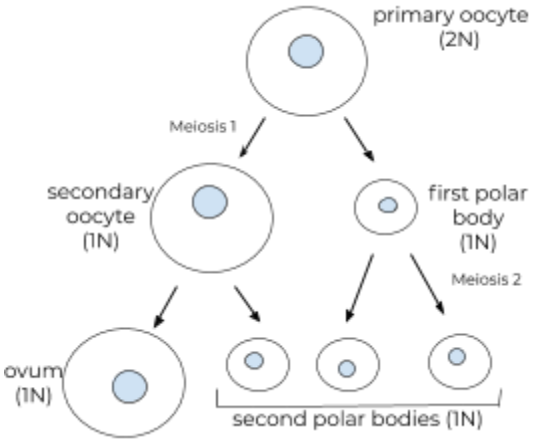
10. Cells that have just completed meiosis I are
    a. Haploid and duplicated
    b. Haploid and unduplicated
    c. Diploid and duplicated
    d. Diploid and unduplicated

Challenge Problems

11. Oogenesis

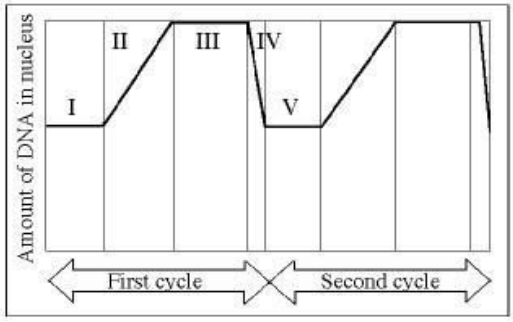
A woman ovulates about 300 eggs (ovum, pl. ova) in her lifetime. Oogenesis is the formation and maturation of an ovum. Oogenesis involves meiosis with unequal cell division. Each division of an oocyte (ovum precursor) produces a large cell and smaller polar body.

Consider the illustration of oogenesis on the right. How many polar bodies will a woman produce in her lifetime?



12. DNA during Cell Division

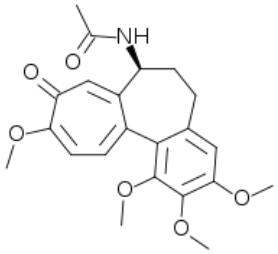
The graph below illustrates the amount of DNA present in a cell as a function of time. Two cell divisions are shown. Different time intervals are labeled with roman numerals.



I. The S phase occurs during which interval? (1 point)
II. Mitosis occurs during which interval? (1 point)

13. Colchicine

Colchicine is a chemical extracted from *Colchicum autumnale* (meadow saffron). Colchicine inhibits cell division by preventing the disassembly of tubulin. Tubulin is the main constituent of microtubules which form the spindle apparatus.

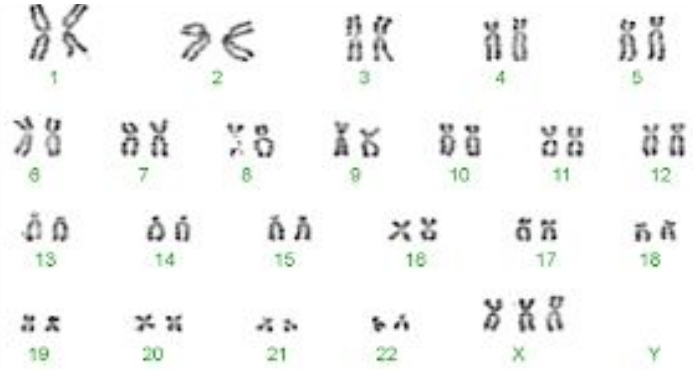


Colchicine Structure
(shamelessly stolen from *Wikipedia*)

A batch of cells that have been induced to divide are treated with colchicine. Upon examination of these cells under a microscope, you would expect that most of the cells would be arrested in which phase of mitosis?

14. Triple X syndrome

Triple X syndrome affects about 1 in 1,000 females and is caused by a nondisjunction during gamete formation in either the mother or father. A nondisjunction is when a pair of homologous chromosomes or sister chromatids fail to separate during cell division. A karyotype of a person with Triple X syndrome is shown below.



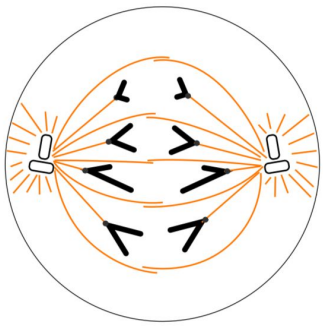
Credit: Elsevier Masson

Where could nondisjunction NOT have occurred?

a. Meiosis I in father
b. Meiosis II in father
c. Meiosis I in mother
d. Meiosis II in mother

15. Mitosis or Meiosis?

The drawing below illustrates a stage of cell division. You may assume that the cell has diploid number 2n = 8 and that relative chromosome lengths are accurate.



