
Multiple-Choice Answer Key

The following contains the answers to
the multiple-choice questions in this exam.

Answer Key for AP Physics 1 Exam, Section I

Question 1: B	Question 21: C
Question 2: A	Question 22: A
Question 3: C	Question 23: C
Question 4: B	Question 24: C
Question 5: D	Question 25: D
Question 6: A	Question 26: D
Question 7: C	Question 27: A
Question 8: C	Question 28: B
Question 9: C	Question 29: A
Question 10: B	Question 30: D
Question 11: C	Question 31: B
Question 12: D	Question 32: D
Question 13: D	Question 33: C
Question 14: B	Question 34: A
Question 15: D	Question 35: B
Question 16: D	Question 36: D
Question 17: C	Question 131: A, D
Question 18: B	Question 132: C, D
Question 19: B	Question 133: B, D
Question 20: C	Question 134: A, B

Free-Response Scoring Guidelines

The following contains the scoring guidelines
for the free-response questions in this exam.

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Question 1

7 points total

**Distribution
of points**

(a) 3 points

For using an equation expressing the conservation of energy

1 point

$$mgh = 2mgR + \frac{1}{2}mv_{\text{top}}^2 \text{ or } mgh = (1/2)mv_1^2 \text{ or } mgh = (1/2)mv^2$$

For using two forms of energy when block B is at the top of the loop or using the initial kinetic energy

1 point

For expressing the correct answer in terms of the listed quantities

1 point

$$h = \frac{2mgR + \frac{1}{2}mv_{\text{top}}^2}{mg}$$

$$h = 2R + \frac{v_{\text{top}}^2}{2g}$$

(b) 2 points

For a correct answer “Greater than $2h$ ” with an explanation

1 point

No point is earned for a correct selection without an explanation.

If an incorrect answer is selected, the following point for using conservation of energy can still be earned.

For using an equation or semi-quantitative reasoning expressing the conservation of energy Note: “semi-quantitative reasoning” here includes reasoning in terms of proportionality, squared relationships, etc.

1 point

$$mgh = \frac{1}{2}mv_1^2$$

$$h = \frac{v_1^2}{2g}$$

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Question 1 (continued)

**Distribution
of points**

(c) 2 points

Correct answer: $v_C = \frac{3}{2} v_A$

Note: there is no “answer point”, so no credit is awarded for an answer with no work shown

For using momentum conservation to relate the speeds before and after the completely inelastic collision between blocks *B* and *C* 1 point

$2mv_C = (2m + m)v_{BC} = 3mv_{BC}$, where v_{BC} is the speed of blocks *B* and *C* after the collision

$$2v_C = 3v_{BC}$$

For setting the speed of blocks *B* and *C* after the collision equal to the speed of block *B* after its elastic collision with block *A*, in order for blocks *B* and *C* to make it over the hump. 1 point

$$2v_C = 3v_A$$

$$v_C = \frac{3}{2} v_A$$

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Question 2

12 points total

**Distribution
of points**

(a)

i. 2 points

For recognizing a small horizontal velocity for the block at point P

1 point

For stating or implying that the block doesn't go very far even though there is a longer fall time

1 point

Example: Even though the large h_2 allows the block to stay in the air for a long time, the small h_1 means the system loses little gravitational potential energy and hence gains little kinetic energy so that it leaves the table with too little speed to cover much distance while aloft.

ii. 2 points

For recognizing a large horizontal velocity for the block at point P

1 point

For mentioning a short time of flight for the falling block

1 point

Example: Now the block gains a lot of kinetic energy on the ramp so that it leaves the table with a large horizontal speed. But the small h_2 means the block spends so little time in the air that it lands before covering much horizontal distance.

(b) 3 points

For using an energy conservation statement (corresponds to step 1 in example below)

1 point

For setting up a time of flight calculation using vertical acceleration (corresponds to step 2a in example below)

1 point

Note: derivation of t must be shown to earn credit.

For using $vt = d$ to determine distance traveled (corresponds to step 2b in example below)

1 point

Example:

Step 1: Use energy conservation to find the block's speed at the bottom of ramp, which equals the launch speed v_1 at point P .

$$mgh_1 = \frac{1}{2}mv_1^2 \Rightarrow v_1 = \sqrt{2gh_1}$$

Step 2a: Find the time of flight, using the independence of the horizontal and vertical motion. Since the block leaves the table with zero *vertical* speed, the vertical

kinematic equation $y = y_0 + v_{y0}t + \frac{1}{2}a_yt^2$ reduces to $h_2 = \frac{1}{2}gt^2$ (taking

downward as positive). Solve for time to get $t = \sqrt{\frac{2h_2}{g}}$.

