SECTION: (circle one): A01 MR (Dr. Lipson) A02 (Dr. Briggs) A03 MWR (Dr. Brolo)

NAME ___________________________________________ Student No. V0_______________________
(Please print clearly.)

DISPLAY YOUR STUDENT ID CARD ON THE TOP OF YOUR DESK NOW

Answer all questions on the bubble sheet provided.

PRINT and shade in only your last name, first name, and the last 7 digits of your student ID number on the bubble sheet. i.e. Omit the leading V0.

Do NOT include any information about the course, section or date on the bubble sheet.

Hand in only the bubble sheet at the end of the test period (60 minutes).

A DATA sheet is included, unstapled, inside the cover page of this test.

This test has 6 pages (not including the DATA sheet). Count the pages before you begin.

The basic Sharp EL510 calculator is the only one approved for use in Chemistry 102.

DO NOT BEGIN UNTIL TOLD TO DO SO BY THE INVIGILATOR
This test consists entirely of multiple choice questions and is worth 50 marks. There are two marks per question except Question 1. The answers for the 26 questions in this part must be coded on the optical sense form (bubble sheet) using a *SOFT PENCIL*.

**Select the BEST response for each question below.**

1. This is Test Version A.  **Mark “A” as the answer to Question 1 on the optical sense form.**

2. A sample of Cl₂ gas with a volume of 0.482 L was collected at 17°C. Calculate the volume in liters of the gas when it is cooled to −3°C if the gas behaves as an ideal gas and the pressure remains constant.

   A. 0.459  B. 0.518  C. **0.449**  D. 0.494  E. 0.508

   \[ V_2 = V_1 \times (T_2/T_1) = 0.482 \text{ L} \times (-3+273)/(17 + 273)) = 0.482 \text{ L} \times (270/290) = 0.449 \]

3. Vessel A contains CO₂(g) at 0°C and 1 atm. Vessel B contains F₂ (g) at 0 °C and 1 atm. The two vessels have the same volume. Which of the following statement(s) are TRUE
   (i) Vessel A contains more molecules. False. They contain the same number of molecules.
   (ii) Vessel B contains more mass of gas. False. Molar mass CO₂ = 44, Molar mass F₂ = 38 Same number of molecules, but ‘lighter’ molecules, so less mass in vessel B.
   (iii) The average kinetic energy of molecules in Vessel B is higher. False. Gases at the same temperature have the same average kinetic energy.
   (iv) The root mean square (rms) speed of molecules in Vessel A is lower. True. Same average kinetic energy but heavier molecules means they are travelling slower on average.

   A. (ii) only  B. (iv) only  C. (iii) & (iv)  D. (ii) & (iv)  E. (i) & (iv)

4. A container holds a mixture of oxygen, neon and helium gases. The partial pressures are 150 torr for oxygen, 300 torr for neon and 450 torr for helium. What is the mole fraction for oxygen?

   A. **0.17**  B. 0.33  C. 0.50  D. 0.67  E. 0.2

   \[ X(O_2) = \frac{\text{moles } O_2}{\text{moles } Ne + \text{moles } He + \text{moles } O_2} = \frac{P_{O_2}}{P_{Ne} + P_{He} + P_{O2}} \]

   \[ X(O_2) = 150/(300 + 450 + 150) = 150/900 = 1/6 = 0.17 \]

5. Consider the following 5 gases. If an equal mass of each gas is placed into a separate balloon, which gas sample will have the greatest volume? Assume that the balloons are all at the same temperature and pressure. I have written in the molar masses from the Data Sheet.

   A. Kr 36  B. Cl₂ 71  C. **N₂ 28**  D. NO 30  E. O₂ 32

   Equal mass, so there will be more moles of one with the lowest molar mass – therefore greatest volume.
6. Consider three samples of gas: NO₂ at 273 K, H₂O at 350 K and SO₂ at 350 K. Compare the average kinetic energies of the molecules in these three samples.

