General Notes About 2009 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 one 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. 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 1

15 points total | **Distribution of points**

(a) 2 points

For indication that total energy is the sum of kinetic and potential energy — 1 point

$E = U(x) + K(x)$

$E = 4.0x^2 + \frac{1}{2}m(\upsilon(x))^2$

$E = \left(4.0\ \text{J/m}^2\right)(-0.50\ \text{m})^2 + \frac{1}{2}(3.0\ \text{kg})(2.0\ \text{m/s})^2$

For correct calculation of the numerical value of the total energy — 1 point

$E = 7.0\ \text{J}$

(b) 3 points

For indication that $E = U$ when $K = 0$ — 1 point

$E = U(x)$

$E = 4.0x^2$

For substitution of E from (a) into the equation — 1 point

$7.0\ \text{J} = \left(4.0\ \text{J/m}^2\right)x^2$

$x = \pm\sqrt{7.0/4.0}\ \text{m}$

For including plus and minus signs in final numerical answer — 1 point

$x = \pm 1.3\ \text{m}$

(c) 3 points

For clear indication that kinetic energy is total energy minus potential energy, using total energy from (a) — 1 point

$K = E_{tot} - U$

$K = 7.0\ \text{J} - \left(4.0\ \text{J/m}^2\right)(0.60\ \text{m})^2 \quad = 5.56\ \text{J}$

For using calculated K to solve for υ — 1 point

$K = \frac{1}{2}m\upsilon^2$

$5.56\ \text{J} = \frac{1}{2}(3.0\ \text{kg})\upsilon^2$

$\upsilon = 1.92\ \text{m/s}$

For substituting calculated value of υ into expression for momentum — 1 point

$p = m\upsilon = (3.0\ \text{kg})(1.92\ \text{m/s}) = 5.8\ \text{kg}\bullet\text{m/s}$

Note: The final 2 points could also be earned by substituting the kinetic energy directly into the expression relating the kinetic energy and momentum $p = \sqrt{2mK}$.

Question 1 (continued)

Distribution of points

(d) 3 points

For a correct relationship between force and potential energy — 1 point

Note: This point was awarded if the negative sign was <u>not</u> included, since the question asks for magnitude of the acceleration.

$$F = -\frac{dU(x)}{dx}$$

For an expression or calculated value for force consistent with relationship above — 1 point

$$F = -\left(\frac{d}{dx}4.0x^2\right) = -8.0x$$

For application of Newton's second law using a derived expression or calculated value for force — 1 point

$$a = \frac{F}{m} = \frac{8.0x}{m}$$

$$a = \frac{\left(8.0\ \text{kg/s}^2\right)(0.60\ \text{m})}{3.0\ \text{kg}}$$

$$a = 1.6\ \text{m/s}^2$$

Alternate Solution — *Alternate Points*

$$E = U + K$$

For a correct energy relationship with potential and kinetic energy substituted — *1 point*

$$7 = 4x^2 + \frac{1}{2}m\upsilon^2$$

$$14 - 8x^2 = m\upsilon^2$$

For taking the derivative with respect to time of each side of this equation — *1 point*

