Note: For all questions involving solutions, assume that the solvent is water unless otherwise stated.

Throughout the test, the following symbols have the definitions specified unless otherwise noted.

H	= enthalpy	atm	= atmosphere(s)
M	= molar	g	= gram(s)
n	= number of moles	J	= joule(s)
P	= pressure	kJ	= kilojoule(s)
R	= molar gas constant	L	= liter(s)
S	= entropy	mL	= milliliter(s)
T	= temperature	mm	= millimeter(s)
V	= volume	mol	= mole(s)
		V	= volt(s)

Questions 1–3 refer to the following topics and relationships concerning states of matter.

A) A general rule for predicting solubility

B) Solid phase changing to the liquid phase

C) A state in which the liquid and gas phases are in equilibrium

D) Relationship between volume and temperature at constant pressure

E) Relationship between absolute temperature and the kinetic energy of particles

1

Particles in a substance vibrate faster and faster until some are able to break from their fixed positions and move around more freely.

Choice (B) is the correct answer. In a solid, particles are fixed in position in a lattice structure but are not motionless. When heated, particles in a solid gain energy and freedom of motion as the solid melts and becomes a liquid. Although particles in a liquid have freedom of motion, they are still close together.

2

Evaporation and condensation rates in a closed container are the same.

Choice (C) is the correct answer. When the liquid and gas phases are in equilibrium in a closed container, the number of particles leaving the liquid (evaporation) is equal to the number of particles entering the liquid from the gas phase (condensation).

3

The spaces between gas particles in air increase as the temperature of the air increases.

Choice (D) is the correct answer. Charles's Law describes the direct relationship of temperature and volume of a gas. Assuming that pressure does not change, a doubling in absolute temperature of a gas causes a doubling of the volume of that gas. A decrease in absolute temperature is proportional to the decrease in volume.

Questions 4–6 refer to the following information.

$$H_2SO_4(aq) + Zn(s) \rightarrow H_2(g) + ZnSO_4(aq)$$
$$AgNO_3(aq) + KI(aq) \rightarrow KNO_3(aq) + AgI(s)$$
$$HF(aq) + H_2O(l) \leftrightarrows F^-(aq) + H_3O^+(aq)$$

A) $Zn(s)$

B) $H_2(g)$

C) $AgI(s)$

D) $H_2O(l)$

E) $H_3O^+(aq)$

4

Which species is classified as an insoluble salt?

Choice (C) is the correct answer. As a solid, this species is formed in the reaction as a precipitate, or insoluble solid. Also, AgI is the only listed species that is a salt, or a neutral compound made of positive and negative ions. The second reaction is a precipitation reaction, showing two salts are switching ion pairs from $Ag^+NO_3^-$ and K^+I^- to $K^+NO_3^-$ and the insoluble salt Ag^+I^-.

5

Which species is the acid of a conjugate acid–base pair?

Choice (E) is the correct answer. The Brønsted-Lowry acid base theory says that an acid donates a proton to a base, which accepts the proton. After the acid reactant donates a proton to the base reactant, the acid reactant becomes the conjugate base product, and the base reactant becomes the conjugate acid product. The HF is the acid that donates a proton to become the conjugate base, F^-. H_2O is the base that accepts the proton to become the conjugate acid, H_3O^+. The third reaction is the only acid–base reaction. Although the first reaction involves a strong acid, it is not an acid–base reaction because there is no proton transfer between the reactants.

6

Which species is acting as a reducing agent?

Choice (A) is the correct answer. The first reaction is the only reduction–oxidation reaction, and the reducing agent loses electrons and increases its oxidation state, or hypothetical charge. In this case, Zn loses two electrons and is oxidized to Zn^{2+}. In the process, it is the agent that reduces H^+ to elemental H^2.

Questions 7–9 refer to the following elements.

A) Al, aluminum

B) C, carbon

C) Ca, calcium

D) F, fluorine

E) Li, lithium

7

Which element is the most electronegative of all elements?

Choice (D) is the correct answer. As you move from left to right across a row in the periodic table, electronegativity increases due to the stronger attraction that atoms obtain as the nuclear charge increases. As you move down a group in the periodic table, electronegativity decreases because the atomic number increases, increasing the distance between the valence electrons and nucleus. The exceptions are the noble or inert gases, because they already have a complete valence shell, and the lanthanides and actinides that do not follow these trends. Fluorine's position at the top right corner of the periodic table corresponds with the fact that it is the most electronegative element.