A. Additional pressure information is needed to compare average kinetic energies. **No, we just need the temperatures.**

B. The heaviest gas (SO₂) has the highest average kinetic energy and the other average kinetic energies decrease with molar mass. **No, all gases at the same temp have the same average kinetic energy.**

C. SO₂ (350 K) and H₂O (350 K) have the same average kinetic energy while NO₂ (273 K) has a higher average kinetic energy. **No, NO₂ (273 K) has a lower average kinetic energy.**

D. SO₂ (350 K) and H₂O (350 K) have the same average kinetic energy while NO₂ (273 K) has a lower average kinetic energy. **Yes.**

E. The lightest gas (H₂O) has the highest average kinetic energy and the other average kinetic energies decrease as molar mass increases. **No, all gases at the same temp have the same average kinetic energy.**

7. Which one of the following statements about the earth’s atmosphere is CORRECT?

A. The mechanism for restoring the ozone layer over Antarctica involves the formation of polar stratospheric clouds.

Incorrect: On page 20 of the Lecture Notebook the first process mentioned under the heading of 'Ozone Depletion in Antarctica' is the formation of polar stratospheric clouds. Moreover, the accompanying illustration shows a prominent ozone hole in October (spring in the antarctic) and restored ozone concentrations by May ( autumn in the antarctic, the southern equivalent of our November). Therefore we see that the ozone concentration in the stratosphere has largely been restored before winter, therefore before the formation of the polar stratospheric clouds.

B. The first step in the formation of ozone in the stratosphere is a photoionization reaction.

Incorrect: In the Lecture Notebook fill-in text (page 19) and in the Custom Textbook (page 280) it is explained that the first step is photodissociation of oxygen molecules to oxygen atoms.

C. Only UV wavelengths of solar radiation can initiate photodissociation reactions.

Response C is correct. We're talking about dissociation of molecules that normally exist in the atmosphere, such as O₂, N₂, water, carbon dioxide, CFCs etc. All these dissociations require photons in the UV part of the spectrum.

D. The pressure of the atmosphere steadily increases with increasing altitude.

Incorrect: The pressure of the atmosphere steadily decreases with increasing altitude.

E. The “hole” in the ozone layer over Antarctica is more pronounced in the winter than in the spring.

Incorrect: The "hole" in the ozone layer over Antarctica is more pronounced in the spring, after the chlorine atoms have been released from the polar stratospheric clouds, than in the winter.

8. Suppose that the mid-day concentration of ozone O₃ in the ground-level air in a city is 0.018 ppm by volume. Calculate the number of moles of O₃ in 1.0 L of this air at STP (i.e. at 0 °C and 1 atm).

A. 1.8 × 10⁻⁸  B. 8.04 × 10⁻¹⁰  C. 1.24  D. 8.04 × 10⁻⁴  E. 0.018

0.018 ppm = 0.018 L O₃/(1×10⁶ L air) = 0.018 mol O₃/ (1×10⁶ mol air)
Standard molar volume of a gas at STP = 22.4 L/mol

so that {0.018 mol O₃/(1×10⁶ mol air) }×{1 mol air/22.4 L air} = 8.04 × 10⁻¹⁰ mol O₃/ L air

There are other ways to do this, but using the standard molar volume is a quick way.
9. It has been suggested that one way to repair the problem of stratospheric ozone depletion would be to manufacture ozone, carry it to the stratosphere, and release it. It has been estimated that it would take about 17 million airplane-loads of ozone to replenish even 10% of the stratospheric ozone. The best reason(s) that such a solution is impractical is/are:

(i) Even if we could temporarily replace the lost ozone, the natural steady-state ozone cycle would quickly be re-established at the pre-existing lower ozone concentrations. True. The delivered ozone would be subject to the same reactions as the natural ozone.

(ii) Ozone is too heavy to transport. No, it's a small-molecule gas of about the same molar mass as carbon dioxide, nitrogen dioxide, krypton, fluorine (F2), etc, so the issue is not that it's heavier to transport than other gases. It could certainly be transported.

(iii) The sudden burst of ozone would cause a climate warming problem. No, ozone was never mentioned as a greenhouse gas nor as a contributor to the greenhouse effect. Moreover, the greenhouse effect is largely a phenomenon of the troposphere, not the stratosphere.

(iv) Ozone is too reactive to be stored in tanks for transport. No, everything can be stored.

(v) Ozone, being denser than oxygen, would sink to the earth’s surface and cause damage. No. Though ozone is denser than oxygen and denser than air, the text points out that mixing of gases across atmospheric layer boundaries is slow (page 276).

A. i 
B. iii and iv 
C. ii and v 
D. i and iv 
E. i, ii, iii, iv, and v

10. Which of the following gases are significant greenhouse gases?

A. O₂, H₂O 
B. CO₂, N₂ 
C. N₂, H₂O 
D. CO₂, H₂O 
E. CO₂, H₂O, Cl₂

The molecules O₂, N₂, and Cl₂ are so symmetrical that they do not undergo a change of dipole moment upon vibration. Therefore they do not absorb IR radiation. Lecture Notebook page 22.

11. In North America, what is the main human-caused source of the sulfur dioxide (SO₂) that contributes to such pollution problems as acid rain?

