AP PHYSICS C: DYNAMICS

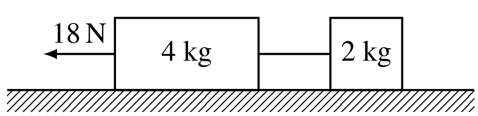
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and place the letter of your choice in the corresponding box on the student answer sheet.

Note: To simplify calculations, you may use $g = 10\,\text{m/s}^2$ in all problems.

1. A small moving block collides with a large block at rest. Which of the following is true of the forces the blocks apply to each other
   (A) The small block exerts twice the force on the large block compared to the force the large block exerts on the small block.
   (B) The small block exerts half the force on the large block compared to the force the large block exerts on the small block.
   (C) The small block exerts exactly the same amount of force on the large block that the large block exerts on the small block.
   (D) The large block exerts a force on the small block, but the small block does not exert a force on the large block.
   (E) The small block exerts a force on the large block, but the large block does not exert a force on the small block.

Questions 2–3

Two blocks, 4 kg and 2 kg, are connected by a string. An applied force F of magnitude 18 N pulls the blocks to the left.

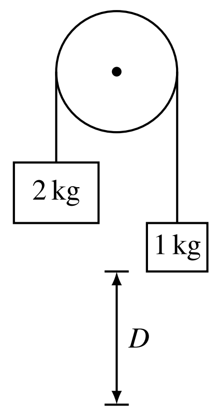


2. The acceleration of the 4-kg block is
   (A) $2\,\text{m/s}^2$
   (B) $3\,\text{m/s}^2$
   (C) $4\,\text{m/s}^2$
   (D) $4.5\,\text{m/s}^2$
   (E) $6\,\text{m/s}^2$

3. The tension in the string between the blocks is
   (A) 4 N
   (B) 6 N
   (C) 12 N
   (D) 16 N
   (E) 18 N

Questions 4–5

A system consists of two blocks having masses of 2 kg and 1 kg. The blocks are connected by a string of negligible mass and hung over a light pulley, and then released from rest.

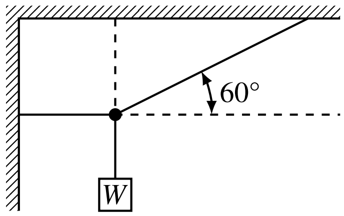


4. The acceleration of the 2 kg block is most nearly
   (A) $\frac{2}{9}g$
   (B) $\frac{1}{3}g$
   (C) $\frac{1}{2}g$
   (D) $\frac{2}{3}g$
   (E) g

5. The speed of the 2 kg block after it has descended a distance D is most nearly
   (A) $\sqrt{\frac{4gD}{3}}$
   (B) $\sqrt{\frac{2gD}{3}}$
   (C) $\sqrt{\frac{gD}{3}}$
   (D) $\sqrt{\frac{gD}{2}}$
   (E) $\sqrt{\frac{4gD}{6}}$

Questions 6–7

A weight of magnitude W is suspended in equilibrium by two cords, one horizontal and one slanted at an angle of 60° from the horizontal, as shown.



6. Which of the following statements is true?
   (A) The tension in the horizontal cord must be greater than the tension in the slanted cord.
   (B) The tension in the slanted cord must be greater than the tension in the horizontal cord.
   (C) The tension is the same in both cords.
   (D) The tension in the horizontal cord equals the weight W.
   (E) The tension in the slanted cord equals the weight W.

7. The tension in the horizontal cord is
   (A) equal to the tension in the slanted cord
   (B) one-third as much as the tension in the slanted cord
   (C) one-half as much as the tension in the slanted cord
   (D) twice as much as the tension in the slanted cord
   (E) three times as much as the tension in the slanted cord

Questions 8–9

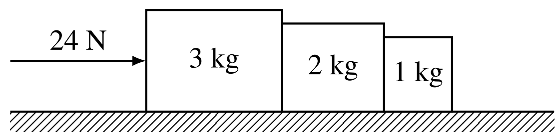
An object of mass m moves along a straight line with a speed described by the equation $v = c + bt^3$.