8

Which element reacts with oxygen in a 2 to 3 ratio of element to oxygen, producing X_2O_3?

Choice (A) is the correct answer. Aluminum has an oxidation state of +3 in the majority of Al-containing compounds, and oxygen commonly has an oxidation state of −2. In order for a molecule with 3 oxygen atoms to have a neutral charge, something must balance out the $(3)(-2) = -6$ charge. Here, the 2 Al ions contribute a charge of $(2)(+3) = 6$ to give a neutral compound. The other elements do not have the oxidation states for making a neutral compound if 2 atoms were to react with 3 oxygen atoms.

9

Which element often forms compounds in which it has four covalent bonds?

Choice (B) is the correct answer. Carbon has four valence electrons and often forms four single bonds with other nonmetals. Students should recognize that this is the basis of organic chemistry.

I		II

10

Sodium and chlorine have different chemical properties	BECAUSE	sodium and chlorine have different principal quantum numbers for the highest occupied energy level.

I True, II False, not CE is the correct answer. Sodium (Na) and chlorine (Cl) have different chemical properties because they have different numbers of valence electrons. Elements in different groups of the periodic table have vastly different chemical properties because they have different numbers of valence electrons in their outer shells. Sodium and chlorine have the *same* principal quantum number for the highest energy electron because they are in the same period; this is true for any of the elements in the first three rows of the periodic table.

11

When 1.0 mol H_2SO_4 reacts with 1.0 mol NaOH according to the reaction by the equation above, NaOH is the limiting reactant	BECAUSE	in the reaction represented by the equation above, the molar mass of H_2SO_4 is more than twice the molar mass of NaOH.

I True, II True, CE No is the correct answer. The stoichiometry shows that 1.0 mol of NaOH will react with only 0.5 mol of H_2SO_4, leaving 0.5 mol of H_2SO_4 unreacted, indicating that NaOH is the limiting reactant. The molar mass of H_2SO_4 is 98.08 g/mol, which is more than twice NaOH's molar mass of 40.00 g/mol. However, the molar masses are not relevant because the limiting reactant is determined by mole ratios, not by the molar masses of the reactants.

I		II

$$2\ NO_2(g) \leftrightarrows N_2O_4(g)$$

12

When the reaction represented by the equation above is at equilibrium in a sealed container, a decrease in the volume of the reaction container will shift the equilibrium toward NO_2	BECAUSE	in the reaction represented above, a shift toward NO_2 decreases the pressure of the system.

I False, II False, CE No is the correct answer. PV is constant; as volume decreases, the pressure will increase. To accommodate for this volume change, the equilibrium will shift in the direction that decreases the number of moles of gas. Because the formation of N_2O_4 uses 2 moles and produces only 1, the number of moles will decrease, countering the increased pressure. Therefore, increasing pressure will produce more N_2O_4, shifting the equilibrium to the right.

13

Evaporation of water results in an increase in entropy	BECAUSE	water molecules are distributed more randomly in the gas state than in the liquid state.

I True, II True, CE Yes is the correct answer. Entropy is a measure of disorder in a system. Ice is more ordered than liquid water, which is more ordered than the particles in water vapor. Intermolecular forces in the liquid state result in an ordered, but fluid, arrangement of molecules, but these forces are not a factor in the gas state because the intermolecular distances are much greater. The fact that molecules of water in the gas state have a higher entropy than liquid water molecules corresponds with an increase in entropy during evaporation.

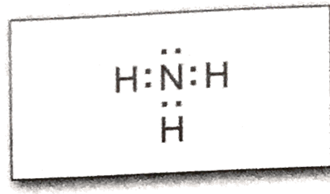
	I		II
14	When magnesium (Mg) reacts with chlorine (Cl), the atoms combine in a 1 to 2 ratio to form $MgCl_2$	BECAUSE	each magnesium atom gains two electrons and each chlorine atom loses one electron.

