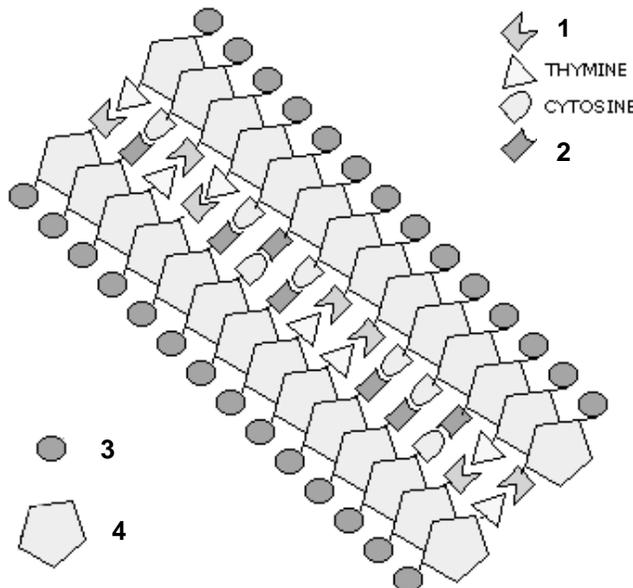


STATION SET -- DO NOT WRITE ON THIS SHEET.
Write only on provided scrap paper or your answer sheet.

STATION 1: Nucleic acids

QUESTIONS 1-4: The following cartoon diagrams some features of a particular nucleic acid. Fill in the name of the indicated component. You must be specific to get credit.



- 5) What type of nucleic acid is depicted above? Standard abbreviation okay.
- 6) How many hydrogen bonds form between 1 and thymine?
- 7) How many hydrogen bonds form between cytosine and 2?
- 8) You take an optical density reading of a DNA sample, but it is too concentrated to give you an accurate reading. Curses! You take 1 μL of the DNA sample and dilute it with 19 μL of distilled water. You then take a reading of the DNA on the spectrophotometer and it gives you an OD reading of 0.200. Written above the spectrophotometer is this conversion factor: 1 OD of dsDNA = 50 $\mu\text{g/mL}$ of DNA. What was the concentration of your original DNA sample?
- 9) An RNA-dependent RNA polymerase is likely to be present in the virion of a
- (A) DNA virus that multiplies in the cytoplasm
 - (B) DNA virus that multiplies in the nucleus
 - (C) minus-strand RNA virus
 - (D) plus-strand RNA virus
 - (E) transforming virus

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- 10) In *E. coli*, the inability of the *lac* repressor to bind an inducer would result in
- (A) no substantial synthesis of β -galactosidase
 - (B) constitutive synthesis of β -galactosidase
 - (C) inducible synthesis of β -galactosidase
 - (D) synthesis of inactive β -galactosidase
 - (E) synthesis of β -galactosidase only in the absence of lactose
- 11) In humans, the Barr body is an
- (A) active X chromosome in females
 - (B) active X chromosome in males
 - (C) inactive Y chromosome in males
 - (D) inactive Y chromosome in females
 - (E) inactive X chromosome in females

QUESTIONS 12-13: The DNA from the bacteriophage ϕ X174 has a base composition of 25% A, 33% T, 24% G, and 18% C.

- 12) How is this base composition different from what is usually expected?
- 13) What is the most likely explanation for this base composition?
- 14) A mutant of *E. coli* with a heat-sensitive DNA ligase (25°C permissive, 37°C nonpermissive) has been used to show that DNA synthesis is discontinuous. Examination of DNA replication in the presence of [³H]-thymidine in the mutant would demonstrate which of following?
- (A) The accumulation of short segments of unlabeled DNA at 25°C and at 37°C
 - (B) The accumulation of short segments of unlabeled DNA at 25°C but not at 37°C
 - (C) The accumulation of short segments of radioactive DNA at 37°C but not at 25°C
 - (D) The accumulation of short segments of radioactive DNA at 25°C but not at 37°C
 - (E) The incorporation of short fragments of radioactive DNA into longer ones at 25°C and at 37°C
- 15) All of the following statements are true about damage by ultraviolet light to DNA in living cells EXCEPT:
- (A) The damage blocks normal DNA replication.
 - (B) The most damaging wavelength is about 260 nm.
 - (C) Covalent bonds are formed that join neighboring pyrimidines.
 - (D) Neighboring phosphodiester bonds are cleaved.
 - (E) Most cells can synthesize proteins capable of repairing UV damage.