Step 2b. Find the horizontal distance d covered while in the air after point P . Since there are no horizontal forces exerted on the block, its horizontal velocity stays constant at v_1 . So, the block travels a horizontal distance

$$d = v_1t = \sqrt{2gh_1} \sqrt{\frac{2h_2}{g}} = 2\sqrt{h_1h_2}$$

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Question 2 (continued)

**Distribution
of points**

(c)

i. 2 points

For mentioning a correct equation or step of reasoning (energy conservation on ramp)

1 point

For correctly explaining why this equation or step mirrors the reasoning of (a)i

1 point

Example: My energy conservation reasoning (part (b) step 1) mirrors my reasoning that a small ramp height corresponds to a low potential energy (mgh_1), which is converted into low kinetic energy and hence a low speed.

ii. 2 points

For mentioning a correct equation or step of reasoning (time of flight)

1 point

For correctly explaining why that equation or step mirrors the reasoning of (a)ii

1 point

Example: My time-of-flight calculation (part (b) step 2a) shows that t is proportional to $\sqrt{h_2}$, so a smaller falling distance h_2 corresponds to a smaller flight time.

(d) 1 point

Correct answer: "The same as"

Note: explanation is scored regardless of checkbox.

Point can be earned if response is consistent with answer in part (b)

For reasoning that is consistent with the functional dependence of the part (b) answer

1 point

Example:

As found in part (b), the distance d does not depend on g . So, doing the experiment on the Moon instead of Earth makes no difference. The increased time of flight (since weaker gravity makes the block take longer to land) compensates for the small speed gained by the block on the ramp.

Checked "Greater than" then g must be in the denominator in the incorrect equation in part (b)

Checked "Less than" then g must be in the numerator in the incorrect equation in part (b)

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Question 3

12 points total

**Distribution
of points**

(a)

i, ii, and iii) 2 points

Note: Parts i, ii, and iii are read together

For measuring the mass or weight of the relevant system

1 point

For making a measurement of force (or something from which a force can be calculated)
with the fan turned on

1 point

Note: fan angles of either 0° or 90° need not be measured directly, since these are given as the minimum and maximum angles possible. If the procedure involves intermediate angles, then these angles must be measured.

Example 1 (variant - Example 1a in parentheses):

(a)i The downward force exerted by the fan-block system (or “mass”, as read on a balance, of the system)

(a)ii A spring scale (or mechanical balance)

(a)iii Set the fan angle to 90° . With the fan off, hang the system from a spring scale to find its weight (or place the system on a mechanical balance to find its mass). Turn the fan on, and record the force from the spring scale (or the mass reading from the mechanical balance).

Example 2:

(a)i Mass of the fan-block system and low-friction cart. Velocity of the cart as a function of time.

(a)ii Scale to measure mass. Motion detector to measure velocity as a function of time.

(a)iii Place the system and a low-friction cart on a scale to find the total mass of the fan-block and cart. Next, on a horizontal surface, place the fan-block on the cart, set the fan angle to zero, turn on the fan, and release the cart from rest. Use the motion detector to graph the cart velocity as a function of time.

iv) 1 point

For correctly indicating a method to determine the force exerted by air on the fan, using the measurements and procedure from parts (a) i, ii, and iii

1 point

Example 1 (and 1a), continued from above:

Take the difference in the force readings with the fan off and the fan on. (1a:

Multiply the difference in the mass readings by g). This difference is the force exerted by air on the fan.

Example 2, continued from above:

Estimate the average slope of the graph, which is the acceleration. Multiply acceleration by the total mass to find the force exerted by air on the fan.

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Question 3 (continued)

**Distribution
of points**

(b)

i, ii, and iii) 2 points

Note: Parts i, ii, and iii are read together

Note: In parts (b) i, ii, and iii, it is acceptable to say "the same as in part (a), with the following changes:", with changes to the procedure in part (a) then listed.

For describing measurements that would allow determination of the acceleration

1 point

For describing a procedure that is practical/feasible in a school laboratory

1 point

Example 3:

Place the fan-block on the track, with angle = 0. Place a motion detector behind it, set to graph velocity vs. time. Turn fan on, and release from rest. Repeat the procedure several times.