8. The initial velocity of the mass is
   (A) c
   (B) $ct + bt^3$
   (C) $ct + bt^4$
   (D) bt^2
   (E) bt

9. The net force acting on the mass at time T is
   (A) $3mbT$
   (B) $3mbT^2$
   (C) $3mbT^3$
   (D) $mc + 2mbT^2$
   (E) $mc^2 + 4mbT^4$

Questions 10–11

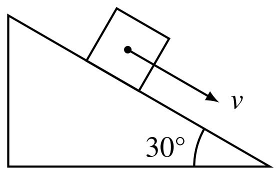
Three blocks of mass 3 kg, 2 kg, and 1 kg are pushed along a horizontal frictionless plane by a force of 24 N to the right, as shown.



10. The acceleration of the 2 kg block is
    (A) $144\,\text{m/s}^2$
    (B) $72\,\text{m/s}^2$
    (C) $12\,\text{m/s}^2$
    (D) $6\,\text{m/s}^2$
    (E) $4\,\text{m/s}^2$

11. The force that the 2 kg block exerts on the 1 kg block is
    (A) 2 N
    (B) 4 N
    (C) 6 N
    (D) 24 N
    (E) 144 N

12. A block of mass 4 kg slides down a rough incline with a constant speed. The angle the incline makes with the horizontal is 30°. The coefficient of friction acting between the block and incline is most nearly

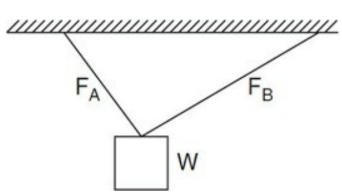


(A) 0.1
(B) 0.2
(C) 0.3
(D) 0.4
(E) 0.6

13. A ball is thrown straight up into the air, encountering air resistance as it rises. What forces, if any, act on the ball as it rises?

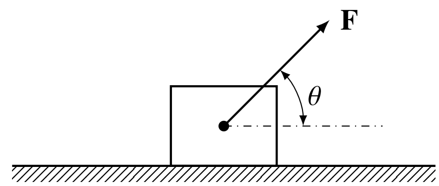
(A) A decreasing gravitational force and an increasing force of air resistance
(B) An increasing gravitational force and an increasing force of air resistance
(C) A decreasing gravitational force and a decreasing force of air resistance
(D) A constant gravitational force and an increasing force of air resistance
(E) A constant gravitational force and a decreasing force of air resistance

14. A weight w is hung from two threads, A and B, as shown below. The magnitudes of the tensions in each string are F_A and F_B, respectively. Which of the following describes the relationship between F_A, F_B, and W?



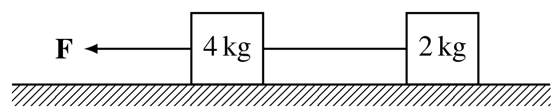
(A) $F_A = F_B = W$
(B) $F_A = F_B$
(C) $F_A < F_B$
(D) $F_A > F_B$
(E) $F_A + F_B = W$

15. A force of magnitude F pulls up at an angle θ to the horizontal on a block of mass m. The mass remains in contact with the level floor and the coefficient of friction between the block and the floor is μ. The frictional force between the floor and the block is



(A) μmg
(B) $\mu(mg - F\sin\theta)$
(C) $\mu(mg + F\sin\theta)$
(D) $\mu(mg - F\cos\theta)$
(E) $\mu(mg + F\cos\theta)$

16. Two blocks are pulled by a force of magnitude F along a level surface with negligible friction as shown. The tension in the string between the blocks is



(A) $F/4$
(B) $F/2$
(C) $F/3$
(D) F
(E) $2F$

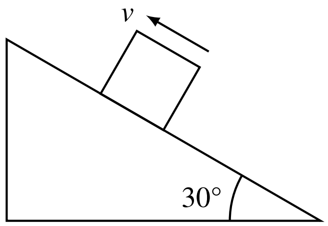
17. A stone falls through the air toward the Earth's surface. The resistive force the air applies to the stone as it falls is given by the equation $F = cv$, where c is a positive constant and v is the speed of the stone. The acceleration of the ball is given by the equation

(A) $c - g$
(B) gcv/m
(C) $g + cv$
(D) $g - cv/m$
(E) cv/m

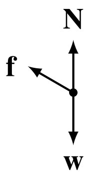
GO ON TO THE NEXT PAGE.