$$-16x\frac{dx}{dt} = 2m\upsilon\frac{d\upsilon}{dt}$$

$$-16x\upsilon = 2m\upsilon a$$

$$-8x = ma$$

For algebraically solving for acceleration — *1 point*

$$a = -\frac{8x}{m}$$

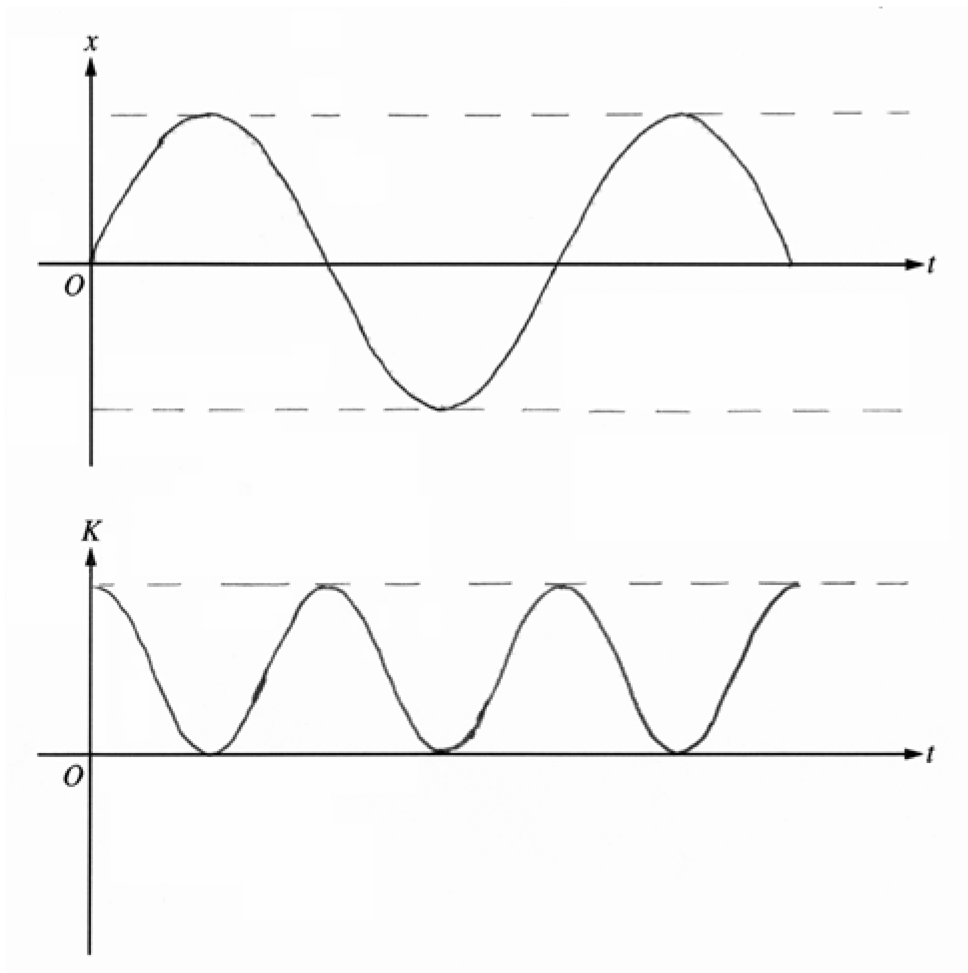
$$a = \frac{\left(8.0\ \text{kg/s}^2\right)(0.60\ \text{m})}{3.0\ \text{kg}}$$

$$a = 1.6\ \text{m/s}^2$$

Question 1 (continued)

Distribution of points

(e) 3 points



For a minimum of one complete cycle of a sine curve starting at the origin on the x versus t graph — 1 point

For a minimum of one complete cycle of a cosine squared curve starting at the maximum value on the K versus t graph — 1 point

For maxima and minima of the x graph matching the zeroes of the K graph — 1 point

Units point

For correct units on <u>all</u> completed nonzero numerical answers — 1 point

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.

Mech. 1.

A 3.0 kg object is moving along the x-axis in a region where its potential energy as a function of x is given as $U(x) = 4.0x^2$, where U is in joules and x is in meters. When the object passes the point $x = -0.50$ m, its velocity is +2.0 m/s. All forces acting on the object are conservative.

(a) Calculate the total mechanical energy of the object.

$E = U + K \quad = 4x^2 + \frac{1}{2}mv^2$

$E = 4(-.5)^2 + \frac{1}{2}(3)(2)^2 = 7$ Joules

(b) Calculate the x-coordinate of any points at which the object has zero kinetic energy.