A. Burning gasoline in cars and trucks. No, most of the sulfur impurities have been removed from automobile fuels.

B. Burning coal and heavy oil for electricity, heating, and industry. 

C. Volcanic gases and forest fires. No. These are mostly not human-caused anyway.

D. Mining of sulfur. No. Sulfur is a non-volatile solid.

E. Decomposition of atmospheric sulfur trioxide (SO₃). No, it doesn’t.

12. Which of the following statements is NOT CORRECT?

A. Visible and ultraviolet radiation wavelengths reach the earth’s surface and this energy is re-emitted by the earth as infra-red radiation (heat). True.

B. Absorption of infra-red radiation increases vibrational energy in a molecule. True.

C. The increase in the average world temperature since industrialization is directly correlated to an increase in the amount of CO₂ in the atmosphere. True.

D. CO₂, CH₄, and water vapour are all greenhouse gases. True.
E. The exothermic dissociation of ozone releases heat and significantly contributes to the problem of climate change/global warming. Ozone reactions occur mainly in the stratosphere. The greenhouse effect is largely a troposphere phenomenon. Besides, the actual dissociation of ozone isn’t exothermic. Energy must be put in in order to break bonds.

13. Which of the following reactions is/are NOT a significant process in the usual natural set of reactions that maintain the protective stratospheric ozone layer?

(i) \( \text{O}(g) + \text{O}_2(g) \rightarrow \text{O}_3^*(g) \) This is the usual formation of ozone.
(ii) \( \text{O}_2(g) + 2\text{NO}(g) \rightarrow 2\text{NO}_2(g) \) This happens, but in the troposphere, as part of the formation of photochemical smog.
(iii) \( \text{O}_3(g) + \text{hv} \rightarrow \text{O}_2(g) + \text{O}(g) \) This is the usual destruction of ozone.

A. (i) B. (ii) C. (iii) D. (i) and (ii) E. (ii) and (iii)

14. A system that does not do work but absorbs heat from the surroundings has

A. \( q > 0 \) and \( \Delta E < 0 \)
B. \( q > 0 \) and \( \Delta E > 0 \) q has a + sign. \( w = 0, \Delta E = q + w \), so \( \Delta E \) is also positive
C. \( q < 0 \) and \( \Delta E > 0 \)
D. \( q < 0 \) and \( \Delta E < 0 \)
E. \( q > 0 \) and \( \Delta E = 0 \)

15. Consider the following data about three identical flasks, numbered 1, 2, and 3. Each flask contains a sample of one gas; one flask contains hydrogen gas (\( \text{H}_2 \)), another nitrogen (\( \text{N}_2 \)), and a third argon gas (\( \text{Ar} \)), but we are not sure which gas is in which flask. We know the following information:

- Each flask contains 4.00 grams of the gas.
- At the same temperature, the pressure in Flask #1 is lower than the pressure in Flask #2. From this we know that moles of gas in Flask 2 > moles of gas in Flask 1
- In order for the pressure in Flask #3 to be equal to the pressure in Flask #2, Flask #3 must be cooled to a lower temperature. From this we know that moles of gas in Flask 3 > moles of gas in Flask 2.

So the order is: moles gas in Flask 3 > moles gas in Flask 2 > moles gas in Flask 1

Which of the following statements is CORRECT?

A. There are more moles of gas in Flask #1 than in Flask #2.
B. There are more moles of gas in Flask #2 than in Flask #1. See above.
C. There are more moles of gas in Flask #2 than in Flask #3.
D. There are more moles of gas in Flask #1 than in Flask #3.
E. The flasks all contain the same number of moles of gas.

16. Consider the system of flasks and gases described in Question #15 above. Which of the following statements is CORRECT?

A. Flask #3 contains Ar. B. Flask #1 contains \( \text{N}_2 \). C. Flask #1 contains \( \text{H}_2 \).
D. Flask #2 contains \( \text{H}_2 \). E. Flask #1 contains Ar.

Since the order is: moles gas in Flask 3 > moles gas in Flask 2 > moles gas in Flask 1 Since the three flasks all contain the same mass of gas, the numbers of moles will be in reverse order of molar mass. That
is, there will be more moles of the lighter gas. So the lightest gas (H₂, MM = 2) is in Flask 3, the next lightest gas (N₂, MM = 28) is in Flask 2, and the heaviest gas (Ar, A=40) is in Flask 1.

