I. Below are six designs that were submitted for reversible heat engines. None have been built, and it is your job to decide which is the best design. The amount of thermal energy transferred from the hot reservoir to the engine, and from the engine to the cold reservoir is shown for one cycle. The amount of work done in one cycle is also shown.

<table>
<thead>
<tr>
<th>Design</th>
<th>T_h (K)</th>
<th>Work (J)</th>
<th>T_c (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>650</td>
<td>800</td>
<td>250</td>
</tr>
<tr>
<td>B</td>
<td>550</td>
<td>900</td>
<td>250</td>
</tr>
<tr>
<td>C</td>
<td>700</td>
<td>2000</td>
<td>350</td>
</tr>
<tr>
<td>D</td>
<td>480</td>
<td>1000</td>
<td>320</td>
</tr>
<tr>
<td>E</td>
<td>600</td>
<td>1000</td>
<td>300</td>
</tr>
<tr>
<td>F</td>
<td>400</td>
<td>800</td>
<td>240</td>
</tr>
</tbody>
</table>

a) Which of the engines, A through F, are allowable by the 1st law of thermodynamics? Please explain your reasoning.

By 1st law, energy is conserved. So \[ Q_{in} = W + Q_{out} \]

Allowable: A, C, D, F

B: \[ 900 \neq 450 + 400 \]

E: \[ 1000 \neq 900 + 500 \]

b) Of those that are allowable by the 1st law (that you selected in part a), which ones are also allowable by the 2nd law of thermodynamics? Please explain your reasoning.

By 2nd law, \[ \sum Q \geq 0 \], so \[ \frac{Q_{in}}{T_h} \leq \frac{Q_{out}}{T_c} \]. Out of A, C, D, F this is true only for C and F.

For C and F, only

A: \[ 0 \leq \frac{900}{480} \] and D: \[ \frac{600}{480} \]

C: \[ \frac{800}{400} = 2 \]

C is

C IS MOST EFFICIENT

C: \[ \frac{W}{Q_{in}} = \frac{800}{2000} = 40\% \]

F: \[ \varepsilon = \frac{W}{Q_{in}} = \frac{300}{800} = 37.5\% \]
II. The P-V diagram shown at the right describes a 3-leg cyclic process. The mass of the gas is constant.

a) Fill in the missing spaces in the table below.

<table>
<thead>
<tr>
<th></th>
<th>What happens to the pressure?</th>
<th>What happens to the temperature?</th>
<th>What happens to the volume?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 → 2</td>
<td><strong>remains constant</strong></td>
<td><strong>DECREASES</strong></td>
<td><strong>DECREASES</strong></td>
</tr>
<tr>
<td>2 → 3</td>
<td><strong>INCREASES</strong></td>
<td><strong>increases</strong></td>
<td><strong>STAYS CONSTANT</strong></td>
</tr>
<tr>
<td>3 → 1</td>
<td><strong>DECREASES</strong></td>
<td><strong>remains constant</strong></td>
<td><strong>INCREASES</strong></td>
</tr>
</tbody>
</table>

b) How much work is done in one complete cycle 1 → 2 → 3 → 1 if:

- \( P_1 = 200 \text{ kPa} \)
- \( P_2 = 640 \text{ kPa} \)
- \( V_1 = 4.0 \times 10^{-3} \text{ m}^3 \) and
- \( V_2 = 1.25 \times 10^{-3} \text{ m}^3 \)

\[ W_{1→2} = -P_1 \Delta V \]
\[ W_{2→3} = 0 \]
\[ W_{3→1} = -nR \Delta T \ln \left( \frac{V_3}{V_1} \right) \]

Since \( PV = nR \Delta T \)

\[ W_{1→2} = (2.0 \times 10^3 \text{ Pa}) \left( \frac{300}{305} \right) \left( \frac{0.18}{0.03} \right)^2 \text{ J} = 550 \text{ J} \]
\[ W_{3→1} = -800 \ln \left( \frac{V_1}{V_3} \right) \text{ J} = -930 \text{ J} \]

\[ W_{\text{TOTAL}} = (-930 \text{ J} + 550 \text{ J}) \text{ J} = -380 \text{ J} \]

\[ W_{\text{By gas}} = 380 \text{ J} \]

c) Circle the Pressure vs Temperature graph that best describes this cycle and EXPLAIN YOUR REASONING.

