Mechanics Diagnostic Test[1]

developed by Boris Korsunsky
as part of the doctoral research study at Harvard Graduate School Education
(thesis defended in 2003)

This test is one of the assessment tools used in my doctoral research on problem solving in physics. It contains 28 questions. I aimed to write the questions of two types:

- questions requiring the use of a single mechanics concept (such as Newton's 3rd law or the law of conservation of momentum) in a familiar context. My hypothesis was that such question require the presence of algorithmic, or **rigid knowledge** (I call the questions of this type "R-type questions"). One may say that these are "easier" questions, both by nature and according to the accumulated statistics.
- questions requiring the use of a concept in an unusual context where the applicability of the concept is not obvious or requiring combining two or more concepts. My hypothesis was that such questions require a distinctly different set of skills: an ability to relate things that are not obviously related – something that I called **bisociation**. These questions ("B-type questions") are, in general, much harder than the "R-type" questions.

One of the purposes of the dissertation study was to see which questions (R-type or B-type) can be better predictors of successful problem-solving. My original hypothesis was that the B-type questions would prove to be better predictors; the experimental evidence, obtained by statistical analysis and through student interviews, appears to support this hypothesis.

After administering the pilot version of the test to about a hundred freshmen at Massachusetts Institute of Technology, I used the feedback from students and faculty to improve the test. Many questions were revised or replaced, ambiguous language eliminated and the errors corrected to the best of my ability. Thus enhanced test was then used in the actual study of more than a hundred AP Physics students; the results, for the most part, confirmed the difficulty rating obtained from the pilot run.

In the current version of the test, 14 "statistically easier" questions are followed by 14 "statistically harder" questions (only 10 questions of each type were used in the final analysis). Feel free to download and administer this test to your students. However, I urge caution in interpreting the results of this test: while they may offer valuable glimpse into your students' state of mind and their ability to reason with physic concepts, I would not recommend using this test for any kind of formal assessment. I have no doubt that the test could be improved further.

Any and all feedback will be appreciated.

Boris Korsunsky
korsunbo@post.harvard.edu

[1] The original version of the test, provided in the dissertation manuscript, is not convenient for online viewing. This document has been prepared for the convenience of my colleagues who may wish to download and administer this test in their classrooms. **Some minor edits, improving clarity and readability, have been made.**
For more detailed explanations, references, etc., the reader is encouraged to refer to the dissertation posted online at http://www.weston.org/schools/hs/sci/apphy/korsunsky/Dissertation-pdf/table_of_contents.htm

Mechanics Diagnostic Test
Choose the best answer!

1. An object cannot remain at rest unless:

A. the net force acting on it is zero
B. the net force acting on it is constant
C. there are no forces acting on it
D. there is only one force acting on it

2. A block is acted upon by two forces of equal magnitude and opposite directions. Therefore, one can conclude that:

A. the velocity of the block must be zero
B. the acceleration of the block must be zero
C. the block must be moving in circles
D. the block must be slowing down

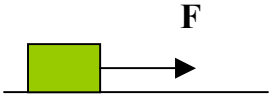
3. If a block is moving to the left at a constant velocity, one can conclude that:

A. there is exactly one force applied to the block
B. the net force applied to the block is directed to the left
C. the net force applied to the block is zero
D. no forces are applied to the block

4. A massive block is being pulled along a horizontal frictionless surface by a constant horizontal force. The block must be:

A. continuously changing direction
B. moving at constant velocity
C. moving with a constant non-zero acceleration
D. moving with continuously increasing acceleration

5. A block is at rest on a horizontal rough surface despite being pulled by a horizontal force F as shown. Since the block is not moving, one can conclude that:



A. the magnitude of the force of friction is less than that of force F
B. the magnitude of the force of friction is equal to that of force F
C. the magnitude of the force of friction is greater than that of force F
D. there is not enough information to answer

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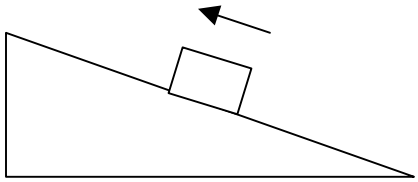
6. A block is sliding up a rough slope as shown. The angle between the force of kinetic friction acting on the block and the force of gravity acting on the block is:



A. less than 90 degrees
B. equal to 90 degrees
C. greater than 90 degrees
D. not enough information to answer

7. A 6-kg bucket of water is being pulled straight up by a string. The upward acceleration of the bucket has a constant magnitude of 3 m/s^2. The tension in the rope is then:

A. about 42 N
B. about 60 N
C. about 78 N
D. increasing as the speed of the bucket increases

8. According to Newton's 3rd law:

A. the action force exceeds the reaction force only when the object accelerates
B. the vector sum of corresponding action and reaction forces is always equal to zero
C. the acceleration of an object is directly proportional to the reaction force
D. none of the above is correct

9. A car is moving along a straight highway. The car hits from behind a heavy truck moving in the same direction. After the collision, the truck and the car do not separate.
During the collision, which vehicle experiences greater average force?