17. Suppose 1.000 × 10³ moles of oxygen gas (O₂) is compressed into a steel tank that has a volume of 45.0 L. Assuming that oxygen behaves as an ideal gas, and that the temperature of the gas and tank is 0°C, calculate the pressure inside the tank in atmospheres.
A. 5.05 × 10⁴  B. 2.24 × 10⁴  C. 498  D. 1.82  E. 489

\[
P = \frac{nRT}{V} = \frac{(1000 \text{ mol} \times 0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1} \times 273 \text{ K})}{45.0 \text{ L}} = 498 \text{ atm}
\]

18. Consider oxygen gas in the steel cylinder as described in Question #17 above. Under the conditions of V, T, and n described above, the real pressure of the oxygen gas is more than twice as high as the value calculated by the ideal gas law. The reason for this difference is:
A. At high pressure O₂ breaks down into O atoms, so there are twice as many moles of gas. No, the O₂ isn’t breaking into atoms because of pressure.
B. Real gas molecules have attractive forces which attract them to the walls of the tank. Well, maybe they do, but this won’t increase the pressure.
C. Kinetic Molecular Theory assumes that gas molecules are bigger than they actually are. No, Kinetic Molecular Theory assumes that gas molecules are smaller than they actually are.
D. **Molecules take up space, and at high pressures this becomes important.** Yes, this is why.
E. The behaviour of real gases at 0°C is not well understood. Yes it is.

19. Assume that the kinetic energy of a 1400 kg car moving at 115 km h⁻¹ can be converted entirely into heat by putting on the brakes and bringing the car to a stop. How much heat (in kJ) is that?
A. 714  B. 8.05 × 10⁴  C. 1428  D. 22.4  E. 510

\[
E_K = \frac{1}{2}mv^2 = \frac{1}{2} \times 1400 \text{ kg} \times 115^2 \text{ km}^2 \text{ h}^{-2} \times (1000)^2 \text{ m}^2 \text{ km}^{-2} \times (1^2 \text{ h}^2/3600^2 \text{ s}^2) = 7.14 \times 10^5 \text{ kg m}^2 \text{ s}^{-2}
\]

19. At an underwater depth of 56 m the pressure is 6.42 atm. What would the mole fraction of oxygen have to be in order for a SCUBA diver to experience a partial pressure of 0.21 atm oxygen in the breathing mixture, the same as it is in air at 1.0 atm?
A. 0.21  B. 0.066  C. 0.29  D. **0.033**  E. 0.33

The gas in the diver’s lungs at 6.42 atm total pressure must have O₂(g) present at a partial pressure of 0.21 atm.

\[
\text{mole fraction O}_2 = X_{O2} = (\text{moles O}_2)/(\text{total moles of gas}) = P_{O2}/P_{total} = 0.21 \text{ atm}/6.42 \text{ atm} = 0.033
\]

21. Strategies that can help decrease the quantity of sulfur dioxide (SO₂) released to the environment include:
   i) Removal of sulfur from coal before burning the coal. **Yes, this is done.**
   ii) Injecting powdered limestone into the combustion gases arising from coal-fired power plants. **Yes, this is done.**
   iii) Relying more heavily on non-hydrocarbon-fuel-generated electricity than we do now. **What a good idea.**
   iv) Mixing coal with calcium sulphate (CaSO₄) prior to combustion. **Nope, this won’t work.**
22. Magnesium burns in oxygen to form magnesium oxide: \(2\text{Mg (s)} + \text{O}_2 (g) \rightarrow 2\text{MgO(s)}\). A piece of magnesium weighing 4.86 g is placed in a sealed rigid container with 1 mole oxygen at a pressure of one atmosphere and at a temperature of 298K. The magnesium is burned completely and the container and contents then allowed to cool to 298 K. What is the final pressure in the flask in atmospheres? (You can assume that the volume occupied by the solids is negligible.)

<table>
<thead>
<tr>
<th>Option</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>A.</td>
<td>1.0</td>
</tr>
<tr>
<td>B.</td>
<td>2.43</td>
</tr>
<tr>
<td>C.</td>
<td>0.1</td>
</tr>
<tr>
<td>D.</td>
<td>0.9</td>
</tr>
<tr>
<td>E.</td>
<td>0.0</td>
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</tbody>
</table>

We could notice that the atomic mass of Mg is 24.3, so a tenth of a mole would be 2.43 g, so the amount supplied in this problem is 0.20 mol Mg. For every two moles of Mg that react, one mole of \(\text{O}_2\) reacts. Therefore 0.10 mol \(\text{O}_2\) will react here. But we started with 1.0 mol. That leaves 0.9 mol \(\text{O}_2\) left over unreacted. If the original pressure of 1 mol of oxygen was 1 atm, and we used up one tenth of it, then the new pressure must be 0.9 atm. (This is because oxygen is the only gas present.)

