AP® PHYSICS B
2010 SCORING GUIDELINES

General Notes

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for the 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 — for example, 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 Exams equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

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 4

10 points total | **Distribution of points**

(a) 3 points

$e = W_{out}/Q_{in}$ or $e = P_{out}/P_{in}$ $\left(\text{i.e. } \dfrac{W_{out}/t}{Q_{in}/t}\right)$

For a correct substitution of the efficiency into a correct equation — 1 point

$0.12 = W_{out}/Q_{in}$ or $0.12 = P_{out}/P_{in}$

For a correct recognition of the relationship between power, energy and time — 1 point

Examples of exhibiting that relationship include: starting with $e = P_{out}/P_{in}$, using $P = W/t$ or Q/t in the efficiency equation or referring to the power as a rate.

$P_{in} = P_{out}/e = 4.5 \times 10^6 \text{ W}/0.12$

For a correct answer with correct units — 1 point

$P_{in} = 3.8 \times 10^7 \text{ W}$

(b) 2 points

$P_{out} = Fv\cos\theta$

$F = P_{out}/(v\cos\theta)$

For a correct substitution of P_{out} into a correct expression — 1 point

The resistive force acts opposite to the velocity, so $\theta = 180°$.

$F = 4.5 \times 10^6 \text{ W}/[(7.0 \text{ m/s})(\cos 180°)]$

For an answer consistent with the value of P_{out} substituted, with correct units — 1 point

$|F| = 6.4 \times 10^5 \text{ N}$

(c)

(i) 1 point

For an answer that uses the word "work" to represent the area — 1 point

(ii) 2 points

For a correct calculation of the work (either on the gas or by the gas) represented by the rectangular path — 1 point

$W = \text{base} \times \text{height} = (V_D - V_A)(P_B - P_A)$

$W = \left(0.60 \text{ m}^3 - 0.20 \text{ m}^3\right)\left(3.0 \times 10^5 \text{ N/m}^2 - 1.0 \times 10^5 \text{ N/m}^2\right) = 8.0 \times 10^4 \text{ J}$

There are four cycles per second, so the time for one cycle is 0.25 s.

$P_{out} = W_{out}/\Delta t = 8.0 \times 10^4 \text{ J}/0.25 \text{ s}$

For a consistent calculation of the power output from the work calculated, with units — 1 point

$P_{out} = 3.2 \times 10^5 \text{ W}$

Question 4 (continued)

	Distribution of points
(d) 2 points	
For indicating *AB* as a correct process	1 point
For indicating *BC* as a correct process	1 point
One point is deducted for each incorrect process indicated, up to the number of points earned for correct processes.	

4. (10 points)

A locomotive runs on a steam engine with a power output of 4.5×10^6 W and an efficiency of 12 percent.

(a) Calculate the rate at which heat is being delivered to the steam engine.

$e = \frac{W}{Q_H}$ $\quad \frac{Q_H}{t} = \frac{W/t}{e/t}$ $\quad Q_H = \frac{W}{e}$ $\quad \frac{Q_H}{t} = \frac{4.5 \times 10^6}{.12}$ / 1sec

$Q_H = 3.75 \times 10^7$ J/sec

(b) Calculate the magnitude of the resistive forces acting on the locomotive when it is moving with a constant speed of 7.0 m/s.

$W = F \cdot d$

$\frac{W}{d} = F$

$F_A = \frac{4.5 \times 10^6}{7}$

$\Sigma F = 0$, no acceleration

$F_A - F_R = 0$

$F_A = F_R$

642857 N = F_R

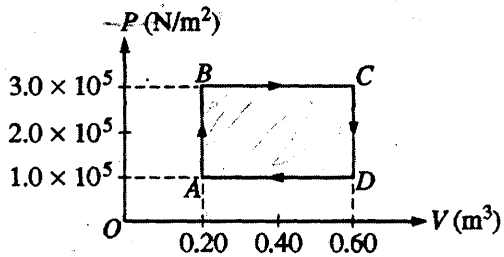
$P = \frac{W}{t}$

$P \cdot t = W$

$4.5 \times 10^6 \cdot 1 = W$

$W = 4.5 \times 10^6$ J

Suppose the gas in another heat engine follows the simplified path *ABCDA* in the *PV* diagram below at a rate of 4 cycles per second.



(c)

i. What does the area bounded by path *ABCDA* represent?

Work done by this engine

ii. Calculate the power output of the engine.

$W = \text{Area}_{ABCD}$

$= 2 \times 10^5 \cdot .4$

$W = 80000$ J

$P = \frac{W}{\Delta t}$

$P = \frac{80000}{4}$

P = 20000 W

(d) Indicate below all of the processes during which heat is added to the gas in the heat engine.

X *AB* X *BC* ___ *CD* ___ *DA*

4. (10 points)

A locomotive runs on a steam engine with a power output of 4.5×10^6 W and an efficiency of 12 percent.