Example 4:

Place the fan-block on the track, with angle = 0. Place a photogate just in front of the block, and the second photogate a meter or two in front of the block. Measure distance from front of block to the front of that second photogate. Turn on fan and release the block from rest. The photogates measure the time it takes the block to travel the measured distance to the second photogate.

Example 5:

(b)i Angle of the fan. Velocity of fan-block system as a function of time.

(b)ii Protractor to measure the angle.

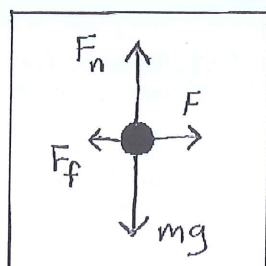
Motion detector to measure the velocity and time.

(b)iii Adjust the fan angle until the fan-block slides with a constant speed after being given a push. Use the motion detector to determine whether the speed is constant (zero slope on a graph of velocity as a function of time).

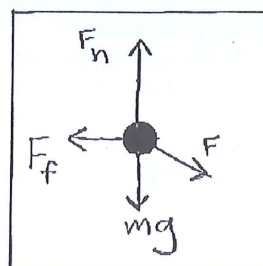
iv) 1 point

For correctly drawn and labeled vectors for the force exerted by air on fan and for the frictional force exerted on the block by the track, corresponding to the experiment described in part (b)iii. Other forces correctly drawn and labeled AND no incorrect forces, corresponding to the experiment described in part (b)iii.

1 point



Examples 3 & 4



Example 5

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Question 3 (continued)

	Distribution of points
(c) 4 points	
For using kinematic data to obtain acceleration, a , or showing that $a = 0$ Alternatively the point can be earned using the Work-Energy solution with kinetic energy $K = (1/2)mv^2$	1 point
For relating frictional force and coefficient of kinetic friction as $F_f = \mu_k F_N$	1 point
For a correct representation of the normal force, correctly referring back to a measurement of the fan-block system	1 point
$F_N = mg$ if $\theta = 0$ or $F_N = mg + F \sin \theta$ if $\theta \neq 0$	
For using Newton's second law, consistently with normal force above, for the appropriate forces or force components in the direction of the fan's motion that would lead to the determination of the coefficient of kinetic friction	1 point
$F_{\text{net}} = ma$ $F - F_f = ma$	
$\mu_k = \frac{F - ma}{mg}$ if $\theta = 0$ or $\mu_k = \frac{F \cos \theta - ma}{mg + F \sin \theta}$ if $\theta \neq 0$	
Alternatively the point can be earned using the Work-Energy solution that would lead to the determination of the coefficient of kinetic friction.	
Example 3 (continued from above): $\theta = 0$ Determine the slope of each v vs. t graph, to get the acceleration for each trial, and average the accelerations. Call this average acceleration a . The kinetic frictional force exerted by track on block is $F_f = \mu F_n = \mu mg$, where m is the mass of the fan-block as found in part (a), since the acceleration is purely horizontal and hence F_n and mg must balance. So, by Newton's second law, letting F denote the force exerted by the air on the fan found in part (a), we get	
$F_{\text{net}} = ma$ $F - F_f = ma$ $F - \mu mg = ma$	
Solve for μ to get $\mu = \frac{F - ma}{mg}$	
Example 4 (continued from above): $\theta = 0$ Let d denote distance from block to second photogate and t denote the corresponding time. Since $v_0 = 0$, $d = \frac{1}{2}at^2$ and hence $a = \frac{2d}{t^2}$. For each trial, calculate that acceleration, and take the average, which becomes our best estimate of a . [Rest of solution is as in example 3]	

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Question 3 (continued)

**Distribution
of points**

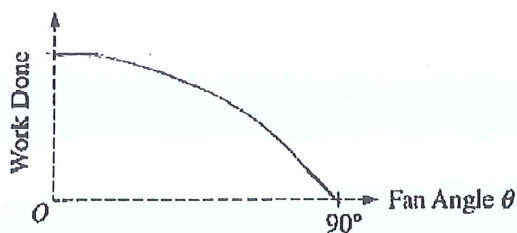
Example 5 (continued from above): $\theta = 0$ Since the acceleration is zero, the net horizontal force is zero. From Newton's second law,

$$F_f = \mu mg = F \cos \theta$$

Solving for μ_k :

$$\mu_k = \frac{F \cos \theta - ma}{mg + F \sin \theta} \text{ if } \theta \neq 0$$

(d) 2 points



A correct graph shows the work done as proportional to $\cos \theta$.