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16) Which of the following mRNA molecules would form the most stable stem-loop structure?

- (A) 5'... GGCUU.....UUCGG..... 3'
- (B) 5'... GGCUU.....AAGCC..... 3'
- (C) 5'... GGCUU.....GGCUU..... 3'
- (D) 5'... GGCUU.....CCGAA..... 3'
- (E) 5'... AAGCC.....AAGCC..... 3'

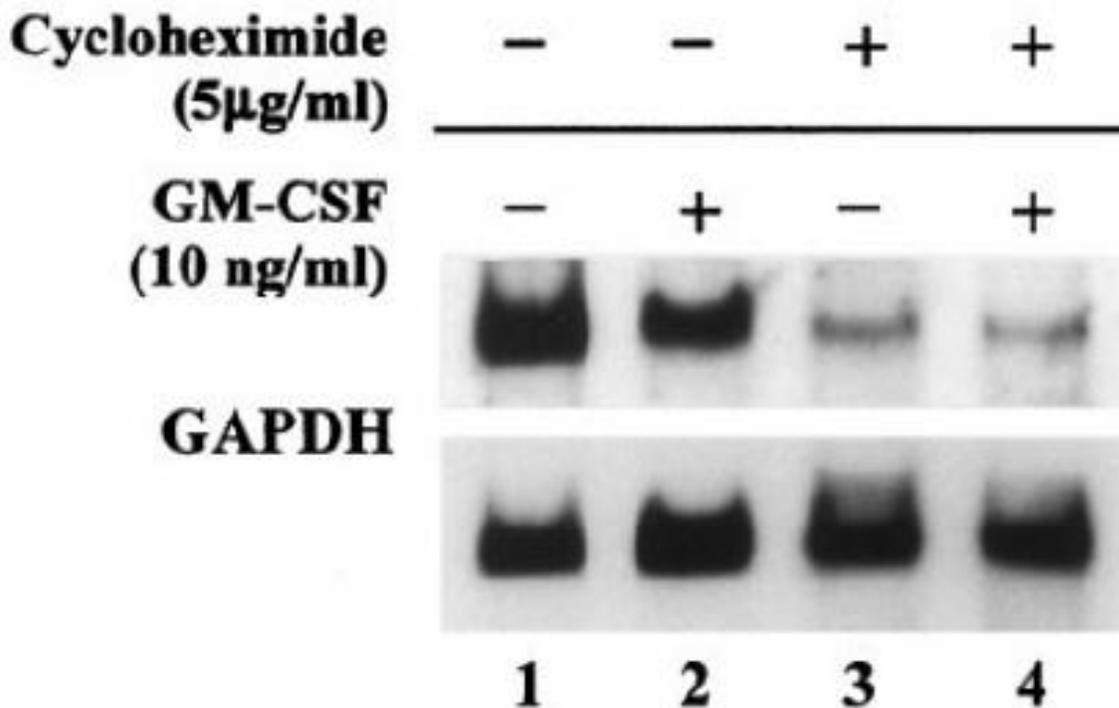
17) A cell biologist introduced radio-labeled thymine into *E. coli* cell culture medium for hundreds of generations, then washed cells well and swapped them into a medium that contained non-radioactive thymine. Hypothetically, how many generations would it have taken for over 90% of the cells in the culture to no longer contain radioactive chromosomal DNA?

18) Explain your answer to question 17. You may use a diagram (that's why there are no lines on the answer sheet), but it must be sufficiently annotated so your reasoning can be followed.