I True, II False, CE No is the correct answer. Magnesium (Mg) is divalent and chlorine (Cl) is monovalent. The 1 to 2 ratio gives each atom a complete octet of electrons. Therefore, one atom of Mg would react with two atoms of Cl to produce $MgCl_2$. Alkaline earth metals in group 2 have two valence electrons and they tend to react to lose those electrons. Halogens are one electron short of an octet, so they tend to react to gain one electron. When $MgCl_2$ is formed, each magnesium atom would lose two electrons, and each chlorine atom would gain one electron.

	I		II
15	If the volume on a buret can be accurately read to the nearest 0.01 mL, then the volume of exactly 20 mL of a solution released from the buret should be recorded as 20.00 mL	BECAUSE	it is standard practice to record data to two decimal places.

I True, II False, CE No is the correct answer. Because the buret can be read accurately to 0.01 mL, the volume of a solution should be measured using two decimal places. However, the standard practice is to record data and report measurements using correct significant figures, not just to use two decimal places. Statement II is not the correct explanation of statement I, because the standard practice is stated incorrectly.

16



This is the Lewis structure of an ammonia (NH_3) molecule.

Based on the Lewis electron-dot diagram shown above, which of the following best describes the shape of an ammonia molecule?

A) T-shaped
B) Tetrahedral
C) Square planar
D) Trigonal planar
E) Trigonal pyramidal

Choice (E) is the correct answer. The lone pair on the N atom repels the bonding electrons of the three NH bonds to create a three-legged stool shape. According to valence shell electron pair repulsion (VSEPR) theory, the shape of the molecule and the angles between bonds are determined by the repulsion of all valence shell electrons. The lone electron pair and the three NH bonding electron pairs repel each other toward the apexes of a tetrahedron. Because the lone pair is not part of the molecular shape, the result is that the three bonds form a three-sided pyramid and are separated by an angle slightly less than the tetrahedral angle, 109.5°.

17

The air trapped in a glass tube occupies 2.0 liters at 1.0 atm. The sample of air is compressed until the pressure on the trapped air molecules is increased to 4.0 atm. Assuming constant temperature, what is the new volume of the air (in L)?

A) 0.25L
B) 0.50L
C) 2.0L
D) 4.0L
E) 8.0L

Choice (B) is the correct answer. The ideal gas law can be used to determine new values for a gas based on changing conditions. Rearranging the ideal gas law formula, $PV = nRT$, and solving for the universal gas constant, R, results in $R = PV/nT$. When comparing a gas at two different conditions, you can set the two conditions equal to each other: $P_1V_1/n_1T_1 = P_2V_2/n_2T_2$. Because temperature ($T$) and amount of gas ($n$) are constant in this situation, the equation simplifies to $P_1V_1 = P_2V_2$. Solving for the final volume results in $V_2 = P_1V_1/P_2$. Plugging in the initial volume and pressure and final pressure for the gas gives $V_2 = (1.0\text{atm})(2.0\text{L})/(4.0\text{L}) = 0.50\text{L}$.

18

Which of these properties generally decreases when moving left to right across a period, or row, of the periodic table?

A) Reactivity

B) Atomic radius

C) Electron affinity

D) First ionization energy

E) Number of valence electrons

Choice (B) is the correct answer. Atomic radii decrease from left to right because the effective nuclear charge of atoms increases across the rows, drawing the valence shell electrons closer. Choice (A) is incorrect because reactivity first decreases as the tendency to lose electrons decreases, then increases as the tendency to gain electrons increases. Choices (C) and (D) are both incorrect because electrons become more tightly held as the number of protons and electrons increase, resulting in increasing electron affinity and ionization energy. Choice (E) is incorrect because each element has one more valence electron than the previous element.

19

Which of these represents the ground-state electron configuration of a neutral aluminum (Al) atom?

A) $1s^2 2s^2 2p^1$

B) $1s^2 2s^2 2p^6 3s^1$

C) $1s^2 2s^2 2p^6 3s^2 3p^1$

D) $1s^2 2s^2 2p^6 3s^2 3p^5$

E) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4s^2$

Choice (C) is the correct answer. Aluminum has the configuration of neon ($1s^2 2s^2 2p^6$) plus a full 3s orbital and one electron in the 3p orbital. Choice (A) is the configuration of boron (just above aluminum), choice (B) is the configuration of sodium, choice (D) is the configuration of chlorine and choice (E) is the configuration of scandium.

20

Which of the following molecules is nonpolar but has polar bonds?