For showing a curve that continually decreases from a maximum value at 0° to a minimum value of zero at 90°

1 point

For showing a curve that is concave-downward (i.e. that has a negative second derivative)

1 point

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Question 4

7 points total

**Distribution
of points**

(a)

i. 1 point

Correct answer: “The same”

For selecting “The same” and explaining that both ladybugs have the same angular displacement over the same interval of time, or that all points on the disk rotate at the same rate

1 point

Notes: No credit is earned if the wrong answer is selected.

No credit is earned for a correct selection with a wrong explanation or no explanation given.

ii. 1 point

Correct answer: “Greater”

For selecting “Greater” and explaining that linear speed is proportional to (or increases with) distance from the center ($v = \omega R$)

1 point

Notes: No credit is earned if the wrong answer is selected.

No credit is earned for a correct selection with a wrong explanation or no explanation given.

(b) 2 points

Correct answer: “Decrease”

If the wrong answer is selected, at most one point can be earned for the explanation.

For stating or implying that the system angular momentum does not change

1 point

For stating that the ladybug gained angular momentum, the disk lost angular momentum

1 point

Note: Full credit can be earned for an alternate solution involving the force exerted by the ladybug (while accelerating) causing a torque on the disk.

(c)

i. 2 points

For using an equation expressing the conservation of angular momentum with I and ω

1 point

$$I_2 \omega_2 = I_1 \omega_1$$

For correctly substituting the angular speed values and obtaining a correct answer or an algebraic equivalent of the correct answer

1 point

$$I_2 = \frac{I_1 \omega_1}{\omega_2} = \frac{I_1 (1/2.5)}{(1/2)}$$

$$I_2 = \frac{4}{5} I_1$$

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Question 4 (continued)

**Distribution
of points**

ii. 1 point

Correct answer: “Yes”

For selecting “Yes” and for providing evidence that a torque is exerted on the disk (e.g., the disk’s angular momentum/speed changes, or the ladybug exerts a non-radial force on the disk) 1 point

Notes: No credit is earned if the wrong answer is selected.

No credit is earned for a correct selection with a wrong explanation or no explanation given.

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Question 5

7 points total

**Distribution
of points**

(a) 1 point

For an explanation using superposition

Note: The term “constructive interference”, while not a part of this course, is an acceptable explanation.

Example:

At *A*, a crest from wave 1 overlaps a crest from wave 2, and their superposition therefore results in a higher crest, as big as it can get for these two waves.

1 point

(b) 1 point

For an explanation using superposition

Note: The term “destructive interference”, while not a part of this course, is an acceptable explanation.

Example:

At *B*, a crest from wave 1 overlaps an equally deep trough from wave 2, and hence the waves “cancel out” resulting in a small amplitude.

1 point

(c) 5 points

For mentioning that waves 1 and 2 become more similar (or, frequency/period of wave 2 decreases/increases), as points *A* and *B* (loud and soft sounds) in the graph of wave 3 get further apart

1 point

For explaining why *A* and *B* (loud and soft sounds) get further apart in the graph of wave 3

1 point

Examples:

...because there are more wave peaks that constructively interfere before they start to destructively interfere.

or

... because the time interval between when the peaks coincide increases.

or

... because it takes more time for the peaks to get out of alignment.

For mentioning that *A* and *B* (loud and soft sounds) getting further apart corresponds to a longer time interval between the piano tuner hearing loud and soft sounds OR the piano tuner hears a lower beat frequency

1 point

For mentioning that, when the string frequency matches that of the fork, the time interval between the loud and soft sounds is infinite OR the loudness no longer fluctuates OR there are no more beats heard by the tuner

1 point

For a response that has sufficient paragraph structure, as described in the published requirements for the paragraph length response

1 point

Example:

The piano tuner hears alternating loud to soft to loud corresponding to *A* to *B* to the next *A* on wave 3. This alternating pattern is called “beats.” As the frequency of the sound produced by the string (wave 2) becomes closer and closer to the tuning fork frequency (wave 1), the distance on the wave 3 graph between *A* and *B* (and the next *A*) becomes greater. That distance on the graph is really the time between beats, i.e., the beat period. So, as the string frequency approaches the tuning fork frequency, the period of the beats increases. In the limit as the frequencies of waves 1 and 2 match perfectly, this period approaches infinity, which means the piano tuner no longer hears beats at all—the piano string is now perfectly tuned.