Explain your reasoning:

1 → 2  **pressure is constant and temp decreases**  (eliminates D)

2 → 3  **pressure and temperature increase**  (eliminates A & C)
3. Three moles of ideal gas are sealed inside a cylinder that has a movable piston. With the piston fixed in place, the pressure, volume and temperature of the gas are measured. Then the volume is allowed to double while temperature is held constant. The average speed of the gas molecules

a) doubles.

b) quadruples.

c) is half as big as it was.

d) is one-quarter as big as it was.

e) is unchanged.

4. It is known that a plastic block changes temperature by 5 °C when 3000 J of heat are transferred to/from it. This block, starting at room temperature (20 °C), is placed into an insulated jar that contains 0.5 kg of water at a temperature of 100 °C. Which of the following choices is closest to the final temperature?

(The specific heat of water is 4180 J/kg • °C, the latent heat of fusion of water is 334 × 10³ J/kg)

a) 30°C

b) 40°C

c) 60°C

d) 80°C

e) 90°C

5. Two blocks with the same weight but different dimensions are floating in water at different levels. Block A is as tall as block B but different in both other dimensions. Compare the buoyant forces exerted on the blocks. Which of the following statements is true?

a) The buoyant force exerted on block A is greater than the buoyant force on block B.

b) The buoyant force exerted on block A is less than the buoyant force on block B.

c) The buoyant force exerted on block A is the same as the buoyant force on block B.

d) We need to know the density of the blocks in order to answer this question.

e) We need to know the volumes submerged and the density of the fluid in order to answer this question.
6. A child plays with a helium-filled balloon inside her warm house. The helium in her balloon has a density \( D \). She takes her balloon outside and it is a very cold day. When she gets outside she notices that the balloon shrinks, and that it takes up 9/10 of the space that it did in her house. If no helium escapes from the balloon, then the density of the helium in the balloon after shrinking is:

\[ D_1 = \frac{M}{V_1} \text{ MASS STAYS THE SAME} \]

\[ D_2 = \frac{M}{\frac{9}{10}V_1} = \frac{10}{9} \left( \frac{M}{V_1} \right) = \frac{10}{9} D \]

a) \( (9/10)D \)

b) \( (10/9)D \)

c) \( D \)

d) \( (1/10)D \)

e) \( (11/10)D \)

7. In each case a beaker is filled with water to the height shown. The diameters of the beakers are also shown. The cylinders have identical holes in their side at the same height above the base. There are corks in all of the holes. The corks are then removed from each tank. Rank the initial speed of the water flowing out of the holes from GREATEST to LEAST.

a) B, D, A, C

b) C, A, D, B

c) C, A=D, B

d) B, A, C=D

e) none of the above are correct

8. A sample of one mole of an ideal gas is confined to a container with a movable piston. The \( PV \) diagram shows the initial state of the sample, represented by point \( X \), and the final state, represented by point \( Y \). Also shown are two different processes that can be used to take the gas sample from \( X \) to \( Y \). (Both Process I and Process II start at state \( X \) and end at state \( Y \).) Which of the statements, I through \( V \), are CORRECT?

I. The heat is transferred out of the gas in both processes.

II. The heat is transferred into the gas in both processes.

III. The heat is transferred into the gas in one of the processes and out of the gas in the other.

IV. The amount of heat transfer in Process I is the same as it is in Process II.

V. The amount of heat transfer in Process I is NOT the same as it is in Process II.

a) I and IV

b) II and IV

c) III and IV

d) I and V

e) II and V

f) III and V
I. Below are six designs that were submitted for reversible heat engines. None have been built, and it is your job to decide which is the best design. The amount of thermal energy transferred from the hot reservoir to the engine, and from the engine to the cold reservoir is shown for one cycle. The amount of work done in one cycle is also shown.