(a) Calculate the rate at which heat is being delivered to the steam engine.

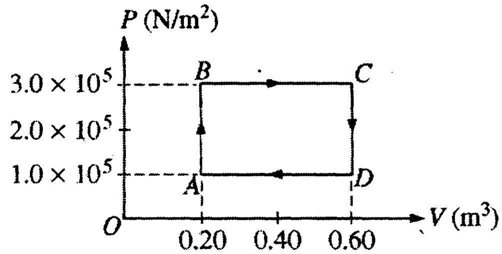
rate: $P_e = (4.5 \times 10^6 \frac{J}{s})(0.12) = 5.4 \times 10^5$ J/s

(b) Calculate the magnitude of the resistive forces acting on the locomotive when it is moving with a constant speed of 7.0 m/s.

$P = \frac{Fd}{t} = Fv \quad F_e = \frac{P}{v} = \frac{5.4 \times 10^5 W}{7.0 m/s} = 7.71 \times 10^5 N$

acceleration is zero, forces are balanced $F_e = F_r = 7.71 \times 10^5 N$

Suppose the gas in another heat engine follows the simplified path *ABCDA* in the *PV* diagram below at a rate of 4 cycles per second.



(c)

i. What does the area bounded by path *ABCDA* represent?

The net work done on the system.

ii. Calculate the power output of the engine.

$P = \frac{W}{t} = \frac{(2 \times 10^5 \frac{N}{m^2})(0.40 m^3)}{0.25 s} = 3.2 \times 10^5$ J/s

(d) Indicate below all of the processes during which heat is added to the gas in the heat engine.

✓ *AB* ✓ *BC* ____*CD* ____*DA*

B4-C

4. (10 points)

A locomotive runs on a steam engine with a power output of 4.5×10^6 W and an efficiency of 12 percent.

(a) Calculate the rate at which heat is being delivered to the steam engine. $e = \left|\frac{W}{Q_H}\right|$ → solve

$P = 3.96 \times 10^6$ W @ $e = 12\%$

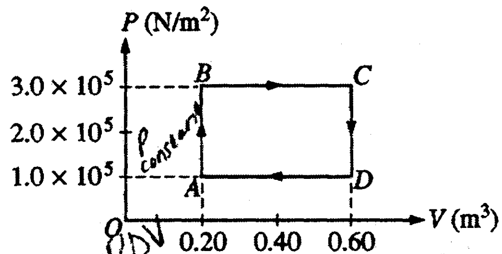
(b) Calculate the magnitude of the resistive forces acting on the locomotive when it is moving with a constant speed of 7.0 m/s. $P = Fv$

$(3.96 \times 10^6) = F(7)$

$F = 565714.2857$ N.

Suppose the gas in another heat engine follows the simplified path *ABCDA* in the *PV* diagram below at a rate of 4 cycles per second.

$.25 = T$



$W = -P\Delta V$

(c)

i. What does the area bounded by path *ABCDA* represent?

the area under a PV graph ($W = -P\Delta V$) is the work done on the system

ii. Calculate the power output of the engine.

$P = \frac{W}{t} \rightarrow \frac{(1 \times 10^5)(.2)}{.25} \rightarrow 8000$ W

(d) Indicate below all of the processes during which heat is added to the gas in the heat engine.

X *AB* ____ *BC* ____ *CD* X *DA* $\Delta U = Q + W$

$\frac{V}{T} = \frac{3V}{T}$

Question 4

Overview

The intent of this thermodynamics problem was to assess students' understanding of concepts such as efficiency, power output, power input and determination of force on an object moving at constant speed. The second section of this question involved interpretation and analysis of a *PV* diagram: understanding what the area bounded by the path represented, determination of power output, and recognition of paths involving heat energy added or removed during the process.

Sample: B4-A
Score: 9

Part (a) earned full credit. Note that the time dependence is included explicitly. Part (b) also received full credit. Part (c)(i) uses the word "work" and thus earned 1 point. In part (c)(ii) the work is calculated correctly for 1 point, but the wrong time is used in the power calculation. In part (d) the two correct processes are indicated, earning 2 points.

Sample: B4-B
Score: 6

Part (a) earned no credit because the expression for efficiency is incorrect, there is no explicit time indication, and the answer is incorrect. In part (b) the power input is used instead of the output, so only 1 point was earned. Part (c)(i) uses the word "work" and thus earned 1 point. Part (c)(ii) earned full credit. In part (d) two correct processes are indicated, earning 2 points.

Sample: B4-C
Score: 3

Part (a) earned no credit because the efficiency is not substituted in correctly, there is no explicit indication of time, and the answer is incorrect. Part (b) earned only 1 point because the input power is used instead of the output. Part (c)(i) uses the word "work" and thus earned 1 point, even though the nature of the work is not described very well. In part (c)(ii) the power is calculated consistently from an incorrect work value and the answer has correct units, so 1 point was earned. In part (d) one correct process is indicated and one incorrect process is indicated, so no points were earned.