Scoring Worksheet

The following provides a scoring worksheet and conversion table used for calculating a composite score of the exam.

2016 AP Physics 1 Scoring Worksheet

Section I: Multiple Choice

$$\frac{\text{Number Correct}}{\text{(out of 40)}} \times 1.0000 = \frac{\text{Weighted Section I Score}}{\text{(Do not round)}}$$

Section II: Free Response

$$\text{Question 1 } \frac{\text{_____}}{\text{(out of 7)}} \times 0.8888 = \frac{\text{_____}}{\text{(Do not round)}}$$

$$\text{Question 2 } \frac{\text{_____}}{\text{(out of 12)}} \times 0.8888 = \frac{\text{_____}}{\text{(Do not round)}}$$

$$\text{Question 3 } \frac{\text{_____}}{\text{(out of 12)}} \times 0.8888 = \frac{\text{_____}}{\text{(Do not round)}}$$

$$\text{Question 4 } \frac{\text{_____}}{\text{(out of 7)}} \times 0.8888 = \frac{\text{_____}}{\text{(Do not round)}}$$

$$\text{Question 5 } \frac{\text{_____}}{\text{(out of 7)}} \times 0.8888 = \frac{\text{_____}}{\text{(Do not round)}}$$

$$\text{Sum} = \frac{\text{_____}}{\text{Weighted Section II Score (Do not round)}}$$

Composite Score

$$\frac{\text{Weighted Section I Score}}{\text{_____}} + \frac{\text{Weighted Section II Score}}{\text{_____}} = \frac{\text{Composite Score (Round to nearest whole number)}}{\text{_____}}$$

AP Score Conversion Chart
Physics 1

Composite Score Range	AP Score
57-80	5
43-56	4
31-42	3
20-30	2
0-19	1

Question Descriptors and Performance Data

The following contains tables showing the content assessed, the correct answer, and how AP students performed on each question.

2016 AP Physics 1: Algebra-Based Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Learning Objectives	Essential Knowledge	Science Practices	Key	% Correct
1	4.A.1.1; 4.A.2.1; 5.D.3.1	4.A.1; 4.A.2; 5.D.3	1.2; 1.4; 6.4; 6.4	B	80
2	3.F.2.1	3.F.2	6.4	A	67
3	3.A.1.1; 3.B.1.1; 5.B.4.1; 5.B.5.4	3.A.1; 3.B.1; 5.B.4; 5.B.5	1.5; 2.2; 6.4; 7.2; 6.4; 7.2; 6.4; 7.2	C	54
4	5.B.3.1; 5.E.1.1	5.B.3; 5.E.1	6.4; 7.2; 6.4	B	39
5	5.D.3.1	5.D.3	6.4	D	46
6	3.A.1.1; 4.A.2.3	3.A.1; 4.A.2	1.5; 2.2; 1.4; 2.2	A	38
7	3.A.3.1; 3.B.1.1; 4.A.2.1	3.A.3; 3.B.1; 4.A.2	6.4; 7.2; 6.4; 7.2; 6.4	C	37
8	5.B.4.2	5.B.4	1.4; 2.1; 2.2	C	30
9	5.B.4.1	5.B.4	6.4	C	67
10	5.B.4.2	5.B.4	1.4; 2.2	B	50
11	5.B.9.3	5.B.9	2.2	C	56
12	5.B.5.2	5.B.5	5.1	D	49
13	3.A.4.2	3.A.4	6.4; 7.2	D	47
14	3.A.1.1; 3.B.1.1; 3.D.2.1; 3.D.2.2; 5.D.1.4	3.A.1; 3.B.1; 3.D.1; 3.D.2; 5.D.1	2.2; 6.4; 2.1; 6.4; 5.1; 6.4	B	38
15	5.D.2.5	5.D.2	2.2	D	36
16	6.D.3.2	6.D.3	6.4	D	33
17	6.B.5.1	6.B.5	1.4	C	33
18	1.B.3.1	1.B.3	6.1	B	36
19	2.B.2.2	2.B.2	2.2	B	36
20	3.A.1.1; 3.B.1.1; 3.C.2.1	3.A.1; 3.B.1; 3.C.2	1.5; 2.2; 6.4; 7.2; 2.2; 6.4	C	44
21	3.A.1.1; 3.D.2.2	3.A.1; 3.D.2	1.5; 6.4	C	37
22	3.B.3.3	3.B.3	2.2	A	22
23	6.D.3.2; 6.D.4.2	6.D.3; 6.D.4	6.4; 2.2	C	62
24	5.D.3.1	5.D.3	6.4	C	40
25	3.A.1.1; 4.B.1.1	3.A.1; 4.B.1	1.5; 2.2; 2.2	D	28
26	3.A.1.1; 4.B.2.2	3.A.1; 4.B.2	1.5; 2.2; 5.1	D	25
27	4.B.1.1; 4.B.2.1	4.B.1; 4.B.2	1.4; 2.2; 2.2	A	26
28	6.D.1.1; 6.D.2.1	6.D.1; 6.D.2	1.4; 5.1	B	32
29	5.B.9.3; 5.C.3.3	5.B.9; 5.C.3	2.2; 6.4; 7.2; 1.4; 2.2	A	65
30	3.A.1.1; 3.A.1.3; 3.A.3.1; 3.B.2.1	3.A.1; 3.A.3; 3.B.2	1.5; 5.1; 6.4; 1.1; 1.4	D	23
31	3.A.4.2; 3.B.1.3	3.A.4; 3.B.1	6.4; 7.2; 1.5; 2.2	B	41
32	3.F.1.1	3.F.1	1.4	D	24
33	3.A.3.1; 3.B.2.1	3.A.3; 3.B.2	6.4; 1.1; 1.4; 2.2	C	24
34	3.A.3.1; 3.B.2.1; 3.B.3.1	3.A.3; 3.B.2; 3.B.3	6.4; 1.1; 1.4; 2.2; 6.4	A	55
35	5.B.3.2	5.B.3	1.4; 2.2	B	32
36	3.B.3.1	3.B.3	6.4	D	17