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STATION 2: Gene expression

QUESTIONS 1-4: A mystery gene was being studied; we'll call it gene E for short. Bone marrow cells were treated as indicated in the figure with + indicating the presence of the compound listed and – indicating the absence of the compound. GAPDH is a “housekeeping gene,” which means scientists already know its transcription is unaffected by any of the treatments. GM-CSF is a growth factor normally secreted in the bone marrow.



- 1) Estimate a relative amount of gene E mRNA in this northern blot for lanes 1 – 4. Use percentages. The first one has been done for you on the answer key.
- 2) Describe the purpose of including a probe for GAPDH in this experiment. (In other words, explain what it tells us about the reliability of your answer for the previous question.)
- 3) What conclusions can we draw about gene E's mRNA production in the presence of GM-CSF? You must reference specific lanes in your answer and describe your reasoning.
- 4) Cycloheximide is a ribosomal inhibitor that blocks translation. What conclusions can we draw about gene E's mRNA production from the data involving cycloheximide?

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5) If the genetic code consisted of four bases per codon rather than three, the maximum number of unique amino acids that could be encoded would be

- (A) $16-1=15$
- (B) $64-1=63$
- (C) $128-1=127$
- (D) $256-1=255$
- (E) $512-1=511$

6) Explain your reasoning for your answer to question 5.

7) Genes *a*, *b*, and *c* are widely spaced in the bacterial genome. Transducing viral phage from an $a^+ b^+ c^+$ bacterium were used to infect a culture of $a^- b^- c^-$ cells, and b^+ transductants were selected. Which of the following best describes the predicted genotypes of these transductants?

- (A) Mostly $a^- b^+ c^-$
- (B) Mostly $a^- b^+ c^+$
- (C) Mostly $a^+ b^+ c^+$
- (D) Mostly $a^+ b^+ c^-$
- (E) $a^+ b^+ c^+$ and $a^- b^+ c^-$ in equal frequencies

8) Explain your reasoning for your answer to question 7.

9) Consider the average *in vivo* turnover rates for proteins, DNA, and mRNA. Which of the following orders best describes the turnover rate from fastest (shortest average lifetime) to slowest (longest average lifetime)?

- (A) mRNA > DNA > proteins
- (B) mRNA > proteins > DNA
- (C) Proteins > mRNA > DNA
- (D) Proteins > DNA > mRNA
- (E) DNA > mRNA > proteins

The next two questions pertain to an RNA molecule with the following sequence:
AUG CCC AAA* CAG UGC GAG CUU ACG

10) Would the protein produced from this mRNA sequence change if the A indicated by * is changed to U? If yes, indicate how.

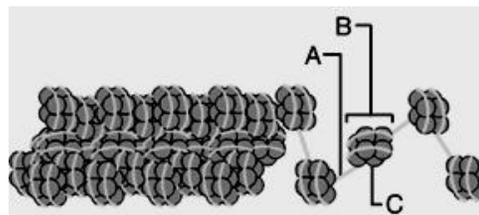
11) Will the protein produced be changed if a C is added just prior to the A*? If yes, indicate how.

12) A geneticist isolates a gene for a specific trait she is studying. She also isolates the corresponding mRNA. Under comparison, the mRNA is found to contain 1,000 fewer bases than the DNA sequence. Did the geneticist isolate the wrong DNA? Explain your answer.