![Diagram of six heat engines A through F](image)

a) Which of the engines, A through F, are allowable by the 1st law of thermodynamics? Please explain your reasoning.

*BY THE 1ST LAW* \( |Q_H| = W + Q_c \)

A, B, E, F

c: \( 450J + 500J = 1000J \)

D: \( 450J + 400J = 900J \)

b) Of those that are allowable by the 1st law (that you selected in part a), which ones are also allowable by the 2nd law of thermodynamics? Please explain your reasoning.

*BY THE 2ND LAW* \( \frac{|Q_H|}{T_H} < \frac{|Q_c|}{T_c} \)

A: \( \frac{1000J}{480K} > \frac{600J}{320K} \) No

B: \( \frac{600J}{400K} < \frac{500J}{240K} \) Yes

E: \( \frac{600J}{400K} < \frac{350J}{350K} \) Yes

F: \( \frac{2000J}{320K} < \frac{1200J}{350K} \) Yes

c) We can assume that these are not all Carnot engines. Of those that are allowable by both the 1st law AND the 2nd law of thermodynamics, which one has the greatest real efficiency, based on the predicted work outcome of the engine? (show your work)

**Efficiencies:**

B: \( \varepsilon = \frac{\text{600 J}}{\text{200 J}} = 37.5\% \)

F: \( \varepsilon = \frac{\text{800 J}}{\text{2000 J}} = 40\% \) => Most Efficient
II. The P-V diagram shown at the right describes a 3-leg cyclic process. The mass of the gas is constant.

a) Fill in the missing spaces in the table below.

<table>
<thead>
<tr>
<th></th>
<th>What happens to the</th>
<th>What happens to the</th>
<th>What happens to the</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pressure?</td>
<td>volume?</td>
<td>temperature?</td>
</tr>
<tr>
<td>1 → 2</td>
<td>remains constant</td>
<td>decreases</td>
<td>decreases</td>
</tr>
<tr>
<td>2 → 3</td>
<td>increases</td>
<td>stays constant</td>
<td>increases</td>
</tr>
<tr>
<td>3 → 1</td>
<td>decreases</td>
<td>increases</td>
<td>remains constant</td>
</tr>
</tbody>
</table>

b) How much work is done by the gas in one complete cycle 1 → 2 → 3 → 1 if:

\[ P_1 = 200 \text{ kPa} \]
\[ P_2 = 800 \text{ kPa} \]
\[ V_1 = 5.0 \times 10^{-3} \text{ m}^3 \]
\[ V_2 = 1.25 \times 10^{-3} \text{ m}^3 \]

\[ W_{1 \rightarrow 2} = -P_1 A V \]
\[ W_{2 \rightarrow 3} = 0 \]
\[ W_{3 \rightarrow 1} = nRT \ln \left( \frac{V_1}{V_2} \right) = -PV \ln \left( \frac{V_2}{V_1} \right) \]
\[ W_{1 \rightarrow 2} = -\left(200 \times 10^3 \text{ Pa}\right)\left(3.75 \times 10^{-3} \text{ m}^3\right) = -750 \text{ J} \]
\[ W_{2 \rightarrow 1} = \frac{1000 \text{ J}}{\ln \left( \frac{5}{1.25} \right)} = -1386 \text{ J} \]
\[ \Rightarrow W_{\text{TOTAL}} = -636 \text{ J} \]

\[ \begin{align*}
W_{\text{TOTAL}} \text{ by gas} & = +640 \text{ J} \\
\end{align*} \]

c) Circle the Pressure vs Temperature graph that best describes this cycle and PLEASE EXPLAIN YOUR REASONING.