$KE_f = 0 \quad = \Delta U \qquad U - 0 = 7$

$KE_i = \frac{1}{2}mv^2 = \frac{1}{2}(3)(2)^2 = 6$ Joules

$6 = U(x) - U(-.5)$ $x = \pm 1.2247$ meters

$6 = 4x^2 - 1$

$7 = 4x^2 \quad x = \boxed{\pm 1.323 \text{ meters}}$

(c) Calculate the magnitude of the momentum of the object at $x = 0.60$ m.

$p = mv \qquad E = U + K$

$7 = U(.6) + \frac{1}{2}mv^2$

$p = mv = 3 \cdot 1.9253 = \boxed{5.7758 \ \frac{\text{Kg} \cdot \text{m}}{\text{s}}}$

$7 = 4(.6)^2 + \frac{1}{2}(3)(v^2)$

$5.56 = \frac{1}{2}(3)(v^2)$

$v^2 = 3.70667$

$v = 1.9253$ m/s

(d) Calculate the magnitude of the acceleration of the object as it passes $x = 0.60$ m.

$\Sigma F = ma$

$F = -\frac{dU}{dx}$ $\qquad -\frac{dU(x)}{dx} = -8x = F(x)$

$F(x) =$

$F(.6) = ma(.6)$

$-8(.6) = -4.8 = 3a$

$a = -1.6 \frac{m}{s^2}$

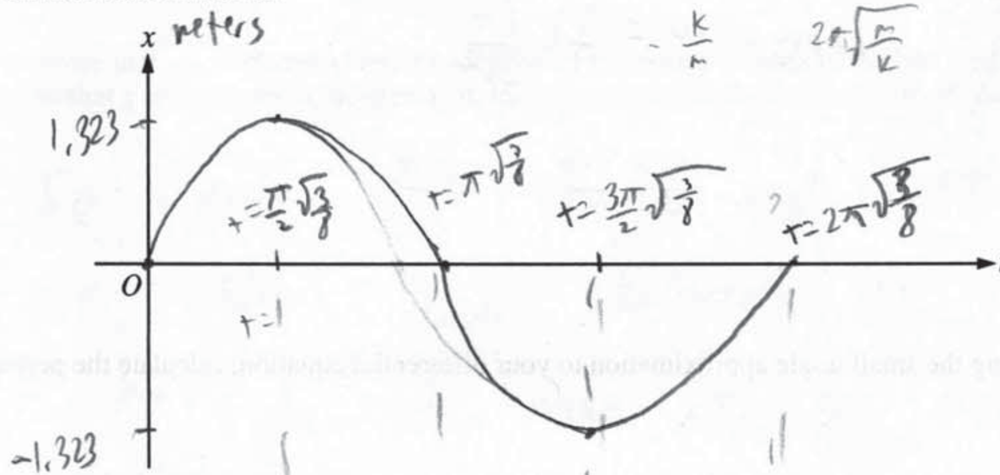
(e) On the axes below, sketch graphs of the object's position x versus time t and kinetic energy K versus time t. Assume that $x = 0$ at time $t = 0$. The two graphs should cover the same time interval and use the same scale on the horizontal axes.

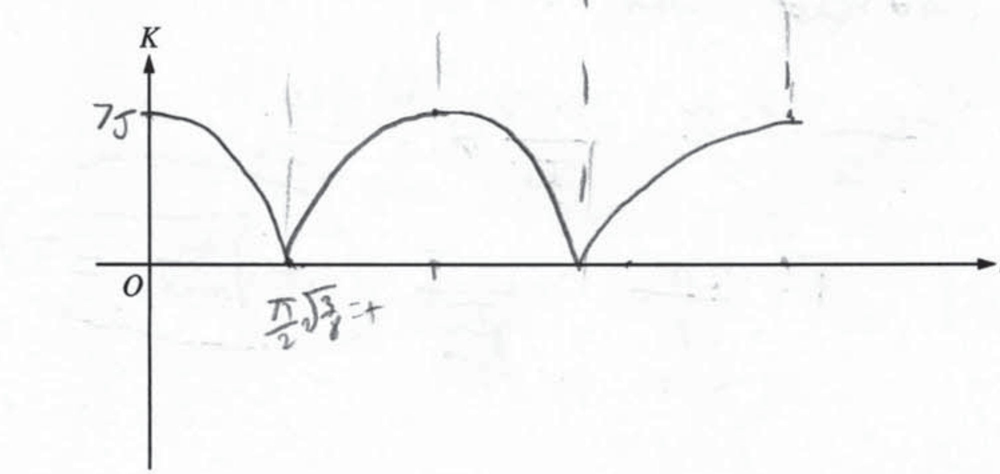
$-\frac{k}{m}$ $\qquad 2\pi\sqrt{\frac{m}{k}}$ $\qquad K =$