A. the car
B. the truck
C. the average forces are equal
D. not enough information to answer

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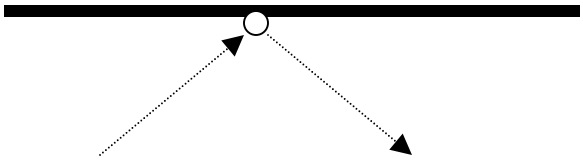
10. A 60-kg student is pushing a 500-kg cart with his hand applying a constant force of 400 N. The car is moving at a constant velocity in the direction of the push. The magnitude of the force applied to the student's hand by the cart is:

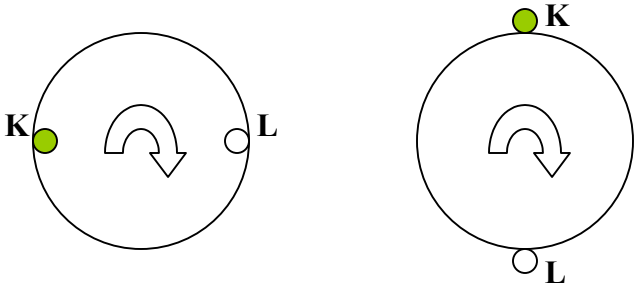
A. greater than 400 N
B. less than 400 N
C. equal to 400 N
D. not enough information to answer

11. An elastic ball slides toward an elastic wall on a horizontal surface and bounces off the wall as shown. Which vector best represents the direction of the change in momentum of the ball?



A.
B.
C.
D

12. Consider an isolated binary system of two stars (K and L) of equal masses, rotating <u>clockwise</u> as shown. Two "snapshots" of the system at moments t_1 and t_2 are shown. Which vector best represents the direction of the change in momentum of star K between t_1 and t_2?



A.
B.
C.
D.

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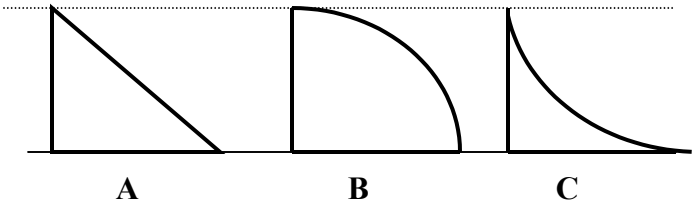
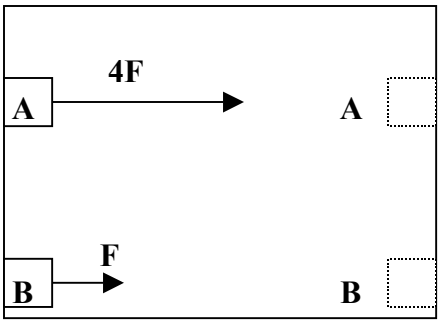
13. Three identical blocks slide down the frictionless slopes A, B and C of equal heights as shown. All three blocks are initially at rest. Which block would reach the ground at the greatest speed?



A. block A
B. block B
C. block C
D. all three blocks have the same speed

14. Two blocks, A and B, have equal masses. They are placed next to each other on a horizontal frictionless table. Each block is then pulled across the table by a horizontal forces of different magnitudes as shown.



Compare the velocities of the blocks as each of them reaches the opposite end of the table.
The velocity of block A is:

A. two times that of block B
B. four times that of block B
C. eight times that of block B
D. sixteen times that of block B

15. A 2-kg block is acted upon by two forces: 3 N, directed to the left and 4 N, directed to the right. The block is then:

A. moving to the left
B. moving to the right
C. remaining at rest
D. not enough information to answer

16. A 3-kg block is acted upon by two forces, 30 N and 60 N, acting at right angles. The block <u>cannot</u> possibly be moving:

A. in a circle
B. with decreasing velocity
C. with increasing acceleration
D. in a parabolic path

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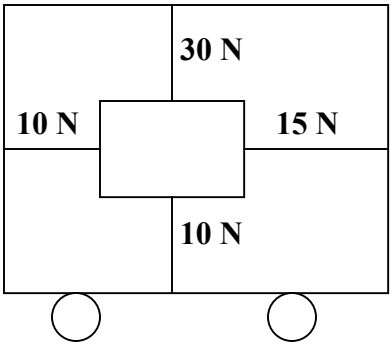
17. One example of an object in equilibrium is:

A. a 2400-kg car, moving north at a speed of 90 km/h
B. a vertically thrown ball at the top of its trajectory
C. a satellite moving around the Earth in a circular orbit
D. a simple pendulum swinging in vacuum

18. Two forces, of magnitudes 5 N and 15 N, are applied to an object. The relative direction of the forces is unknown. The net force acting on the object:

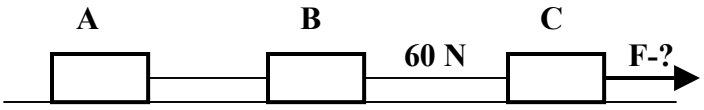
A. <u>may not</u> be directed perpendicular to the 5-N force
B. <u>may</u> be directed perpendicular to the 15-N force
C. <u>may not</u> equal to 5 N
D. <u>may not</u> equal to 15 N

19. A bus is moving along a horizontal stretch of highway from Boston to New York. Inside the bus, a block of unknown mass is suspended using two horizontal and two vertical strings as shown. The force of tension in each string is given on the diagram. The acceleration of the bus is then:



A. about 0.5 m/s^2
B. about 2.5 m/s^2
C. about 4.0 m/s^2
D. not enough information to answer

20. Three identical blocks are connected by ideal strings are being pulled along a horizontal frictionless table by a constant horizontal force F (see the diagram). What is the magnitude of force F is the tension of the string connecting blocks B and C is 60 N?



A. 60 N
B. 120 N
C. 180 N
D. none of the above

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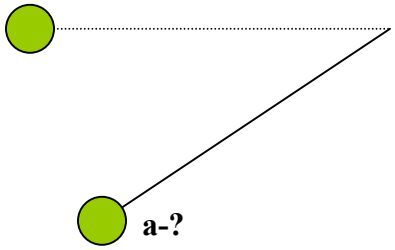
21. A pendulum is held in a horizontal position and then released. The pendulum then swings downward freely.
At an "intermediate" position (see the diagram), the instantaneous net acceleration of the pendulum <u>may</u> be directed:

A. vertically downward
B. perpendicular to the string
C. horizontally
D. none of the above is possible



22. A car is at rest on a slope of a hill. The following two forces <u>must</u> have equal magnitudes:

A. the weight of the car and the normal force acting on the car
B. the force of friction acting on the car and the force of friction acting on the slope
C. the weight of the car and the force of friction acting on the car
D. none of the above is true

23. A student stands on a chair. The chair rests on a horizontal floor. The reaction force to the normal force acting on the student is:

A. the force applied to the chair by the student's feet
B. the weight of the student
C. the combined weight of the student and the chair
D. the force applied to the floor by the chair

24. A satellite orbits the Earth in a circular orbit. Consider the system "Earth-satellite." What is the reaction force to the weight of the satellite?

A. the centripetal force directed toward the Earth
B. the force of inertia directed away from the Earth
C. the force of gravity applied to the Earth
D. there is no reaction force since gravity is not a contact force

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25. A 2.0-kg block is dropped from a 500-m height. Due to air resistance, the fall takes 18 s. What is the net impulse exerted on the block during the fall? Assume that the acceleration due to gravity is 10 m/s^2.

A. 200 kg-m/s
B. 3600 kg-m/s
C. 1000 kg-m/s
D. not enough information to answer

26. Two blocks of masses 2 kg and 3 kg slide on a frictionless horizontal surface with the speeds of 4 m/s and 2 m/s, respectively. After an inelastic collision, the blocks move together at a speed of 2 m/s. What was the relative direction of motion before the collision?

A. at 45 degrees
B. at right angles
C. toward each other
D. not enough information to answer

27. Two blocks of equal masses are launched upward at the same angle above a horizontal plane. Block A is launched as a projectile. Block B is pushed up a slope. In the absence of friction and air resistance, which block would reach greater maximum height?

A. block A
B. block B
C. both blocks would reach the same height
D. not enough information to answer

28. A projectile is launched vertically upward. It explodes into two pieces at the top point of its trajectory. One piece has twice the mass of the other. Immediately after the explosion, the more massive piece has kinetic energy E. What is the total kinetic energy of both pieces immediately after the explosion?

A. 1.5E
B. 2E
C. 3E
D. not enough information to answer

END OF THE TEST

Answer key

1. A

2. B

3. C

4. C

5. B

6. A

7. C

8. B

9. C

10. C

11. B

12. B

13. D

14. A

15. D

16. C

17. A

18. C

19. B

20. D

21. C

22. B

23. A

24. C

25. D

26. B

27. B

28. C