A  

B  

C  

D  

Explain your reasoning:

See V.1
3. Three moles of ideal gas are sealed inside a cylinder that has a movable piston. With the piston fixed in place, the pressure, volume and temperature of the gas are measured. Then the volume is halved while the temperature is held constant. The average speed of the gas molecules

a) is half as big as it was.

b) is one-quarter as big as it was.

c) doubles.

d) is unchanged.

e) quadruples.

4. It is known that a plastic block changes temperature by 5 °C when 1500 J of heat are transferred to/from it. This block, starting at room temperature (20 °C), is placed into an insulated jar that contains 0.5 kg of water at a temperature of 100 °C. Which of the following choices is closest to the final temperature? (The specific heat of water is 4180 J/kg °C)

a) 90°C

b) 80°C

c) 60°C

d) 40°C

e) 30°C

5. Two blocks with the same weight but different dimensions are floating in water at different levels. Block A is as tall as block B but different in both other dimensions. Compare the buoyant forces exerted on the blocks. Which of the following statements is true?

a) The buoyant force exerted on block A is less than the buoyant force on block B.

b) The buoyant force exerted on block A is greater than the buoyant force on block B.

c) We need to know the density of the blocks in order to answer this question.

d) We need to know the volumes submerged and the density of the fluid in order to answer this question.

e) The buoyant force exerted on block A is the same as the buoyant force on block B.
6. One night Marcia pumped up a soccer ball inside of her warm house, filling the ball with air of density \( D \), and then she tossed the ball into the back of her car. The temperatures plummeted overnight, and when she saw the ball in the morning she noticed that it took up only \( \frac{10}{11} \) of the space that it did in her house. Assuming that no air escaped from the ball, then the density of the air in the ball in the morning was:

- a) \( D \)
- b) \( \left( \frac{1}{10} \right) \) * \( D \)
- c) \( \left( \frac{11}{10} \right) \) * \( D \)
- d) \( \left( \frac{9}{10} \right) \) * \( D \)
- e) \( \left( \frac{10}{9} \right) \) * \( D \)

\[
D_{\text{in}} = \frac{M}{V_{\text{in}}} = \frac{\text{mass}}{\text{volume}_{\text{in}}}
\]

\[
D_{\text{out}} = \frac{\text{mass}}{\text{volume}_{\text{in}} \left( \frac{10}{11} \right)} = \left( \frac{10}{11} \right) D_{\text{in}}
\]

7. In each case a beaker is filled with water to the height shown. The diameters of the beakers are also shown. The cylinders have identical holes in their side at the same height above the base. There are corks in all of the holes. The corks are then removed from each tank. Rank the initial speed of the water flowing out of the holes from GREATEST to LEAST.

- a) B, A, C=D
- b) B, D, A, C
- c) C, A, D, B
- d) C, A=D, B
- e) none of the above are correct

\[
p - p_0 = \rho gh \quad \text{and} \quad p - p_0 = \frac{1}{2} \rho v^2 \quad \Rightarrow \quad \rho gh = \frac{1}{2} \rho v^2 \quad \text{so the speed depends on h only}
\]

8. A sample of one mole of an ideal gas is confined to a container with a movable piston. The PV diagram shows the initial state of the sample, represented by point X, and the final state, represented by point Y. Also shown are two different processes that can be used to take the gas sample from X to Y. (Both Process I and Process II start at state X and end at state Y.) Which of the statements below, I through V, are CORRECT?

I. The heat is transferred out of the gas in both processes.
II. The heat is transferred into the gas in both processes.
III. The heat is transferred into the gas in one of the processes and out of the gas in the other.
IV. The amount of heat transfer in Process I is the same as it is in Process II.
V. The amount of heat transfer in Process I is NOT the same as it is in Process II.

- a) I and IV
- b) I and V
- c) II and IV
- d) II and V
- e) III and IV
- f) III and V

\[
\text{See V.1}
\]