$\frac{1}{2}kx^2 = ax^2$

$K \propto x$

2π





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Mech. 1.

A 3.0 kg object is moving along the x-axis in a region where its potential energy as a function of x is given as $U(x) = 4.0x^2$, where U is in joules and x is in meters. When the object passes the point $x = -0.50$ m, its velocity is +2.0 m/s. All forces acting on the object are conservative.

(a) Calculate the total mechanical energy of the object.

$\frac{1}{2}mv^2 + U(x) = ME$

$\frac{1}{2}(3kg)(2m/s)^2 + (4.0)(-.5m)^2 = \boxed{7J}$

(b) Calculate the x-coordinate of any points at which the object has zero kinetic energy.

$U(x) = 7J$

$\frac{4.0x^2}{4.0} = \frac{7J}{4.0}$

$\sqrt{x^2} = \sqrt{1.75m^2}$

$x = \pm 1.32m$

(c) Calculate the magnitude of the momentum of the object at $x = 0.60$ m.

$\frac{1}{2}(3kg)v^2 + (4.0)(.6m)^2 = 7J$

$\frac{1}{2}(3kg)v^2 + 1.44J = 7J$

$-1.44J \quad -1.44J$

$\frac{1}{2}(3kg)v^2 = 5.56J$

$\frac{3kg\,v^2}{3kg} = \frac{11.12J}{3kg}$

$v^2 = 3.71 m^2/s^2$

$v = 1.93 m/s$

$(1.93m/s)(3kg) = \boxed{5.78 kg\,m/s}$

(d) Calculate the magnitude of the acceleration of the object as it passes $x = 0.60$ m.

~~1.93m/s = 2m/s~~ +

$(1.93\,m/s)^2 = (2\,m/s)^2 + 2a(1.1\,m)$

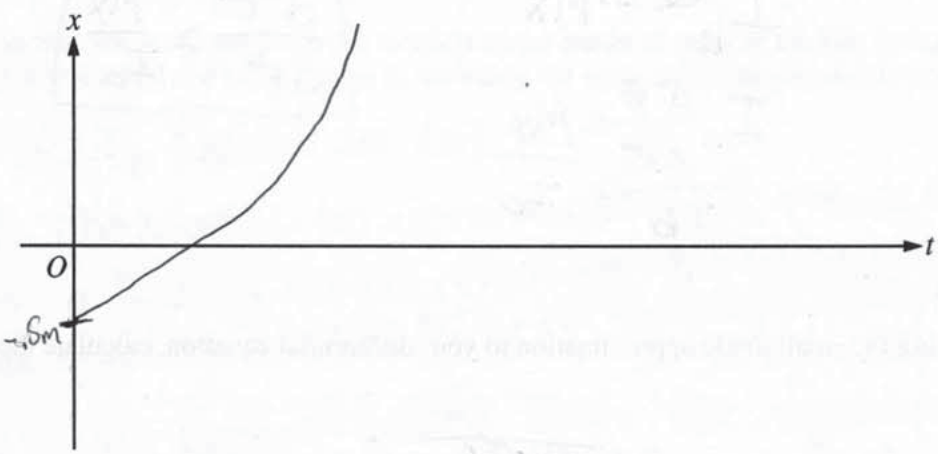
$3.71\,m^2/s^2 = 4\,m^2/s^2 + 2.2\,m\,a$