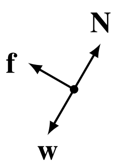
Questions 18–19

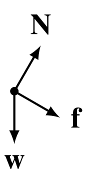
A 1-kg block is sliding up a rough 30° incline and is slowing down with an acceleration of $-6\,\mathrm{m/s^2}$. The mass has a weight **w**, and encounters a frictional force **f** and a normal force **N**. The direction up the ramp is positive.

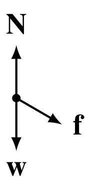


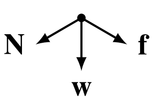
18. Which of the following free body diagrams best represents the forces acting on the block as it slides up the plane?

(A) 

(B) 

(C) 

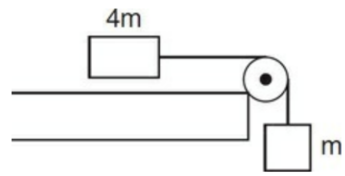
(D) 

(E) 

19. The magnitude of the frictional force f between the block and the plane is most nearly

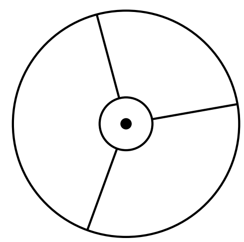
(A) 1 N
(B) 2 N
(C) 3 N
(D) 4 N
(E) 5 N

20. A block of mass $4m$ can move without friction on a horizontal surface. Another block of mass m is attached to the larger block by a string that is passed over a light pulley. The acceleration of the system is



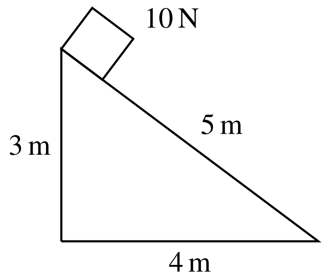
(A) $g/5$
(B) $g/2$
(C) $2g/3$
(D) g
(E) $5g$

21. Three strings are attached to a ring in the center of a force table. The top view of the force table is shown. For the ring to remain in the center of the table, which of the following must be true?



(A) The vector sum of the three forces must equal zero.
(B) The lengths of the strings must be equal.
(C) The strings must form an angle of 90° relative to each other.
(D) The magnitudes of two of the tensions in the strings must equal the tension in the third string.
(E) The tension in each string must be equal to each other.

Questions 22–23
A 10 N block sits atop an inclined plane in the shape of a right triangle of sides 3 m, 4 m, and 5 m, as shown. The block is allowed to slide down the plane with negligible friction.



22. The acceleration of the block is most nearly
   (A) $2\ \text{m/s}^2$
   (B) $4\ \text{m/s}^2$
   (C) $6\ \text{m/s}^2$
   (D) $10\ \text{m/s}^2$
   (E) $12\ \text{m/s}^2$

23. The normal force exerted on the block by the plane is most nearly
   (A) 2 N
   (B) 4 N
   (C) 6 N
   (D) 8 N
   (E) 10 N

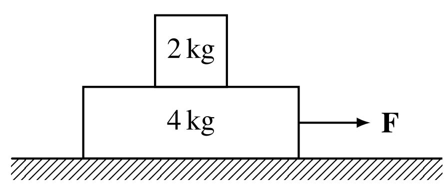
Questions 24–25
The position of a 2-kg object is described by the equation $x = 2t^2 - 3t^3$, where x is in meters and t is in seconds.

24. The net force acting on the object at a time of 1 s is
   (A) −4 N
   (B) −8 N
   (C) −14 N
   (D) −20 N
   (E) −24 N

25. The net force acting on the object is positive from $t = 0$ until a time of
   (A) 0.11 s
   (B) 0.22 s
   (C) 0.44 s
   (D) 0.67 s
   (E) 1.0 s

26. A constant force acts on a particle in such a way that the direction of the force is always perpendicular to its velocity. Which of the following is true of the particle's motion?
   (A) The acceleration of the particle is increasing
   (B) The acceleration of the particle is decreasing.
   (C) The speed of the particle is increasing.
   (D) The speed of the particle is constant.
   (E) The speed of the particle is decreasing.

