INSTRUCTIONS:
1. Please write your name (name on your name tags), grade, and school on both this exam booklet and the scantron (bubble) sheet provided.
2. NO CALCULATOR is allowed.
3. Fill in the bubble clearly and erase the bubble COMPLETELY if you would like to make a change.
4. If you are using a pen for bubbling, make sure to cross out any answers you don’t want to be marked for.
5. Write clearly for FRQ, any handwriting that cannot be deciphered will not be scored.
6. Look at your own paper ONLY.
7. If you complete your exam early, please leave all pieces of paper in a neat pile on your desk and make your way to the new cafe for snacks. (You will not be allowed to leave in the last 10 minutes should you finish early)
Multiple Choice Questions

1. When an orange light with wavelength of 600 nm travels through diamond which has refractive index of 2.4, what is its wavelength in nm?
   a. 208
   b. 250
   c. 357
   d. 980
   e. 1440

2. When cytochrome C molecule are compared, cat and weasel are found to differ by approximately 54 amino acids per 100 residues; dog and raccoon are found to differ by 19 amino acids per 100 residues. What can one conclude from these data?
   a. Cat and weasel diverged from a common ancestor more recently than did dog and raccoon.
   b. Dog and raccoon diverged from a common ancestor more recently than did cat and weasel.
   c. The DNA sequences for the cytochrome c must be compared to derive any conclusion from this data.
   d. The evolution of cytochrome c occurred more rapidly in cat and weasel than in dogs and raccoon.

3. Of the compounds below, in which one does chlorine have the highest oxidation number?
   a. HCl
   b. KClO₄
   c. KClO₃
   d. HClO₂
   e. CaCl₂

4. Which is NOT a characteristic of lipid based hormones?
   a. It diffuses across cell membrane and enter the cell
   b. It binds to receptor proteins in cytoplasm and nucleus
   c. It triggers secondary messenger pathway
   d. It binds to DNA as transcription factors
5. A satellite gains speed during the part of the orbit where it is getting closer to the planet while traveling in its elliptical orbit around it. Which following can be used to explain this gain in speed?
   a. The torque exerted on the satellite by the planet during this portion of the orbit increases the angular momentum of the satellite-planet system.
   b. As the satellite gets closer to the planet, the satellite-planet system loses potential energy and the satellite gains kinetic energy.
   c. A component of the gravitational force exerted on the satellite is perpendicular to the direction of motion, causing an acceleration and hence a gain in speed along that direction.
   d. The centripetal force exerted on the satellite is greater than the gravitational force during this portion of the orbit, which causes the satellite to gain speed as it gets closer to the planet.

![Diagram of distribution pattern]

6. In a very large population, a quantitative trait has the distribution pattern shown in the figure above. If the curve diverges into two peaks, there is no gene flow, and the population size consequently increases over successive generations. Which of the following is (are) probably occurring?
   1. immigration or emigration
   2. directional selection
   3. Adaptation
   4. genetic drift
   5. disruptive selection
      a. 1
      b. 4
      c. 2, 3
      d. 3, 5
      e. 1, 2, 3
7. Salts containing which of the following ions are generally insoluble in cold water?
   a. Acetate
   b. Ammonium
   c. Potassium
   d. Nitrate
   e. Phosphate

8. In the diagram of the nitrogen cycle in Figure 42.3, which number represents nitrite (NO$_2$)?
   a. 1
   b. 2
   c. 3
   d. 4

9. CO$_2$ absorbed by the oceans combines with water to form H$_2$CO$_3$. Which of the following will result from increasing the concentration of H$_2$CO$_3$ in the oceans?
   a. Ocean pH will be stabilized by the buffering capacity of H$_2$CO$_3$.
   b. Ocean pH will become acidic.
   c. Ocean pH will become basic.
   d. The concentration of carbonate ions (CO$_3^{2-}$) in the ocean will increase.
   e. The concentration of bicarbonate ions (HCO$_3^-$) in the ocean will decrease.

