AP® PHYSICS B
2006 SCORING GUIDELINES

General Notes About 2006 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 5

10 points total | **Distribution of points**

(a)

(i) 2 points

From the ideal gas law
$PV = nRT$

For recognizing that $\frac{PV}{T}$ is constant throughout the cycle — 1 point

Using the fact that pressure is the same for states 1 and 2

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$T_2 = \frac{V_2 T_1}{V_1}$$

For substituting correct values into a correct expression — 1 point

$$T_2 = \left(0.50\ \text{m}^3\right)(373\ \text{K})\Big/\left(0.25\ \text{m}^3\right)$$

$$T_2 = 746\ \text{K}$$

<u>Note</u>: *Some students earned the first point by correctly calculating the value of n or the product nR using the given conditions in state 1. The student could have then proceeded to the correct substitutions in both parts (i) and (ii).*

(ii) 1 point

Using the fact that volume is the same for states 1 and 3

$$\frac{P_1}{T_1} = \frac{P_3}{T_3}$$

$$T_3 = \frac{P_3 T_1}{P_1}$$

For substituting correct values into a correct expression — 1 point

$$T_3 = \left(1.5 \times 10^5\ \text{Pa}\right)(373\ \text{K})\Big/\left(1.0 \times 10^5\ \text{Pa}\right)$$

$$T_3 = 560\ \text{K}$$

Question 5 (continued)

Distribution of points

(b) 4 points

Calculate the work done on the gas in each of the three processes making up the cycle.

For calculating the work done from state 1 to state 2 given constant pressure — 1 point

$W_{1\to2} = -P\Delta V = -(1.0\times10^5\ \text{Pa})(0.25\ \text{m}^3) = -25000\ \text{J}$ (negative sign not required)

For calculating the work done from state 2 to state 3 using average pressure — 1 point

$W_{2\to3} = -P_{avg}\Delta V = -(1.25\times10^5\ \text{Pa})(-0.25\ \text{m}^3) = +31250\ \text{J}$ (positive sign not required)

Note: *A student that correctly calculated the area under the curve for either process earned the point for that process.*

For noting that no work is done going from state 1 to state 3 or for indicating net work is only contributed in going from state 1 to 2 and state 2 to 3 — 1 point

$W_{3\to1} = 0$ or $W_{net} = W_{1\to2} + W_{2\to3}$

For the correct answer with the correct sign — 1 point

$W_{net} = +6250\ \text{J}$

Alternate solution — *Alternate points*

For stating that the net work done is the area of the triangle or for implying such by using the expression for the area of a triangle, $A = \frac{1}{2}\text{base}\cdot\text{height}$ — *1 point*

For correctly substituting the base value from the graph — *1 point*

For correctly substituting the height value from the graph — *1 point*

$$W = \frac{1}{2}\left(1.5\times10^5\ \text{Pa} - 1.0\times10^5\ \text{Pa}\right)\left(0.50\ \text{m}^3 - 0.25\ \text{m}^3\right)$$

For the correct answer with the correct sign — *1 point*

$W_{net} = +6250\ \text{J}$

(c) 3 points

For checking "Removed" — 1 point

Note: *Checking the box consistent with the sign of the net work calculated in part (b) earned full credit, but checking the incorrect option resulted in no additional credit.*

For referring to the first law of thermodynamics implicitly or explicitly — 1 point

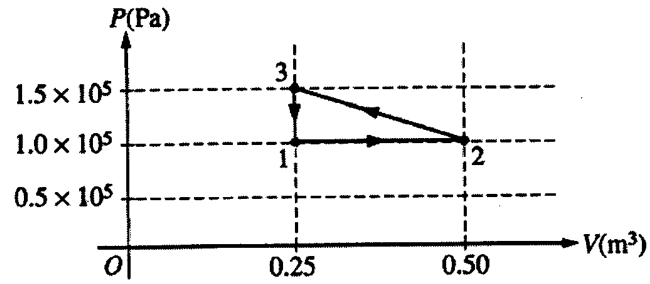
$\Delta U = Q + W$

For noting that the consequence of the closed thermodynamic cycle is that the internal energy does not change (since the gas ends at the same temperature at which it started), and/or that the heat transferred equals the opposite of the work done on gas — 1 point

$\Delta U = 0$ or $Q = -W$

This can also be expressed in words.