23. The change in internal energy (\(\Delta E\)) for combustion of carbon is -410 kJ mol\(^{-1}\).

\[
\text{C(s)} + \text{O}_2 (g) \rightarrow \text{CO}_2(g) \quad \Delta E = -410 \text{ kJ}
\]

Assuming that no work is done by the reaction, calculate the change in internal energy (\(\Delta E\)) for the complete combustion of 60.0 g carbon?

<table>
<thead>
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<th>Option</th>
<th>Value</th>
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<tbody>
<tr>
<td>A.</td>
<td>82 kJ</td>
</tr>
<tr>
<td>B.</td>
<td>-2050 kJ</td>
</tr>
<tr>
<td>C.</td>
<td>+2050 kJ</td>
</tr>
<tr>
<td>D.</td>
<td>2050 J</td>
</tr>
<tr>
<td>E.</td>
<td>-82 kJ</td>
</tr>
</tbody>
</table>

Atomic mass of carbon is 12. Therefore 60.0 g C is 5.0 mol. Therefore the change in internal energy will be five times the amount shown above for one mole, namely -2050 kJ.

24. Consider the reaction that forms ammonia from nitrogen and hydrogen:

\[
\text{N}_2 (g) + 3\text{H}_2 (g) \rightarrow 2\text{NH}_3 (g)
\]

1.2 mol \(\text{N}_2\) (g) and 3.0 mol \(\text{H}_2\) (g) are mixed in a rigid flask at 0°C. The initial total pressure upon mixing is 4.7 atm. Assuming that the reaction goes to completion (i.e. until one or both reactants is/are used up), what is the final pressure (atm) in the flask?

<table>
<thead>
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<th>Option</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
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</tr>
<tr>
<td>B.</td>
<td>2.2</td>
</tr>
<tr>
<td>C.</td>
<td>2.6</td>
</tr>
<tr>
<td>D.</td>
<td>9.0</td>
</tr>
<tr>
<td>E.</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Every 3 mol \(\text{H}_2\) consumed uses up 1 mol \(\text{N}_2\). So all the \(\text{H}_2\) will be consumed forming 2 mol \(\text{NH}_3\) (g), and there will be 0.2 mol \(\text{N}_2\) left over. Therefore the final number of moles of gas present is \(2 + 0.2 = 2.2\) mol gas. The volume is constant (rigid flask) and the temperature is the same (there’s no information to the contrary), so we can manipulate the ideal gas law to show that \(P_1/n_1 = P_2/n_2\), leading to \(P_2 = P_1 (n_2/n_1)\)

\[
P_2 = P_1 (n_2/n_1) = 4.7 \text{ atm } (2.2 \text{ mol/4.2 mol}) = 2.5 \text{ atm}
\]
25. The graph at the right shows PV/RT as a function of pressure for one mole of an ideal gas (horizontal dashed line) and for several real gases. One notices that for most of the real gases PV/RT is smaller than predicted by the ideal gas law for lower pressures. The reason for this deviation from ideal behavior is:

A. Real gas molecules take up space (i.e. have volume). This explains the deviation at high pressures.

B. Kinetic Molecular Theory assumes that collisions of gas particles are perfectly elastic. True, but doesn’t by itself explain this observation about real gases.

C. Real gas molecules have intermolecular forces of attraction. Yes, and this makes the observed volume smaller than predicted for modest pressures.

D. The volume of an ideal gas is inversely proportional to the pressure. True, but not an explanation of this observation.

E. The volume of real gas molecules is negligible in comparison to the total gas volume. True, but not an explanation of this observation.

26. Which of the following reactions is/are important in the formation of ground-level photochemical smog? (Molecule M is some unspecified gas molecule.)

(i) \( \text{NO}_2 (g) + \text{hv} \rightarrow \text{NO} (g) + \text{O} (g) \)

(ii) \( \text{N}_2 (g) + \frac{1}{2}\text{O}_2 (g) + \text{heat} \rightarrow \text{N}_2\text{O} (g) \) \( \text{N}_2 \) and \( \text{O}_2 \) do react and this reaction contributes to the formation of photochemical smog, but the product is mostly nitric oxide (NO), not \( \text{N}_2\text{O} \).

(iii) \( \text{O} (g) + \text{O}_2 (g) + \text{M} (g) \rightarrow \text{O}_3 (g) + \text{M}^* (g) \)

A. (i) only  B. (i), (ii) & (iii)  C. (iii) only  D. (i) and (ii)  E. (i) and (iii)

END