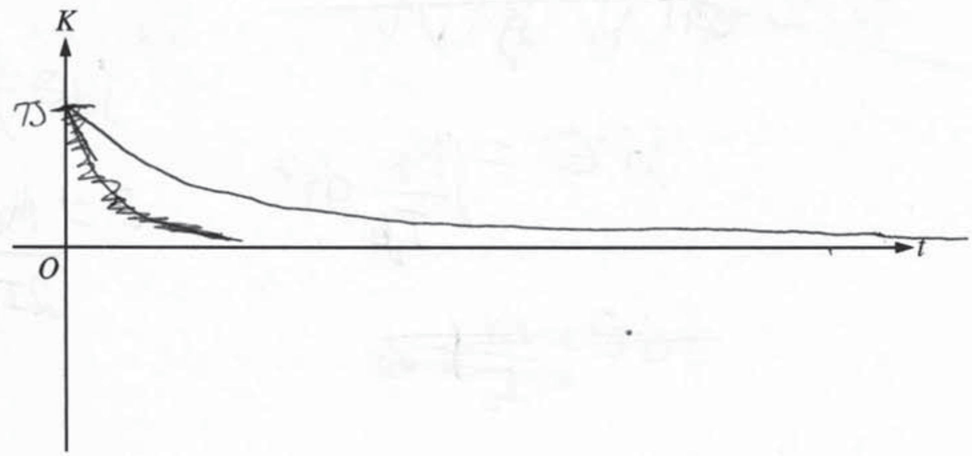
$-4\,m^2/s^2 \quad -4\,m^2/s^2$

$\dfrac{-.29\,m^2/s^2}{2.2\,m} = \dfrac{2.2\,m\,a}{2.2\,m}$

$\boxed{a = -.13\,m/s^2}$

(e) On the axes below, sketch graphs of the object's position x versus time t and kinetic energy K versus time t. Assume that $x = 0$ at time $t = 0$. The two graphs should cover the same time interval and use the same scale on the horizontal axes.





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(a) Calculate the total mechanical energy of the object.

$E_{mech} = KE + U$

$U = 4(-.5)^2$

$KE = \frac{1}{2}mv^2$

$\frac{1}{2}(3)(2)^2$

6

$= 6 + 1$

$\boxed{\text{7 is the total mechanical energy}}$

(b) Calculate the x-coordinate of any points at which the object has zero kinetic energy.

$\frac{1}{2}mv^2 = 0$

zero kinetic energy when object has all potential (U)

$4.0x^2$

(c) Calculate the magnitude of the momentum of the object at $x = 0.60$ m.

$mv = P$

$(3)(.979)$

$\boxed{2.939}$

$4.0x^2 = \frac{1}{2}mv^2$

$4.0(.6)^2 = \frac{1}{2}(3)(v)^2$

$1.44 = \frac{3}{2}v^2$

(d) Calculate the magnitude of the acceleration of the object as it passes $x = 0.60$ m.