Example: Work is done on the gas, which would add energy to the gas. Heat must be removed in order for the internal energy to be unchanged after one cycle.



5. (10 points)

A cylinder with a movable frictionless piston contains an ideal gas that is initially in state 1 at 1×10^5 Pa, 373 K, and 0.25 m^3. The gas is taken through a reversible thermodynamic cycle as shown in the PV diagram above.

(a) Calculate the temperature of the gas when it is in the following states.

i. State 2 $PV = nRT$, at both states, nR equal

$$\therefore \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad T_2 = \frac{P_2 V_2 T_1}{P_1 V_1}, \quad P_2 = P_1$$

$$T_2 = \frac{(0.50 m^3)(373 K)}{(0.25 m^3)} = 746 K.$$

ii. State 3

$$\frac{P_1 V_1}{T_1} = \frac{P_3 V_3}{T_3} \quad V_1 = V_3 \quad T_3 = \frac{P_3 T_1}{P_1}$$

$$T_3 = \frac{(1.5 \times 10^5 Pa)(373 K)}{(1 \times 10^5 Pa)}$$

$$= 560 K$$

(b) Calculate the net work done on the gas during the cycle.

1 → 2. $W_{on} = -P\Delta V$

$= 1.0\times10^5 Pa\,(0.50 - 0.25)\,m^3$

$= -25000\,J$

2 − 3 W = area under $2 \xrightarrow{line} 3$ $= \frac{h(s_1+s_2)}{2}$

$= \frac{(0.50-0.25)}{2}(1.0\times10^5 + 1.5\times10^5)$

$= +31250\,J$

3 − 1 No work.

$W_{net} = 31250 - 25000 = 6250\,J$

(c) Was heat added to or removed from the gas during the cycle?

____ Added ✓ Removed ____ Neither added nor removed

Justify your answer.

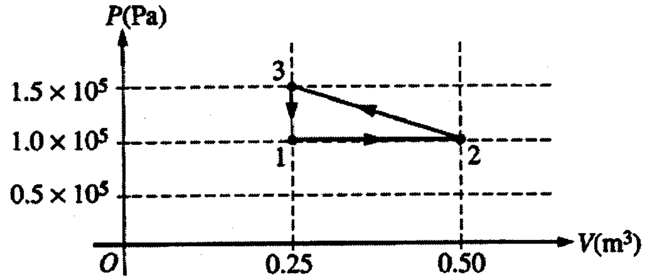
$\Delta U = 0$ since any cycle returns to its original state at the end.

$\Delta U = \Delta Q + \Delta W$

$\Delta Q = -W$

Since $W = +$, $Q = -$

∴ heat removed



5. (10 points)

A cylinder with a movable frictionless piston contains an ideal gas that is initially in state 1 at 1×10^5 Pa, 373 K, and 0.25 m^3. The gas is taken through a reversible thermodynamic cycle as shown in the PV diagram above.

(a) Calculate the temperature of the gas when it is in the following states.

i. State 2

$PV = nRT$

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$\frac{(1\times10^5 Pa)(.25 m^3)}{373 K} = \frac{(1.0\times10^5 Pa)(.5 m^3)}{T_2}$

$T_2 = 746 K$

ii. State 3

$\frac{P_1V_1}{T_1} = \frac{P_3V_3}{T_3}$

$\frac{P_1}{T_1} = \frac{P_3}{T_3}$

$\frac{(1\times10^5 Pa)}{373 K} = \frac{(1.5\times10^5 Pa)}{T_3}$

$T_3 = 559.5 K$

(b) Calculate the net work done on the gas during the cycle.