A) Carbon dioxide (CO_2)

B) Hydrogen chloride (HCl)

C) Water (H_2O)

D) Sulfur dioxide (SO_2)

E) Phosphorus trichloride (PCl_3)

Choice (A) is the correct answer. The electronegativity difference between carbon and oxygen is large enough to make these bonds polar, but the overall molecule is nonpolar because it is linear. Choices (B), (C), (D), and (E) are polar molecules with polar bonds. Choices (C), (D), and (E) are polar because of geometry.

21

Substance	Molar mass (g)	Boiling point (°C)
Methane	16	-162
Water	18	100

The table above lists the molar masses and boiling points of methane and water at standard pressure. Which of the following best explains the large difference between the boiling points of methane and water?

A) Methane is an organic compound.

B) Water needs more energy to boil because it ionizes into hydrogen and hydroxide ions.

C) Most compounds that contain oxygen have high boiling points

D) London dispersion forces are not present for simple hydrocarbons with low molar mass.

E) Hydrogen bonding in water increases the attractive forces between molecules.

Choice (E) is the correct answer. The value of a boiling point reflects the strengths of the intermolecular forces between liquid molecules. In order to boil, liquid molecules must overcome these attractive forces to separate and form a vapor. Water molecules have very strong, attractive forces because they form hydrogen bonds. Water molecules are also polar, with large dipoles that attract each other. Methane cannot form hydrogen bonds, and it is nonpolar. The only attractive forces between methane molecules are London dispersion forces. Choice (A) is incorrect because many organic compounds have higher boiling points than water. Choice (B) is incorrect because ionization is different from boiling. Ionization requires the covalent bonds between molecules to break; this requires a lot more energy than boiling, which is the liquid molecules overcoming attractive forces so they can form vapors. Choice (C) is not correct because there is not a connection between whether or not a compound contains oxygen and its boiling point. Choice (D) is incorrect because London dispersion forces are the most important intermolecular force for hydrocarbons.

22

Which of the following best explains how some nonpolar substances can be liquids at room temperature?

A) The molecules share electrons, forming bonds.

B) The molecules form temporary dipoles with partial charges.

C) The molecules transfer electrons, forming ions with opposite charges.

D) The molecules form positive ions that are held together by free electrons.

E) The molecules form temporary bonds between hydrogen and electronegative atoms.

Choice (B) is the correct answer. In liquids, the intermolecular attractive forces are strong enough to hold molecules close together. Because of the nature of the electron cloud, there are temporary dipoles in nonpolar molecules that can induce dipoles in nearby molecules. The induced dipoles cause the molecules to attract each other. Choices (A), (C), and (D) are incorrect because they describe covalent, ionic, and metallic bonding, respectively. Choice (E) is incorrect because it describes hydrogen bonding, which is not a feature of nonpolar substances.

23

The phase diagram for carbon dioxide (CO_2) is shown to the right. Crossing through which of the following represents a phase change directly from solid to gas?

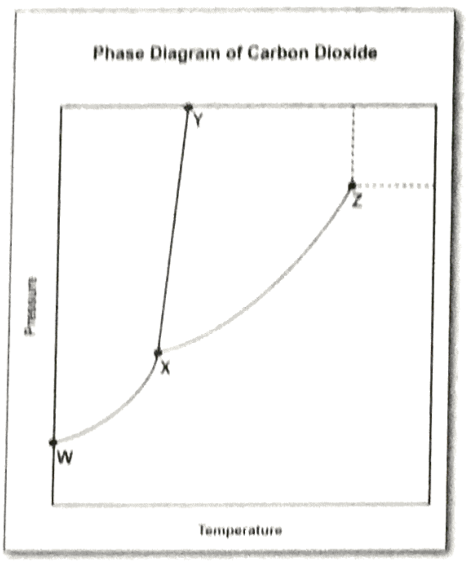
A) point Y

B) point Z

C) line WX

D) line XY

E) line XZ



Choice (C) is the correct answer. Crossing segment WX (by decreasing pressure, increasing temperature, or both) represents a phase change directly from solid to gas, otherwise known as sublimation. Above the segment, carbon dioxide is solid, and below the segment, it is gas. At the segment, the two phases of matter are in equilibrium. Choice (A) is an arbitrary point between solid and liquid phases. Choice (B) represents the point past which there is no physical distinction between vapor and liquid phases. Choice (D) represents a change between solid and liquid, and choice (E) represents a change between liquid and gas.