Questions 27–28
A block of mass 2 kg rests on top of a larger block of mass 4 kg. The larger block slides without friction on a table, but the surface between the two blocks is not frictionless. The coefficient of friction between the two blocks is 0.2. A horizontal force **F** is applied to the 4 kg mass.



27. What is the maximum force that can be applied such that there is no relative motion between the two blocks?
   (A) zero
   (B) 1 N
   (C) 2 N
   (D) 4 N
   (E) 12 N

28. What is the acceleration of the 2-kg block relative to the 4-kg block if a force is applied to the 4-kg block that causes the 4 kg block to accelerate at $3\ \text{m/s}^2$ to the right?
   (A) $1\ \text{m/s}^2$ to the right
   (B) $1\ \text{m/s}^2$ to the left
   (C) $2\ \text{m/s}^2$ to the right
   (D) $2\ \text{m/s}^2$ to the left
   (E) zero

AP PHYSICS C: DYNAMICS
SECTION II
5 Questions

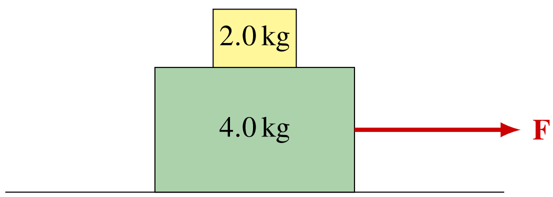
Directions: Answer all questions. The parts within a question may not have equal weight. All final numerical answers should include appropriate units. Credit depends on the quality of your solutions and explanations, so you should show your work. Credit also depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should clearly indicate which part of a question your work is for.

1. A 2.0 kg block sits on a 4.0 kg that is resting on a frictionless table, as shown below. The coefficient of friction between the blocks are $\mu_s = 0.30$ and $\mu_k = 0.20$.

   (a) What is the maximum force **F** that can be applied if the 2.0 kg block is not to slide on the 4.0 kg block.

   (b) If **F** is half this value, find the acceleration of each block and the force of firciotn acting on each block.

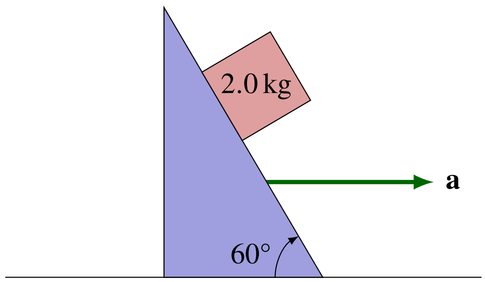
   (c) If **F** is twice the value found in (a), find the acceleration of each block.



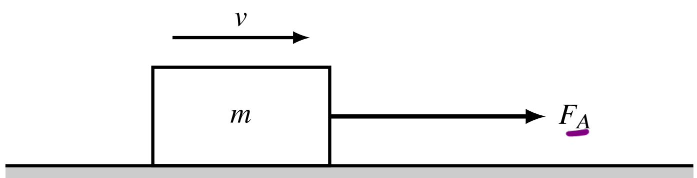
2. A 2.0 kg body rests on a smooth wedge that has an inclination of 60° and an acceleration **a** to the right such that the mass remains stationary relative to the wedge.

   (a) Find acceleration **a**.

   (b) What would happen if the wedge were given a greater acceleration?

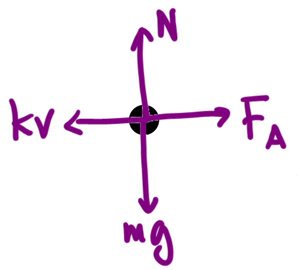


3. A pick-up truck with two stacked crates in the truck bed brakes quickly. The crate on the bottom just barely stays put on the bed of the truck. Does the top crate stay put or does it fall off? The top crate has a mass of 27 kg and the mass of the bottom crate is 22 kg. The coefficient of static friction between the bottom crate and the truck is 0.42, and the coefficient of kinetic friction for that surface is 0.35. The coefficient of static friction between the crate is 0.40, and the coefficient of kinetic friction is 0.32.