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- 13) Products made from microRNA genes:
- (A) bind directly to DNA and alter its transcription
 - (B) bind directly to mRNA and alter its translation
 - (C) bind directly to ribosomes and alter their ability to make protein
 - (D) none of the above
- 14) You want to perform a DNase-I protection experiment to see where binding sites for regulatory transcription factors for the mouse calmodulin gene are located. What would you use for a probe?
- (A) The calmodulin gene coding sequence.
 - (B) A DNA fragment including about 100 bp on either side of the promoter.
 - (C) A DNA fragment containing several thousand bp upstream of the promoter, one small piece at a time.
 - (D) Any of these would be useful probes.
 - (E) None of these would be useful probes.
- 15) Methylation of CpG islands
- (A) Enhances binding of regulatory transcription factors.
 - (B) Prevents activation of enhancers.
 - (C) Prevents binding of chromatin remodeling proteins.
 - (D) Interferes directly with RNA polymerase binding.
- 16) What would be the effect of a mutation in the *lacI* gene that blocked binding of the *lac* repressor to the operator?
- (A) The *lacZYA* genes would be repressed by lactose.
 - (B) The genes would be inducible by lactose.
 - (C) The *lacZYA* genes would not be expressed.
 - (D) The *lacZYA* genes would be expressed constitutively.
 - (E) None of the above.
- 17) In the *lac* and *trp* operators, the repressor is said to be an allosteric molecule because
- (A) It induces the production of lactose or tryptophan.
 - (B) Interaction with another molecule causes conformational change in the repressor's active site.
 - (C) It stimulates the mutation of these operons
 - (D) It diminishes the transcription of the related gene structure.
 - (E) It represses the production of lactose or tryptophan.
- 18) Where in this diagram does RNA polymerase attach?

- (A) A only
- (B) B only
- (C) C only
- (D) two of the above
- (E) A, B, and C



STATION 3: Modern lab techniques

1) When bacteria produce mammalian proteins, cDNA is used rather than genomic DNA. Which of the following is the best explanation?

- (A) It is easier to clone cDNA than genomic DNA of comparable size.
- (B) It is easier to clone RNA than DNA.
- (C) It is not possible to clone the entire coding region of the gene.
- (D) Most eukaryotic genes have introns that cannot be removed in bacteria.
- (E) Most eukaryotic gene promoters do not function in bacteria.

QUESTIONS 2-6: In no more than one sentence each, summarize the laboratory techniques listed below.

- 2) western blotting
- 3) northern blotting
- 4) *in situ* hybridization
- 5) polymerase chain reaction
- 6) electroporation

7) Which of the techniques of questions 2-6 would be useful to demonstrate that particular RNAs are important for development are located in distinct regions of the *Drosophila* embryo?

8) A microarray is a large collection of specific DNA oligonucleotides spotted in a defined pattern on a microscope slide. What is the most common experiment that can be done with such a tool?

- (A) Predicting the presence of specific metabolites in a cell
- (B) Comparing newly synthesized nuclear RNA with cytoplasmic RNA to locate introns
- (C) Comparing RNA produced under two different physiological conditions to understand patterns of gene expression
- (D) Comparing proteins produced under two different physiological conditions to understand their function
- (E) Evaluating the linkage relationships of genes

9) Two protein sequences are compared by BLAST and produce an e value of e^{-100} . This e value most likely signifies which of the following about the genes encoding these two proteins?

- (A) They function in the same tissue.
- (B) They have unrelated functions.
- (C) They are descended from a common ancestor.
- (D) They encode proteins that form a dimeric complex.

10) What is one reason why restriction digests of DNA result in unique banding patterns after gel electrophoresis?

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QUESTIONS 11-16: The following is the DNA sequence of the wild type allele and flanking region of Gene Z that you want to amplify using the polymerase chain reaction.



11) If you amplify a DNA sequence through PCR, what is one reaction component that you would absolutely need? Briefly state the function of this component.

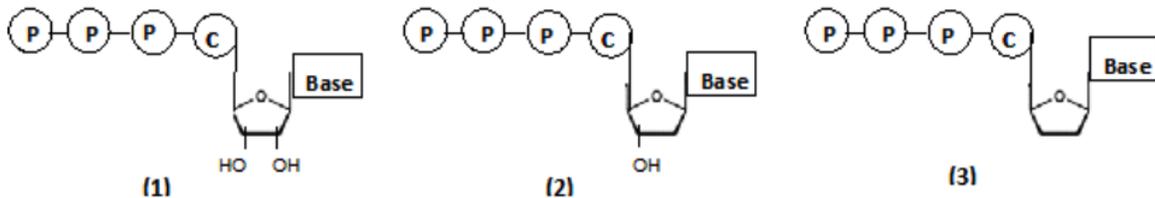
12) What is another reagent you would absolutely need? Briefly state its function.