24

How many milliliters of 0.20 M sulfuric acid (H_2SO_4) solution will be needed to exactly neutralize 200 mL of 0.10 M sodium hydroxide (NaOH) solution?

A) 50.0 mL

B) 80.0 mL

C) 100 mL

D) 200 mL

E) 400 mL

Choice (A) is the correct answer. Sodium hydroxide = NaOH = 1 mol Na^+ and 1 mol OH^-. Sulfuric acid = H_2SO_4 = 2 mol H^+ and 1 mol SO_4^{2-}. Therefore, to neutralize 1 mol of sulfuric acid (2 mol H^+), you need 2 mol of sodium hydroxide (2 × 1 mol OH^-).

(200 mL) × (1 L / 1000 mL) = 0.2 L
0.10 M = 0.1 mol/ 1 L
0.20 M = 0.2 mol/ 1 L

Therefore: (0.20 L NaOH) × (0.10 mol NaOH/L) × (1 mol H_2SO_4/2 mol NaOH) × (1L/0.20 mol H_2SO_4) = 0.050 L = 50 mL

Choice (B) is the mass of two moles of NaOH. Choice (C) is incorrect because it uses equal molar equivalents of NaOH and H_2SO_4 rather than 2 moles NaOH per mole of H_2SO_4. Choice (D) could be the result of inverting the stoichiometry fraction and calculating for 2 moles H_2SO_4 per 1 mole NaOH, or assuming that half as much H_2SO_4 solution is needed because of its molarity. Choice (E) is two times the amount of NaOH solution to be neutralized.

25

The
base
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A) I
B) II
C) I
D) II
E) II

Choice (I
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23

Solution	Concentration (mol/L)	pH
I	0.1	14
II	0.1	2.9
III	0.01	2.0
IV	0.001	3.0

The table shown above describes four solutions needed for an acid–base laboratory experiment. Which solution(s) were prepared using weak acids?

A) I only
B) II only
C) I and II only
D) III and IV only
E) II, III, and IV

Choice (B) is the correct answer. The data for Solution II are based on a dilute acetic acid solution. Together, the concentration of 0.1 M and pH of 2.9 indicate that the solution most likely contains a weak acid. These data demonstrate that the acid does not completely dissociate (else the pH would be 1.0). Solution I is a strong base in choices (A) and (C). Solutions III and IV, in choices (D) and (E), are both examples of strong acids. For all three of these solutions, the concentrations and pH values together demonstrate that they completely dissociate.

26

$$2\ KMnO_4 + 3\ Na_2SO_3 + H_2O \rightarrow 2\ MnO_2 + 3\ Na_2SO_4 + 2\ KOH$$

Potassium permanganate ($KMnO_4$) reacts with sodium sulfite (Na_2SO_3) in water to produce manganese dioxide (MnO_2), sodium sulfate (Na_2SO_4), and potassium hydroxide (KOH), as shown by the equation above

A) K^+

B) MnO_4^-

C) Na^+

D) SO_3^{2-}

E) H_2O

Choice (D) is the correct answer. SO_3^{2-} is the reducing agent, or reductant, in this reaction because it is oxidized to SO_4^{2-}. The oxidation state of sulfur in SO_3^{2-} is +4: $(+4 \times 1) + (-2 \times 3) = -2$. The oxidation state of sulfur in SO_4^{2-} is +6 to give the sulfate ion a −2 charge: $(+6 \times 1) + (-2 \times 4) = -2$. Choice (B) is wrong because MnO_4^- is reduced to MnO_2; the oxidation state of Mn decreases from +7 to +4, so MnO_4^- is an oxidizing agent. Choices (A), (C), and (E) are incorrect because the elements K, Na, H, and O do not change oxidation state.

27

Analysis of a sample of an unknown hydrocarbon yields 2.4 g of carbon and 0.30 g of hydrogen. These results indicate an empirical formula of C_2H_3. Based on this information and the usual bonding patterns of the atoms involved, which of these formulas COULD be the molecular formula?