10. Which one is true about plants?
    a. They only conduct photosynthesis.
    b. Plants have many other pigments other than chlorophyll.
    c. Plants are the only living organisms that are autotrophs.
    d. They conduct photosynthesis most efficiently in green light.
11. What is the pH of a 1-millimolar NaOH solution?
   a. pH 1
   b. pH 2
   c. pH 8
   d. pH 9
   e. pH 11

12. In the pedigree above, black circles indicate that a muscle-wasting disorder is observed in that individual. Which of the following is the best explanation for the inheritance pattern observed?
   a. Imprinting
   b. Sex-linked trait
   c. Incomplete dominance
   d. The trait is polygenic
   e. Autosomal recessive

13. Man A of mass 3m and Man B of mass 2m are initially at rest at the center of a frozen pond together. They push each other so that Man A slides to the left by velocity \( v \) and Man B slides to the right. What is the total work done by the children?
   a. 0
   b. \( 3/2 \, mv^2 \)
   c. \( 9/2 \, mv^2 \)
   d. \( 15/2 \, mv^2 \)
   e. \( 15/4 \, mv^2 \)

14. A cell has the following molecules and structures: enzymes, DNA, ribosomes, plasma membrane, and mitochondria. It is:
   a. A bacterium
   b. An archaeal or eukaryotic organism
   c. Any eukaryotic organism
   d. An animal, but not a plant cell.
   e. A plant cell, but not an animal cell.
For 15-19, choose the answer from the following cells.

A. Muscle cell in thigh of long distance runner
B. Pancreatic cell that secretes digestive enzymes
C. Ovarian cell that produces the steroid hormone estrogen
D. Cell in tissue layer lining digestive tract
E. White blood cell that engulfs bacteria

15. In which cell would you find the most lysosomes?
16. In which cell would you find the most mitochondria?
17. In which cell would you find the most Smooth ER?
18. In which cell would you find the most Rough ER?
19. In which cell would you find the most tight junctions?

20. In an oxidation-reduction reaction, the oxidizing agent
   a. Gains electrons and loses potential energy.
   b. Gain electrons and gains potential energy.
   c. Gains electrons but no change in potential energy.
   d. Loses electrons and loses potential energy.
   e. Loses electrons and gains potential energy.

21. Which of the following pairs of atoms would be most likely to form a polar covalent bond?

   ![Atoms Diagram]
22. A hot dog contains 500 kcal of energy. If we could burn the hot dog and use all the heat to warm a 50 L container of cold water, what would be the approximate increase in the temperature of the water? (Note: 1L of cold water has mass of exactly 1kg.)
   a. 1 °C
   b. 5 °C
   c. 10 °C
   d. 25 °C
   e. 50 °C

23. Which of Kepler’s laws most directly leads us to have terms such as apogee, aphelion, and perigee?
   a. 1st
   b. 2nd
   c. 3rd
   d. 4th
   e. None
24. If life arose on a planet where carbon is absent, which element might fill the role of carbon?
   a. Boron
   b. Nitrogen
   c. Oxygen
   d. Silicon
   e. Aluminium

25. Doubling a musical note's amplitude:
   a. Increases its pitch
   b. Doubles its wavelength
   c. Increases its loudness
   d. Halves its frequency
   e. Decreases in loudness

26. Which of the following is sometimes called volcanic glass because of its shiny appearance?
   a. Granite
   b. Diorite
   c. Obsidian
   d. Quartz
   e. Graphite

27. Flipper of the whale and human arm are considered as
   a. congruent structures
   b. analogous structures
   c. homologous structures
   d. vestigial structures
28. Used primarily in fertilizers, which element is never found free in nature even though it makes up about 2.5% of the earth's crust?
   a. K  
   b. Ca  
   c. Na  
   d. Mg  
   e. Al

29. A botanist measured the amount of ATP and NADPH consumed by the Calvin cycle in 1 hour and have noticed that 3000 molecules of ATP was consumed, but only 2000 molecules of NADPH was consumed. Which step was the source of leftover ATP?
   a. Cyclic electron flow  
   b. Linear electron flow  
   c. Photosystem I  
   d. Photosystem II  
   e. Cellular respiration

30. \[\text{HCl(aq)} + \text{MnO}_2(s) \rightarrow \text{MnCl}_2(aq) + \text{Cl}_2(g) + \text{H}_2\text{O(l)}\]
When the equation above is balanced and all coefficients are reduced to lowest whole number terms, what is the coefficient for HCl?
   a. 1  
   b. 2  
   c. 3  
   d. 4  
   e. 7