13) From the options below, which you would use for this PCR reaction?

- (A) 5' TACTACTTATACTTTC 3' and 3' GTAAACCGCGCATTAG 5'
- (B) 5' CTCGAGGTGAATAT 3' and 3' CCGCGCATTAGCTAT 5'
- (C) 5' GAGTTACACTTATAC 3' and 3' TGGCGAGTAATCGATA 5'

14) In the PCR reaction, you need a three-step reaction cycle, which results in a chain reaction that produces an exponentially growing population of identical DNA molecules. Each step of a reaction cycle is performed at a specific temperature (i.e., 95°C for Step 1, 55°C for step 2 and 70°C for Step 3). Briefly explain why the three steps are performed under the different temperatures.

15) You decide to determine the complete nucleotide sequence of Gene Z by DNA sequencing using fluorescent nucleotides. Which of the nucleotide(s) (1, 2, and/or 3) below are used in DNA sequencing reactions? Select all that apply.

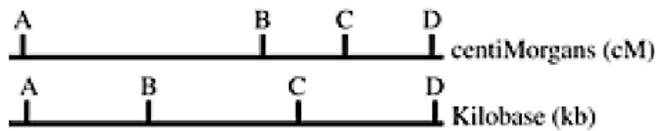


16) Which of the above nucleotide(s) (1, 2, and/or 3) would you fluorescently tag for DNA sequencing? Select all that apply.

17) In gene therapy and genetic engineering, a marker gene is often included in the DNA vector to be incorporated into the patient/tomato/mouse, etc. What is the purpose of a marker gene?

18) Dolly the sheep (the first cloned mammal!) was cloned using a nucleus taken from an adult sheep cell that had been growing in culture. The cell donor was 6 years old, and its cells had been growing in culture for several weeks. What surprised scientists about Dolly's chromosomal structure when she died young? You must be specific to get credit.

STATION 4: Heredity



1) The uppermost figure above shows the locations of four genes on the genetic recombination map of an organism; the lower figure shows the locations of the same four genes on a physical map derived from the nucleotide sequence of the DNA of that organism.

The maps are not identical because

- (A) there is no relationship between the position of genes in a genetic map and their positions on the DNA.
- (B) recombination frequencies per kb of DNA are not uniform throughout a chromosome.
- (C) the farther apart two genes are, the more likely they are to recombine.
- (D) the closer two genes are, the more likely they are to recombine.
- (E) some genes contain introns.

2) In *Drosophila melanogaster*, cinnabar eye (*cn*) and vestigial wing (*vg*) are simple recessive traits. A female, heterozygous for both genes, was crossed with a male with cinnabar eyes and vestigial wings. The offspring resulting from this cross are listed in the table below.

Class	Phenotype	Number
I	Wild type	445
II	Cinnabar eye, wild-type wing	51
III	Wild-type eye, vestigial wing	49
IV	Cinnabar eye, vestigial wing	455

Which of the four classes include genetic combinations that are different from the parents?

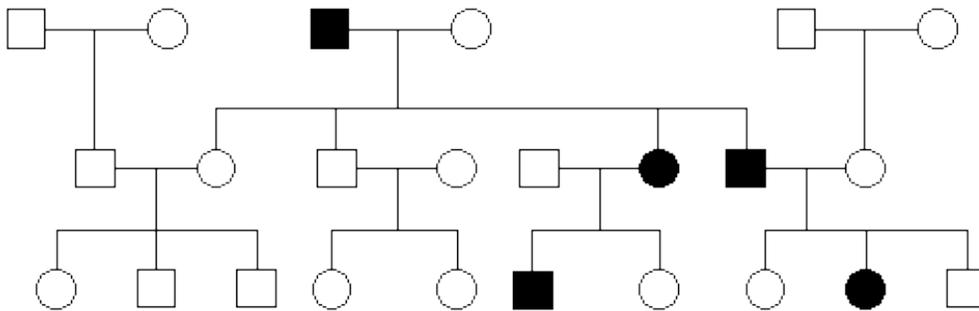
3) In humans, red/green colorblindness is an X-linked recessive trait: the gene for the protein that produces the necessary photoreceptors is located on the X chromosome. A color-blind woman and a color-blind man have a son with normal color vision. What is one likely explanation for this observation? Your answer must display appropriate understanding of molecular biology.