$W = -P\Delta V$

$W_{1\to2} = (1\times10^5)(.25)$

$= 2.5\times10^4$ J

$W_{2\to3} \cdot 1.5\times10^5(-.25)$

$= -3.75\times10^4$ J

$= -2.5\times10^4$ J

$W_{3\to1} = (1.0\times10^5)(0) = 0$

NET WORK

2.5×10^4 J

-3.75×10^4 J

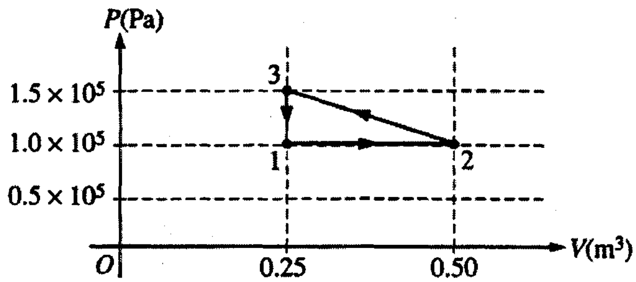
-1.25×10^4 J

(c) Was heat added to or removed from the gas during the cycle?

____ Added ✓ Removed ____ Neither added nor removed

Justify your answer.

If work is negative, the system did work on its surroundings, and therefore gave up heat.



5. (10 points)

A cylinder with a movable frictionless piston contains an ideal gas that is initially in state 1 at 1×10^5 Pa, 373 K, and 0.25 m^3. The gas is taken through a reversible thermodynamic cycle as shown in the *PV* diagram above.

(a) Calculate the temperature of the gas when it is in the following states.

i. State 2

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{(1\cdot10^5 Pa)(.25 m^3)}{373 K} = \frac{(1.0\cdot10^5 Pa)(.50 m^3)}{x}$$

$$\frac{x(1\cdot10^5 Pa)(.25 m^3)}{(1.10^5 Pa)(.25)} = \frac{(373)(1.0\cdot10^5)(.50 m^3)}{(1\cdot10^5)(.25)}$$

$$x = \frac{(373)(.50)}{.25} = 746 K$$

ii. State 3

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{(1\cdot10^5)(.25)}{373} = \frac{(1.5\cdot10^5)(.25)}{x}$$

$$x(1\cdot10^5)(.25) = (373)(1.5\cdot10^5)(.25)$$

$$x = \frac{(373)(1.5\cdot10^5)(.25)}{(1.10^5)(.25)} \quad x = 562.5 K$$

(b) Calculate the net work done on the gas during the cycle.

$W = -P\Delta V$

$W = -(1 \cdot 10^5)(0)$

net work = 0

(c) Was heat added to or removed from the gas during the cycle?

____ Added ____ Removed __✓__ Neither added nor removed

Justify your answer.

The heat was niether added or removed because the pressure and volume were conserved. By Plank's rules we can use the equation $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$, to show that the heat remained the same.

Question 5

Overview

This 10-point question was intended to test student understanding of thermodynamics. An unspecified amount of an ideal gas was taken through a cyclic thermodynamic process, which traced out a triangle as shown on the given PV diagram. Students were given the initial temperature of the gas. In part (a) they were to use the ideal gas equation of state along with pressure and volume data taken from the graph to calculate the temperatures in the two other states at the vertices of the cycle. In part (b) students were asked to calculate the net work done on the gas in one cycle. In part (c) they were directed to decide whether the net effect of the cycle was to add heat to the gas or remove heat from the gas, or whether no net heat transfer occurred. For full credit, students had to justify their answer.

Sample: B5A
Score: 10

This student explicitly states in part (a) that PV/T is constant. The entire response is complete and concise.

Sample: B5B
Score: 5

Part (a) earned full credit. In part (b) the work done from state 2 to state 3 is incorrect, so only 2 points were earned there. Part (c) earned nothing since the choice is inconsistent with the sign of the net work obtained.

Sample: B5C
Score: 4

Part (a) earned full credit. In part (b) the student arrives at zero work because the volume does not change after one cycle. Part (c) earned 1 point for a consistent choice, but the justification is incorrect.