31. Which of the following controls the activity of all the others?
   a. Hypothalamus  
   b. Thyroid gland  
   c. Adrenal gland  
   d. Ovaries  
   e. Pituitary gland

32. What is the most common term for the maximum downward speed an object can attain, considering air resistance, when it is in free fall from a few miles up in the atmosphere?
   a. Escape velocity  
   b. Terminal velocity  
   c. Initial velocity  
   d. Final velocity
33. Which of the following is NOT true?
   a. The Milky Way is an elliptical galaxy
   b. our Sun will become a red giant in the far distant future
   c. constellations are patterns of stars in the night sky
   d. the average sunspot cycle is 11 years
   e. There is a supermassive black hole at the centre of our galaxy

34. If plants convert 1% of the sunlight they receive into energy, and 10% of the energy exchanged between trophic levels is converted into biomass, then what percent of the energy in the incident sunlight is embodied in a secondary consumer?
   a. 10%
   b. 1%
   c. 0.1%
   d. 0.01%
   e. 0.001%

Questions 35-38 Refer to a situation in which a tennis ball is projected straight upward in the +y direction. Ignore air resistance. The answer choices are found in the figure.

35. Which graph shows the vertical position y of the ball as a function of time?
36. Which shows the acceleration a_y of the ball as a function of time?
37. Which graph shows the potential energy of the ball as a function of time?
38. Which graph shows the momentum p_y of the ball as a function of time?
39. Two people facing each other sit at opposite ends of a boat that is initially at rest. The person in the front of throws a heavy ball to the person in the back. What is the motion of the boat at the time immediately after the ball is thrown and after the ball is caught by the person at the back of the boat? (Air resistance and water friction are negligible.)

<table>
<thead>
<tr>
<th>Immediately after the throw</th>
<th>After the catch</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Boat moves forward</td>
<td>Boat does not move</td>
</tr>
<tr>
<td>b. Boat moves forward</td>
<td>Boat moves backward</td>
</tr>
<tr>
<td>c. Boat moves forward</td>
<td>Boat moves forward</td>
</tr>
<tr>
<td>d. Boat moves backward</td>
<td>Boat moves backward</td>
</tr>
<tr>
<td>e. Boat moves backward</td>
<td>Boat does not move</td>
</tr>
</tbody>
</table>

40. The figure above shows four resistors -- A, B, C, and D -- connected in a circuit with a battery. Which of the following correctly ranks the potential difference, $\Delta V$, across four resistors?

a. $\Delta V_B > \Delta V_A > \Delta V_C = \Delta V_D$

b. $\Delta V_B = \Delta V_D > \Delta V_C = \Delta V_A$

c. $\Delta V_D = \Delta V_C > \Delta V_B > \Delta V_A$

d. $\Delta V_D > \Delta V_C > \Delta V_B > \Delta V_A$

e. $\Delta V_B > \Delta V_A > \Delta V_D > \Delta V_C$

41. The antigen-binding sites of an antibody molecule are formed from the molecule’s variable regions. Why are these regions called variable?

a. They can change their shapes when they bond to an antigen.

b. Their specific shapes are unimportant.

c. They can change their shapes on command to fit different antigen.

d. Their sizes vary considerably from one antibody to another.

e. They have different shapes on antibodies to different antigens.

42. A string, fixed at both ends, has a length of 6 m and supports a standing wave with a total of 4 nodes. If a transverse wave can travel at 32 m/s down the rope, what is the frequency of this standing wave in Hz?

a. 5.33

b. 8

c. 10

d. 16

e. 20.6
43. \( H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad \Delta H > 0 \)

Which of the following changes to the equilibrium system represented above will increase the quantity of HI(g) in the equilibrium mixture?