Credit: IBO 2013 Theory Part A

This cell is undergoing

a. Mitosis
b. Meiosis I
c. Meiosis II

Part 4: Protein Synthesis

General Knowledge

1. What is the general flow of information in a cell?
    a. RNA → DNA → protein
    b. DNA → protein → RNA
    c. Protein → RNA → DNA
    d. DNA → RNA → protein

2. Which enzyme catalyzes transcription?
    a. DNA polymerase
    b. RNA polymerase I
    c. RNA polymerase II
    d. RNA polymerase III

3. Which of the following is NOT directly involved in translation?
    a. DNA
    b. mRNA
    c. tRNA
    d. Ribosomes

4. A 300-base-pair-long mRNA will code for a polypeptide with how many amino acids?
    a. 100
    b. 200
    c. 300
    d. 400

5. How many subunits does a ribosome have?
    a. 1
    b. 2
    c. 3
    d. 4

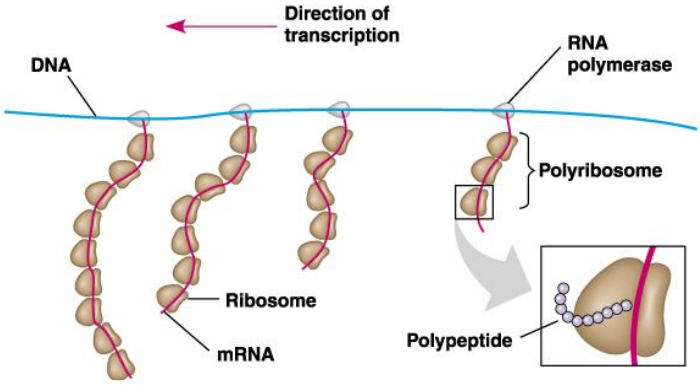
6. Ribosomal subunits are synthesized is which region of the cell?
    a. Nucleus
    b. Nucleolus
    c. Cytoplasm
    d. Other ribosomes

7. Ribosomes can be found in all of the following regions of a cell except
    a. Smooth endoplasmic reticulum
    b. Rough endoplasmic reticulum
    c. Mitochondria
    d. Chloroplasts
    e. Cytosol

8. In eukaryotes, the initiator tRNA always carries which amino acid?
    a. Leucine
    b. Valine
    c. Methionine
    d. Histidine

9. Which of the following is involved in protein folding?
    a. Ubiquitin
    b. Proteasomes
    c. Chaperonins
    d. Ribosomes

10. The phenomenon of simultaneous transcription and translation is shown below.



Credit: Campbell Biology

This phenomenon is most likely to occur in:
    a. Only eukaryotic cells
    b. Only prokaryotic cells
    c. Either eukaryotic or prokaryotic cells
    d. Neither eukaryotic or prokaryotic cells

Challenge problems

11-12. DNA Mutations

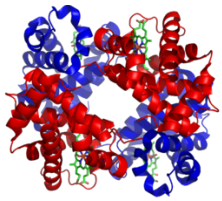
Consider the following DNA sequence: 5'-ATGACCGACTTGAAAGGGACC-3'
You may assume that this DNA sequence is a coding strand. Several similar sequences containing various mutations are shown below:

a. 5'-ATGACCGACTTGAAAACC-3'
b. 5'-ATGACCGACTTAAAAGGGACC-3'
c. 5'-ATGCCGACTTGAAAGGGACC-3'
d. 5'-ATGACCACCGACTTGAAAGGGACC-3'
e. 5'-ATGACCGACTTCAAAGGGACC-3'

11. Which mutated DNA sequence contains a missense mutation?
12. Which mutated DNA sequence is most likely to produce a nonfunctional protein?

13. Hemoglobin

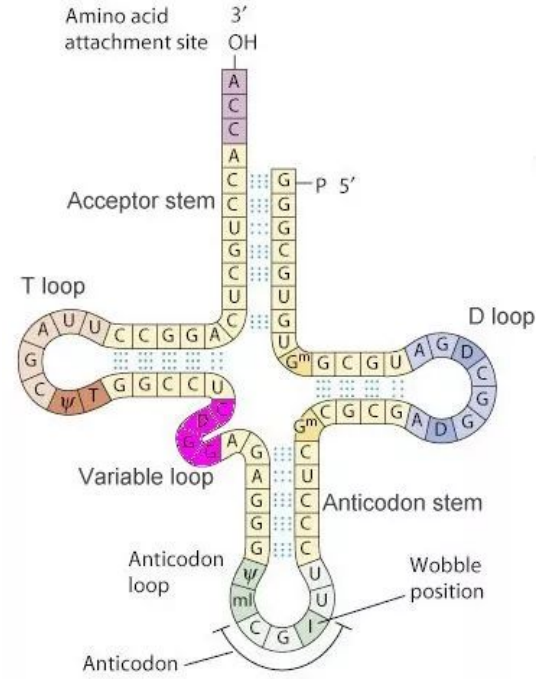
Hemoglobin is a protein found in red blood cells that transports oxygen in blood. The mRNA of hemoglobin has a lifetime of 120 days. Suppose that an erythroblast (a developing red blood cell that contains a nucleus) synthesizes 20 hemoglobin mRNAs per day. How many hemoglobin mRNAs are present in the steady state of an erythroblast?



Hemoglobin Structure
(shamelessly stolen from *Wikipedia*)

14. Transfer RNA

Which amino acid would you expect the tRNA shown below to carry? (Hint: pay attention to 5'-3' directionality and consider where codons and anticodons are located)



15. Polypeptides

Which of the following mRNA sequences could potentially code for the polypeptide Met-Arg-Ser-Thr-Cys? (Hint: use the codon chart on your answer sheet)

a. 5'-AUGCGUUCUAAUUGU-3'
b. 5'-AUGGGCUCUACUUGC-3'
c. 5'-AUGCGCUUAACUUGC-3'
d. 5'-AUGCGCUCGACAUGU-3'