2016 AP Physics 1: Algebra-Based
Question Descriptors and Performance Data

Question	Learning Objectives	Essential Knowledge	Science Practices	Key	% Correct
131	6.B.4.1; 6.D.3.3	6.B.4; 6.D.3	4.2; 5.1; 7.2; 5.1	A, D	57
132	3.A.2.1; 3.B.2.1	3.A.2; 3.B.2	1.1; 1.1; 1.4	C, D	35
133	5.D.1.5	5.D.1	2.2	B, D	48
134	4.D.2.2	4.D.2	4.2	A, B	27

Free-Response Questions

Question	Learning objectives	Essential Knowledge	Science Practices	Mean Score
1	5.B.3.1; 5.B.3.3; 5.B.4.1; 5.B.4.2; 5.D.2.3; 5.D.2.5	5.B.3; 5.B.4; 5.D.2	2.2; 6.4; 1.4; 2.2; 6.4; 1.4; 2.1; 2.2; 6.4; 7.2; 2.1; 2.2	1.63
2	3.A.1.1; 5.B.3.1; 5.B.3.3; 5.B.4.2; 5.B.5.5	1.A.1; 2.A.1; 3.A.1; 5.B.3; 5.B.4; 5.B.5	1.5; 2.1; 2.2; 2.2; 6.4; 7.2; 1.4; 2.2; 1.4; 2.2; 2.2; 6.4	2.76
3	3.A.1.2; 3.A.1.3; 3.A.2.1; 3.B.1.2; 3.B.2.1; 4.A.2.3; 4.A.3.1; 4.C.2.1; 4.C.2.2; 5.B.5.3	3.A.1; 3.A.2; 3.B.1; 3.B.2; 4.A.2; 4.A.3; 4.C.2; 5.B.5	4.2; 5.1; 1.1; 4.2; 5.1; 1.1; 1.4; 1.4; 2.2; 2.2; 6.4; 1.4; 2.2; 7.2; 1.4; 2.2; 6.4	3.96
4	3.A.1.1; 4.D.2.1; 4.D.3.1; 5.E.1.1; 5.E.1.2	3.A.1; 4.D.2; 4.D.3; 5.E.1; 5.E.2	1.5; 2.1; 2.2; 1.2; 1.4; 2.2; 6.4; 2.2	1.44
5	6.D.2.1; 6.D.5.1	6.D.2; 6.D.5	5.1; 1.2	2.28