I. Adding \( I_2 \) (g)
II. decreasing the temperature
III. increasing the pressure
   a. None of the above
   b. I only
   c. III only
   d. I, II
   e. II, III

44. A simple pendulum of length \( L \) and mass \( m \) swings about the vertical equilibrium position with a maximum angular displacement of \( \theta_{\text{max}} \). What is the tension in the connecting rod when the pendulum’s angular displacement is \( \theta = \theta_{\text{max}} \)?

   a. \( mg\cos\theta_{\text{max}} \)
   b. \( mgsin\theta_{\text{max}} \)
   c. \( mgL\sin\theta_{\text{max}} \)
   d. \( mgL\cos\theta_{\text{max}} \)
   e. \( mgL(1-\cos\theta_{\text{max}}) \)

45. An atom has five electrons in a 3d subshell. How many orbitals in this subshell have an unpaired electron?

   a. 0
   b. 1
   c. 2
   d. 4
   e. 5

46. If blood was supplied to all of the body's capillaries at the same time,
   a. Resistance to blood flow would increase.
   b. The blood level will skyrocket and eventually cause inner bleeding.
   c. Blood will simply flow too rapidly through the capillaries.
   d. Blood pressure would fall significantly.
   e. The increased gas exchange in the lungs and in the supply of \( O_2 \) to the muscles would allow for strenuous exercise.
Zn(s) + 2HCl(aq) → ZnCl₂(aq) + H₂(g)

47. Given this chemical equation, one would NOT ________ in order to form more products.
   a. Increase the concentration of HCl.
   b. Decrease the concentration of ZnCl₂
   c. Decrease the pressure
   d. Add catalyst
   e. Put more Zn metal pieces

48. Calculate the number of joules required to completely evaporate 9 grams of H₂O at 97°C.
   (Hᵥ = 2000 J/g and c = 4.0 J/gK)
   a. 20340 J
   b. 18108 J
   c. 6018 J
   d. 9054 J
   e. 503 J

49. A double stranded DNA molecule contains a total of 144 purines and 144 pyrimidines.
   This DNA molecule could be composed of:
   a. 12 pairs of adenine and 12 pairs of guanine molecules.
   b. 72 thymine and 72 adenine molecules.
   c. 144 adenine and 144 uracil molecules.
   d. 144 cytosine and 144 thymine molecules.
   e. 144 thymine and 144 adenine molecules.

50. The organic compound represented above is an example of
   a. Alcohol
   b. Aldehyde
   c. Ketone
   d. Ether
   e. Organic acid
1. An incident ball A of mass 0.2 kg is sliding at 1.8 m/s on the horizontal table top of negligible friction. It collides with a target B ball of mass 0.5 kg at rest at the edge of the table. As a result of collision, the ball rebounds sliding backwards at 1 m/s immediately after the collision. (Note: leave all answers in original form e.g. roots, fractions, etc.)
   a. Calculate the speed of the ball B immediately after the collision
   b. Calculate the horizontal displacement $d$.
   c. Suppose there was a spring on the floor, right under the position of the target ball B’s landing (shown in the diagram). Calculate the maximum compression of the spring immediately after the ball B’s landing on that spring.

In another similar experiment on the same table, but the table’s legs broke and made 30° angle with the floor, one side of the table touching the floor. Ball A was at rest and was released from the top of the inclined table, directed towards ball C right at the bottom of the table with unknown mass. When two balls collide, ball A stops and ball C moves forward at 6 m/s.
   d. What is the mass of the ball C?
2. Metallic bonding is unique and explains a number of properties that are not found among ionic salts or covalent molecules.
   a. Describe a metallic bond and use the image below to illustrate your definition.
   ![Metallic bond diagram]
   b. List two differences between a solid created with ionic bonds versus metallic bonds.
   c. Explain why the material is
      i. Low in volatility
      ii. Able to conduct heat and electricity
   d. A mixture of metals is known as an alloy. Explain one property that is altered by the presence of an alloy and explain one property that stays the same.
   e. Analyze the difference between a substitutional alloy and an interstitial alloy.
      i. Provide one example of each of these differences.
3. The ability to taste PTC is due to a single dominant allele “R”. Researchers have sampled 215 individuals in a biology class, and determined that 150 could detect the bitter taste of PTC and 65 could not. (Note: Able to taste PTC is dominant over non-tasting.)

(Hardy-Weinberg equation: p+q = 1, p^2 + 2pq + q^2 = 1)

a. What is the predicted frequency of the recessive allele “t”?

b. What is the predicted frequency of dominant allele “T”?

c. In a population of 1000 people, find the number of people for the following:
   i. Heterozygous
   ii. Homozygous dominant
   iii. Homozygous recessive

d. If a mother who can taste PTC and a father with an unknown genotype have 4 children who are all tasters, what are the genotypes for all the members of the family?