## Question 2: Translation Between Representations (TBR) — 12 points

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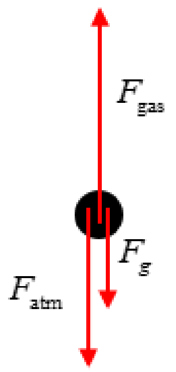
|---|---|---|
| **A** | For drawing an appropriately labeled arrow downward to represent the direction of the force $F_g$ of gravity that is exerted on the piston | **Point A1** |
| | For drawing an appropriately labeled arrow downward to represent the direction of the force $F_{\text{atm}}$ of the atmosphere that is exerted on the piston | **Point A2** |
| | For drawing an appropriately labeled arrow upward to represent the direction of the force $F_{\text{gas}}$ of the gas that is exerted on the piston | **Point A3** |

**Example Response**

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| **B** | For a multistep derivation that includes $U = \frac{3}{2}nRT$, $U = \frac{3}{2}Nk_BT$, $PV = nRT$, $PV = Nk_BT$, $\vec{a}_{\text{sys}} = \frac{\sum \vec{F}}{m_{\text{sys}}} = \frac{\vec{F}_{\text{net}}}{m_{\text{sys}}}$, $\sum \vec{F} = 0$, $P = \frac{F_\perp}{A}$, an equation that is equivalent to one of the equations listed, or a relevant equation<br>**Scoring Note:** Vector notation is not required for this point to be earned. | **Point B1** |
| | For correctly relating the internal energy of the gas to $PV = nRT$ or $PV = Nk_BT$ (e.g., $U = \frac{3}{2}PV$)<br>**Scoring Note:** This point can be earned if the response refers to a generic pressure instead of an absolute pressure. | **Point B2** |
| | For an expression for **one** of the following:<br>• The correct absolute pressure $P$ of the gas (e.g., $PA - P_{\text{atm}}A - Mg = 0$ or $P = P_{\text{atm}} + \frac{Mg}{A}$).<br>• The absolute pressure of the gas that is consistent with an incorrect diagram provided in part A. | **Point B3** |
| | For an expression for the internal energy of the gas that is consistent with the expression for the pressure $P$ of the gas that is derived for point B3 (e.g., $U = \frac{3}{2}\left(P_{\text{atm}} + \frac{Mg}{A}\right)V_0$)<br>**Scoring Note:** A correct, isolated, final expression earns points B2, B3, and B4. | **Point B4** |

**Example Response**

$$\vec{a}_{\text{sys}} = \frac{\sum \vec{F}}{m_{\text{sys}}} = \frac{\vec{F}_{\text{net}}}{m_{\text{sys}}}$$

$$\Sigma\vec{F} = 0$$

$$P = \frac{F_{\perp}}{A}$$

$$PA - P_{\text{atm}}A - F_g = 0$$

$$PA - P_{\text{atm}}A - Mg = 0$$

$$P - P_{\text{atm}} - \frac{Mg}{A} = 0$$

$$P = P_{\text{atm}} + \frac{Mg}{A}$$

$$U = \frac{3}{2}nRT$$

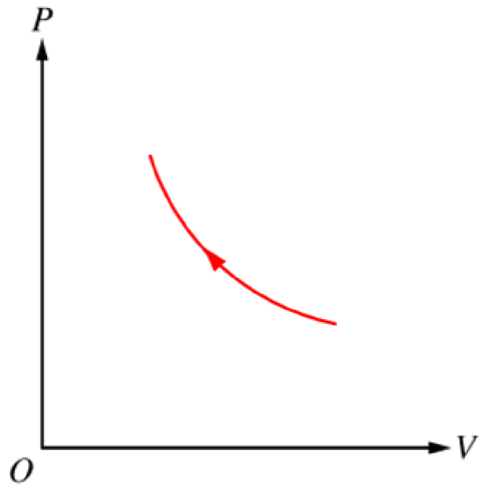
$$PV = nRT$$

$$U = \frac{3}{2}PV$$

$$U = \frac{3}{2}\left(P_{\text{atm}} + \frac{Mg}{A}\right)V_0$$

| | | |
|---|---|---|
| **C** | For drawing a line or curve that connects a point in the lower right region of the diagram to the upper left region of the diagram | **Point C1** |
| | For drawing a curve that is concave up | **Point C2** |
| | For drawing an arrow that points from a greater to a lesser volume or from a lesser to a greater pressure | **Point C3** |

**Example Response**



| | | |
|---|---|---|
| **D** | For indicating $T_{\text{new}} > T_0$ or an indication that is consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C | **Point D1** |
| | For **one** of the following:<br>• A correct justification that indicates that the pressure of the gas has increased for the same volume using features of the diagram in part A, the derivation in part B, or features of the graph in part C<br>• A correct justification that indicates that the volume of the gas has increased for the same pressure using features of the diagram in part A, the derivation in part B, or features of the graph in part C<br>• A justification that is consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C<br>**Scoring Notes:**<br>• If the justification is consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C, and the justification is consistent with an incorrect selection, points D1 and D2 are earned.<br>• If the justification is consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C, but the justification is not consistent with an incorrect selection, only point D2 is earned.<br>• If the justification is not consistent with incorrect features of the diagram in part A, an incorrect derivation in part B, or incorrect features of the graph in part C, but $T_{\text{new}} > T_0$ is selected, only point D1 is earned. | **Point D2** |

**Example Responses**

*Using the representation from part A if the response considers the volume of the gas at time $t_0$ and the final volume of the gas after the process described in part D*

- *For the piston to remain in equilibrium, the increase in weight from the block would require a greater force, and, therefore, pressure, from the gas on the piston. Because the two volumes are equal, a greater pressure will correspond to a greater temperature. Therefore, $T_{\text{new}} > T_0$.*

*Using the representation from part B*

- *According to the derivation in part B, if volume increases while pressure remains constant, the internal energy of the gas increases, and, therefore, the temperature will increase. Therefore, $T_{\text{new}} > T_0$.*
- *According to the derivation in part B, the added mass on the piston when the volume is back to the original volume increases the internal energy of the gas. Thus, the temperature increases. Therefore, $T_{\text{new}} > T_0$.*

*Using the representation from part C if the response considers the volume of the gas at time $t_f$ and the final volume of the gas after the process described in part D*

- *Looking at the graph, if the volume is increased at constant pressure, from the end of the curve that I drew, the product of pressure and volume, and therefore, temperature, will be greater at the end of this process than at the beginning. Therefore, $T_{\text{new}} > T_0$.*

*Using the representation from part C if the response considers the volume of the gas at time* $t_0$ *and the final volume of the gas after the process described in part D*

- *According to the graph in part C, the pressure of the gas at the end of the process in part C is greater than that at the beginning of the process. For the gas to occupy the original volume (at time* $t_0$*), the final gas pressure must be greater than the original gas pressure. Therefore,* $T_{\text{new}} > T_0$.
- *According to the graph in part C, if the pressure is increased by the added block, and the volume is the same from the beginning of the curve that I drew, the product of pressure and volume, and, therefore, temperature, will be greater at the end of this process than at the beginning. Therefore,* $T_{\text{new}} > T_0$.