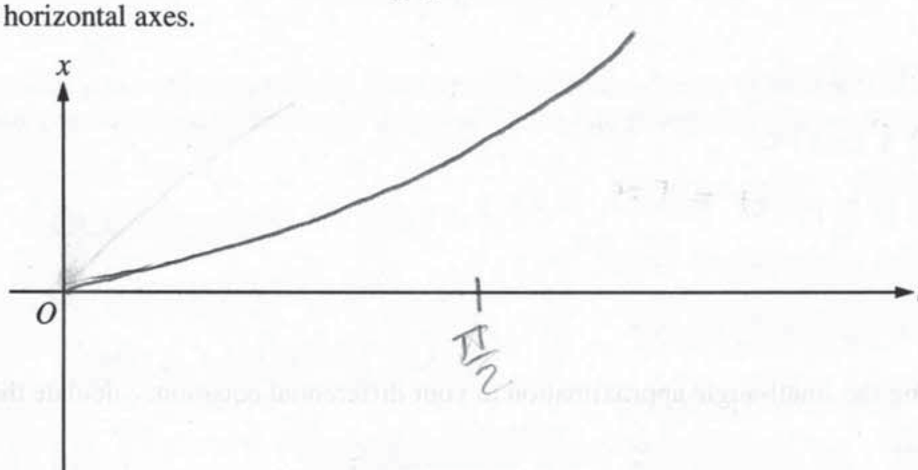
$a = \frac{dv}{dt}$

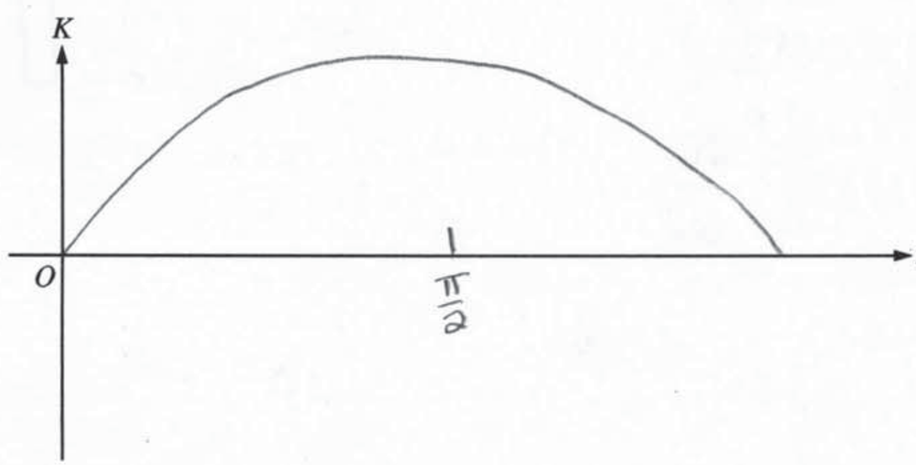
$v = v_0 + at$

$\boxed{9.8\ m/s^2}$

$-4.9t^2$

(e) On the axes below, sketch graphs of the object's position x versus time t and kinetic energy K versus time t. Assume that $x = 0$ at time $t = 0$. The two graphs should cover the same time interval and use the same scale on the horizontal axes.





AP® PHYSICS C: MECHANICS
2009 SCORING COMMENTARY

Question 1

Overview

The purpose of this question was to check students' understanding of simple harmonic motion—without telling the students that is what it was. Students were expected to know how to find total mechanical energy and how to use that total mechanical energy to find the positions where the kinetic energy of the object was zero. They were also expected to be able to find the momentum at a given point, using conservation of energy. In addition, students were asked to find the acceleration of the object at a given point. The final part of the problem asked students to graph the object's position and kinetic energy as functions of time.

Sample: CM-1A
Score: 15

This is a well-written solution, clearly laid out and easy to follow. Note that, for the graph of K versus t in part (e), a curve with sharp turnarounds was accepted. Since students were asked to <u>sketch</u>, a graph that showed understanding of the general behavior of the kinetic energy and its relationship to the position graph earned full credit.

Sample: CM-1B
Score: 9

The response earned 2 points in part (a) and 3 points each in parts (b) and (c). No points were earned in part (d), which uses a constant-acceleration equation when acceleration is changing, or for the incorrect graphs in part (e). The response earned the units point.

Sample: CM-1C
Score: 5

Two points were earned in part (a). The response earned 1 point in part (b) for indicating that when kinetic energy is zero, the total energy is in the form of potential energy. One point was lost in part (c) for an incorrect expression for the kinetic energy; the remaining 2 points were earned for solving the expression for the speed and substituting the value into the expression for momentum. No points were earned in parts (d) and (e), nor was the units point earned.