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4) DNA fingerprints are used to determine whether Sam could be the father of Becky's baby. Sam is not the father if _____ genetic fingerprint shows some bands not present in _____ genetic fingerprint.

- (A) Sam's ... the baby's
- (B) Becky's ... the baby's
- (C) the baby's ... Sam's
- (D) the baby's ... Becky's
- (E) the baby's ... Sam's or Becky's

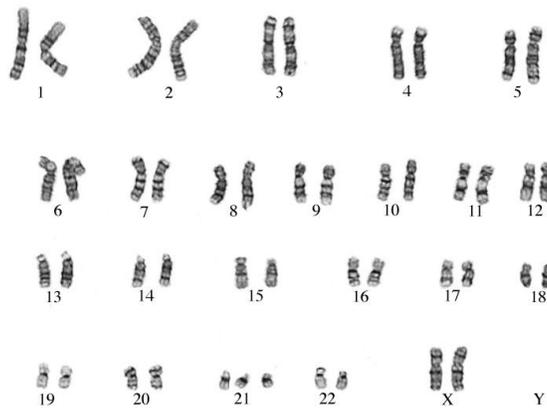
5) A population of cute, furry animals is affected by a terrible genetic disease. This condition affects 1 in 10,000 of the births in this population. The pedigree for an affected family of these cute, furry animals is shown below.



Which is the most likely mode of inheritance: X-linked recessive, autosomal recessive, or autosomal dominant? Explain your answer.

QUESTIONS 6-7: The following karyotype was taken as part of routine prenatal testing on a pregnant mother's unborn baby.

ZWK99011 KEY

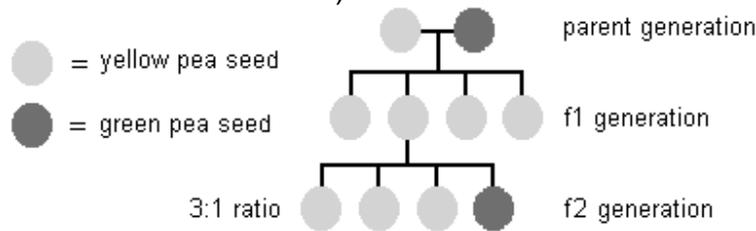


6) Is the baby male or female? How do you know?

7) The fetus has three copies of an autosomal chromosome. Where did the third copy come from?

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8) In the diagram below, what accounts for the green pea seed in the f2 generation?
(The f1 plant is allowed to self- fertilize.)



9) Explain a mechanism by which a nonlethal mutation might be propagated to produce more fit members of a species.

10) Which of the following terms refer(s) to a process that enables bacteria to undergo heritable genetic recombination?

- (A) conjugation
- (B) induction
- (C) transcription
- (D) mutation
- (E) translation

11) Viruses containing what type of nucleic acid can become silently integrated into the host's genome?

12) What is the genotypic outcome of a non-silent point mutation in a coding region? In other words, what happens to the DNA sequence?

13) What is the phenotypic outcome of a non-silent point mutation in a coding region? In other words, what happens to the protein sequence?

14) Describe one way in which non-silent point mutations can cause new phenotypes. You must specifically refer to how the change in protein sequence might affect function.

15) A cell in a young frog's skin epithelium develops a lethal mutation during DNA replication. Will the offspring of this frog experience symptoms as a result of this mutation? Explain your reasoning.

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QUESTIONS 16-18 refer to a series of experiments carried out by a microbiologist.

16) A bacterial donor strain and bacterial recipient strain are mixed together in a broth. Genetic markers are transferred from the donor to the recipient. What three forms of genetic exchange could be involved?

17) The donor is separated by a membrane that does not allow bacteria to pass through. If genetic exchange still occurs, what form(s) of exchange could be responsible?