4. A box of mass m initially at rest is acted upon by a constant applied force of magnitude F_A, as shown in the figure above. The friction between the box and the horizontal surface can be assumed to be negligible, but the box is subject to a drag force of magnitude kv where v is the speed of the box and k is a positive constant. Express all your answers in terms of the given quantities and fundamental constants, as appropriate.

(4) (a) The dot below represents the box. Draw and label the forces (not components) that act on the box.



(2) (b) Write, but do not solve, a differential equation that could be used to determine the speed v of the box as a function of time t. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

$\rightarrow (+)$

$F_{net} = ma$

$F_A - kv = ma \longrightarrow \boxed{F_A - kv = m\frac{dv}{dt}}$

[1] (c) Determine the magnitude of the terminal velocity of the box.

at V_T, $a=0$

$\frac{dv}{dt} = 0$

$F_A = kv_T \rightarrow \boxed{V_T = \frac{F_A}{k}}$

[5] (d) Use the differential equation from part (b) to derive the equation for the speed v of the box as a function of time t. Assume that $v = 0$ at time $t = 0$.

$F_A - kv = m\frac{dv}{dt}$

$\int_0^t dt = \int_0^v \frac{m\,dv}{F_A - kv}$

$t = \frac{-m}{k}\ln(F_A - kv)$

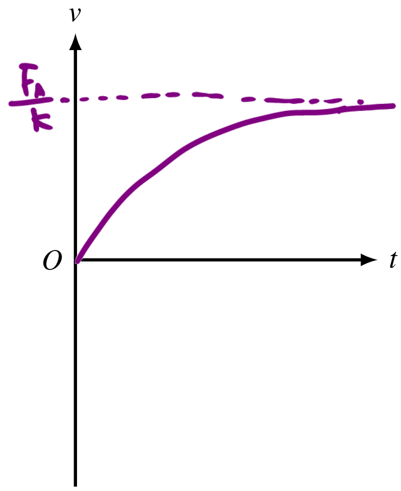
$-\frac{k}{m}t\Big|_0^t = \ln(F_A - kv)\Big|_0^{v(t)}$

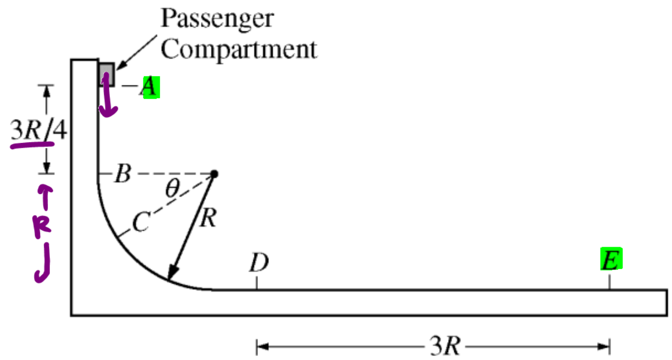
$\frac{-k}{m}t = \ln\left(\frac{F_A - kv}{F_A}\right)$

$e^{-\frac{k}{m}t} = \left(\frac{F_A - kv}{F_A}\right) = 1 - \frac{kv(t)}{F_A}$

$\boxed{v(t) = \frac{F_A}{k}\left(1 - e^{-\frac{k}{m}t}\right)}$

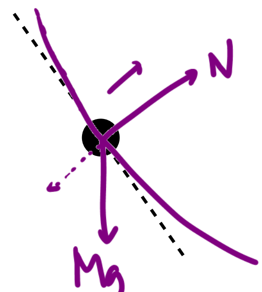
(e) On the axes below, sketch a graph of the speed v of the box as a function of time t. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.





5. An amusement park ride features a passenger compartment of mass M that is released from rest at point A, as shown in the figure above, and moves along a track to point E. The compartment is in free fall between points A and B, which are a distance of $3R/4$ apart, then moves along the circular arc of radius R between points B and D. Assume the track is frictionless from point A to point D and the dimensions of the passenger compartment are negligible compared to R.

[2] (a) On the dot below that represents the passenger compartment, draw and label the forces (not components) that act on the passenger compartment when it is at point C, which is at an angle θ from point B.