A) C_2H_6

B) C_3H_4

C) C_3H_6

D) C_4H_6

E) C_6H_9

Choice (D) is the correct answer. Empirical formulas state the simplest ratio of atoms for each element in a compound. Choice (D) is correct because C_4H_6 is the simplest molecular formula for the given empirical formula. C_4H_6 can be the formula for both butadiene (a linear 4-carbon chain with 2 double bonds) and cyclobutene (a 4-carbon chain cycloalkene). Choices (A), (B), and (C) are incorrect because the C:H ratio must be 2:3. Choice (E) is not possible; a 6-carbon hydrocarbon will only have an even number of hydrogen atoms.

15

An analytical chemist is given a sample of aluminum oxide (Al_2O_3). She finds that it contains approximately 12 moles of oxygen. Knowing that the atomic mass of aluminum is 27 g/mol and the atomic mass of oxygen is 16 g/mol, what is the total mass of this Al_2O_3 sample?

A) 102 g

B) 192 g

C) 408 g

D) 1,224 g

E) 3,672 g

Choice (C) is the correct answer. Using the atomic mass of aluminum and oxygen, calculate the molar mass of Al_2O_3:

$$2 \text{ mol Al} \times (27 \text{ g/ mol}) = 54 \text{ g/mol}$$
$$3 \text{ mol O} \times (16 \text{ g/mol}) = 48 \text{ g/mol}$$
$$Al_2O_3 = 54 \text{ g/mol} + 48 \text{ g/mol} = 102 \text{ g/mol}$$

Next, knowing the moles of oxygen in the Al_2O_3 sample (12), that there are 3 moles of oxygen in every mole Al_2O_3, and the atomic mass of Al_2O_3, calculate the mass of the sample:

$12 \text{ mol O} \times (1 \text{ mol } Al_2O_3/3 \text{ mol O}) \times (102 \text{ g } Al_2O_3/1 \text{ mol } Al_2O_3) = 408 \text{ g } Al_2O_3$.

Choice (A) is the mass of 1 mol of aluminum (III) oxide. Choice (B) is the mass of 12 mols of oxygen. Choice (D) ignores the stoichiometry fraction, and choice (E) inverts the stoichiometry fraction.

29

$$\ldots C_3H_8O + \ldots O_2 \rightarrow \ldots CO_2 + \ldots H_2O$$

The equation above represents the complete combustion of propanol (C_3H_8O). When this equation is balanced and all coefficients are reduced to lowest whole number terms, the coefficient for O_2 is

A) 6

B) 8

C) 9

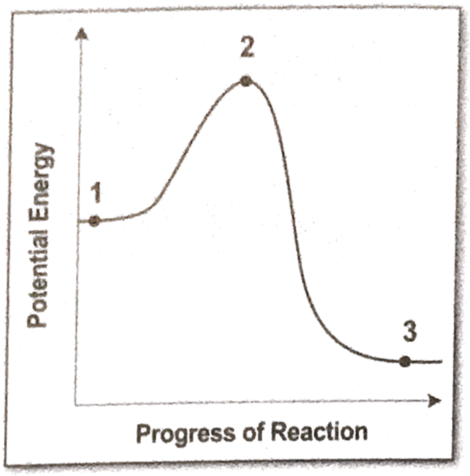
D) 12

E) 18

Choice (C) is the correct answer. The balanced equation is 2 C_3H_8O + 9 $O_2 \rightarrow$ 6 CO_2 + 8 H_2O. The coefficient for O_2 is 9. Choices (A) and (B) are the coefficients of the products. Choice (D) is the sum of the coefficients of the products minus the coefficient of C_3H_8O. Choice (E) is the number of oxygen *atoms* in the balanced chemical equation (ignoring the subscript, 2, in the O_2 molecule).

30

The graph to the right shows how potential energy changes during a chemical reaction. Which aspect of the graph provides the best evidence that the chemical reaction is exothermic?



A) The potential energy at point 2

B) The time needed to reach point 3

C) The time elapsed between points 2 and 3

D) The energy difference between points 1 and 2

E) The energy difference between points 1 and 3

Choice (E) is the correct answer. This is the potential energy difference between reactants and products. Because the change is negative, the reaction must release energy, so it is exothermic. Choice (A) is the potential energy of the transition state, when the reaction always has the highest potential energy. Choices (B) and (C) may provide information about the reaction rate but not about whether the reaction is exothermic. Choice (D) is the activation energy, which is the amount of energy the reaction needs to proceed.