18) DNase is added to the mix and genetic exchange still occurs. What form(s) of genetic exchange could be responsible?

STATION 5: Miscellaneous Molecular Biology!

- 1) When the nucleus of a frog red blood cell, which does not replicate DNA, is transplanted into an enucleated frog egg, the egg goes through several cell divisions. Which of the following is the best interpretation for this phenomenon?
- (A) Isolated red-blood-cell nuclei synthesize DNA.
 - (B) The nucleus plays no role in cell division.
 - (C) An enucleated frog egg can divide.
 - (D) Genes do not function during early cleavage.
 - (E) The cytoplasm controls nuclear DNA synthesis.
- 2) Why are dicentric chromosomes unstable?
- 3) Scientists wished to create an organism capable of breaking down several kinds of toxic wastes, so they combined genes from several species of bacteria to create a single superbacterium. They probably did NOT need to use which of the following?
- (A) nucleic acid probes
 - (B) reverse transcriptase
 - (C) plasmids
 - (D) restriction enzymes
 - (E) DNA ligase
- 4) Explain your answer to question 3.
- 5) Gene therapy involves
- (A) replacing defective human genes with the correct human gene.
 - (B) adding genes to plants to make them pesticide resistant.
 - (C) making "pharm" animals that secrete drugs.
 - (D) adding genes to bacteria so they can digest toxic waste.
 - (E) sequencing the human genome.
- 6) The dideoxynucleotide chain-termination method _____.
- (A) produces a ladder of DNA fragments, with each individual band labeled with one of four different fluorescent tags
 - (B) can be used to sequence entire eukaryotic chromosomes in a single reaction
 - (C) is very slow, requiring several weeks to determine a sequence of about 200 nucleotides
 - (D) does not involve electrophoresis
 - (E) is difficult to automate and must be performed under close human supervision

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QUESTIONS 7-8: The human genome has around 3×10^9 base pairs. The smallest bacterium genomes (those belonging to *Mycoplasmas*) have around 6×10^5 base pairs.

7) Give a rough (order of ten) magnitude estimation for the number of base pairs in the flowering plant with the smallest genome. Your answer must be in scientific notation.

8) Give a rough (order of ten) magnitude estimation for the number of base pairs in the largest flowering plant genome. Your answer must be in scientific notation.

9) Which of these statements regarding RFLP analysis is correct?

- (A) RFLP analysis requires Southern blotting for detection of fragments.
- (B) RFLPs can identify single base pair changes at any site in the chromosome.
- (C) An RFLP typically produces several different alleles.
- (D) All of these are correct.
- (E) None of these are correct.

10) Blood from a violent crime scene was tested for three polymorphisms: x, y, and z. Below is a table showing the percentage of people in the U.S. population that are carriers of each polymorphism:

Polymorphism	Variant A	Variant B
x	10%	90%
y	50%	50%
z	20%	80%

The blood sample tested positive for Variant A for each of the three polymorphisms, as does a suspect who denies wrongdoing. What percentage of the U.S. population would also match these results from the crime scene?

11) Your black unicorn and your neighbor's white unicorn just had a litter of cornlets, and they are all gray! What kind of inheritance pattern does this represent?

12) Explain your reasoning for your answer to question 11.

13) What inheritance pattern would you have suggested if the cornlets were all spotted like black-and-white cows?

14) Explain your reasoning for your answer to question 13.

15) Order the following sequencing vehicles in a list from smallest to largest in size:

- bacterial artificial chromosome
- plasmid
- yeast artificial chromosome

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16) What information does FISH (fluorescent *in situ* hybridization) provide that regular karyotyping does not?

17) Until a recent court decision blocking the sale of genetically-modified sugar beets, what percentage of sugar beets in the U.S. was genetically modified? Your answer must be within 5%.

18) A man and woman living in a tropical area where malaria is prevalent and health care is not accessible have seven children. The genotypes of these children are ss, Ss, SS, ss, Ss, Ss, and SS for the sickle-cell anemia gene. What must the genotypes of the mother?