[1] (b) In terms of θ and the magnitudes of the forces drawn in part (a), determine an expression for the magnitude of the centripetal force acting on the compartment at point C. If you need to draw anything besides what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

$$\boxed{F_c = N - Mg\sin\theta}$$

centripetal force is (+) towards the centre of curvature

[2] (c) Derive an expression for the speed v_D of the passenger compartment as it reaches point D in terms of M, R, and fundamental constants, as appropriate.

$$U_g + \cancel{K} = \cancel{U_g'} + K'$$

$$Mg\left(R + \frac{3R}{4}\right) = \frac{1}{2}Mv_D^2$$

$$\frac{7}{4}\cancel{M}gR = \frac{1}{2}\cancel{M}v_D^2$$

$$v_D^2 = \frac{7}{2}gR \longrightarrow \boxed{v_D = \sqrt{\frac{7}{2}gR}}$$

- Better to use conservation of energy instead of dynamics, because the acceleration is not constant (integration is messy)
- only conservative work done by gravity.

GO ON TO THE NEXT PAGE.

A force acts on the compartment between points D and E and brings it to rest at point E.

[2]

(d) If the compartment is brought to rest by friction, calculate the numerical value of the coefficient of friction μ between the compartment and the track.

$F_k = \mu N = \mu mg$

$F_k = ma$

$-\mu mg = ma$

$a = -\mu g$

$F = ma$

$V_E^2 = V_D^2 + 2ad$, with $V_E = 0$, $V_D^2 = \frac{7}{2}gR$, $a = -\mu g$, $d = 3R$

$V_D^2 = -2ad$

$\frac{7}{2}gR = (-2)(-\mu g)(3R)$

$\frac{7}{2}\cancel{gR} = 6\mu \cancel{gR}$

$\boxed{\mu = \frac{7}{12}}$

(e) Now consider the case in which there is no friction between the compartment and the track, but instead the compartment is brought to rest by a braking force $-k\mathbf{v}$, where k is a constant and $\mathbf{v}$ is the velocity of the compartment. Express all algebraic answers to the following in terms of M, R, k, v_D, and fundamental constants, as appropriate.

[2] i. Write, but do NOT solve, the differential equation for $v(t)$.

kv

$ma = -kv$

$\boxed{m\frac{dv}{dt} = -kv}$

$\frac{dv}{v} = -\frac{k}{m}dt$

[2] ii. Solve the differential equation you wrote in part i.

$m\frac{dv}{dt} = -kv$

integrate $\rightarrow$ $\frac{dv}{v} = \left(\frac{-k}{m}\right)t$

constant of integration

$\ln v = \frac{-k}{m}t + C$

$v = e^{\left(-\frac{k}{m}t + c\right)}$

$v = V_D e^{-\frac{k}{m}t}$

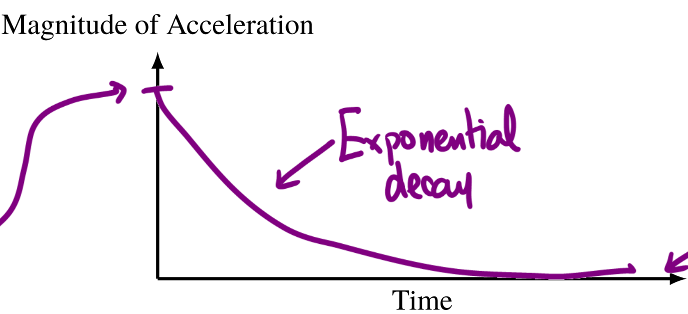
$\boxed{v(t) = \sqrt{\frac{7}{2}gR}\, e^{-\frac{k}{m}t}}$

[3] iii. On the axes below, sketch a graph of the magnitude of the acceleration of the compartment as a function of time. On the axes, explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.

$a = \frac{dv}{dt} = \frac{-V_D k}{m}e^{-\frac{k}{m}t}$

$|a| = \frac{V_D k}{m}e^{-\frac{k}{m}t}$

$|a(0)| = \frac{V_D k}{m} = \frac{k}{m}\sqrt{\frac{7}{2}gR}$



Exponential decay

asymptote

GO ON TO THE NEXT PAGE.