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No time limit. No notes. No books. Testing Center calculators only.

Constants:

$g = 9.8 \text{ m/s}^2 \rightarrow$ **but you may use 10 m/s² in nearly all cases**
 $G = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$
 $k_B = 1.381 \times 10^{-23} \text{ J/K}$
 $N_A = 6.022 \times 10^{23}$
 $R = k_B \cdot N_A = 8.314 \text{ J/mol}\cdot\text{K}$
 $\sigma_{\square} = 5.67 \times 10^{-8} \text{ W/m}^2\cdot\text{K}^4$
 Mass of Sun = $1.991 \times 10^{30} \text{ kg}$
 Mass of Earth = $5.98 \times 10^{24} \text{ kg}$

Radius of Earth = $6.38 \times 10^6 \text{ m}$
 Radius of Earth's orbit = $1.496 \times 10^{11} \text{ m}$
 Density of water: 1000 kg/m^3
 Density of air: 1.29 kg/m^3
 Young's modulus of steel: $20 \times 10^{10} \text{ N/m}^2$
 Linear exp. coeff. of copper: $17 \times 10^{-6} /^\circ\text{C}$
 Linear exp. coeff. of steel: $11 \times 10^{-6} /^\circ\text{C}$
 Specific heat of water: $4186 \text{ J/kg}\cdot^\circ\text{C}$
 Specific heat of ice: $2090 \text{ J/kg}\cdot^\circ\text{C}$
 Specific heat of steam: $2010 \text{ J/kg}\cdot^\circ\text{C}$

Specific heat of aluminum: $900 \text{ J/kg}\cdot^\circ\text{C}$
 Latent heat of melting (water): $33 \times 10^5 \text{ J/kg}$
 Latent heat of boiling (water): $2.26 \times 10^6 \text{ J/kg}$
 Thermal conduct. of aluminum: $238 \text{ J/s}\cdot\text{m}\cdot^\circ\text{C}$
 $\sin(30^\circ) = 0.5$
 $\cos(30^\circ) \approx 0.866$
 $\tan(30^\circ) \approx 0.577$
 $\pi \approx 3.14$

Conversion factors

1 inch = 2.54 cm
 1 m³ = 1000 L

1 atm = $1.013 \times 10^5 \text{ Pa} = 14.7 \text{ psi}$
 $T_F = \frac{9}{5}T_C + 32$

$T_K = T_C + 273.15$

Other equations

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Surface area of sphere = $4\pi r^2$

Volume of sphere = $(4/3)\pi r^3$

$$v_{ave} = \frac{v_i + v_f}{2}$$

$$v = v_o + at$$

$$x = x_o + v_o t + \frac{1}{2}at^2$$

$$v_f^2 = v_o^2 + 2a\Delta x$$

$$w = mg, PE_g = mgy$$

$$F = -kx, PE_s = \frac{1}{2}kx^2$$

$$f = \mu_k N \text{ (or } f \leq \mu_s N)$$

$$P = F_{\parallel} / v = Fv \cos \theta$$

$$\vec{F}\Delta t = \Delta \vec{p}$$

Elastic: $(v_1 - v_2)_{\text{bef}} = (v_2 - v_1)_{\text{after}}$

arc length: $s = r\theta$

$$v = r\omega$$

$$a_{\text{tan}} = r\alpha$$

$$a_c = v^2/r$$

$$F_g = \frac{GMm}{r^2}, PE_g = -\frac{GMm}{r}$$

$$I_{\text{pt mass}} = mR^2$$

$$I_{\text{sphere}} = (2/5) mR^2$$

$$I_{\text{hoop}} = mR^2$$

$$I_{\text{disk}} = (1/2) mR^2$$

$$I_{\text{rod (center)}} = (1/12) mL^2$$

$$I_{\text{rod (end)}} = (1/3) mL^2$$

$$L = r_{\perp} p = rp_{\perp} = rp \sin \theta$$

stress = F/A ; strain = $\Delta L/L$

$Y = \text{stress/strain}$

$$P = P_0 + \rho gh$$

$$VFR = A_1 v_1 = A_2 v_2$$

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho gy_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gy_2$$

$$\Delta L = \alpha L_0 \Delta T$$

$$\Delta V = \beta V_0 \Delta T; \beta = 3\alpha$$

$$KE_{ave} = \frac{1}{2}mv_{ave}^2 = \frac{3}{2}k_B T$$

$$Q = mc\Delta T; Q = mL$$

$$\frac{\Delta Q}{\Delta T} = kA \frac{T_2 - T_1}{L}$$

$$P = e\sigma AT^4$$

$|W_{\text{on gas}}| = \text{area under P-V curve}$
 $= P\Delta V \text{ (constant pressure)}$

$$U = \frac{3}{2}Nk_B T = \frac{3}{2}nRT \text{ (monatomic ideal gas)}$$

$$Q_h = |W_{\text{net}}| + Q_c$$

$$e = \frac{|W_{\text{net}}|}{Q_{\text{added}}} = 1 - \frac{Q_c}{Q_h}$$

$$e_{\text{max}} = 1 - \frac{T_c}{T_h}$$

$$\omega = \sqrt{\frac{k}{m}}, T = 2\pi\sqrt{\frac{m}{k}}$$

$$\omega = \sqrt{\frac{g}{L}}, T = 2\pi\sqrt{\frac{L}{g}}$$

$$v = \sqrt{\frac{T}{\mu}}, \mu = m/L$$

$$v = \sqrt{\frac{Y}{\rho}}, v = \sqrt{\frac{B}{\rho}}$$

$v_{\text{air}} = 343 \text{ m/s at } 20^\circ\text{C}$

$$\beta = 10 \log\left(\frac{I}{I_0}\right) \quad I_0 = 10^{-12} \text{ W/m}^2$$

$$f' = f \frac{v \pm v_0}{v \pm v_s}$$

$$f_n = n \frac{v}{2L} \quad n = 1, 2, 3, \dots$$

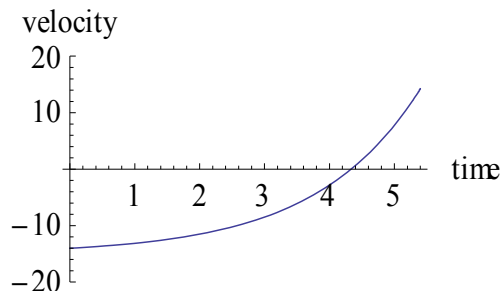
$$f_n = n \frac{v}{4L} \quad n = 1, 3, 5, \dots$$

Did you write down your CID at the top of the page? _____ If not, you may not get this test booklet back.

Instructions:

- Record your answers for problems 1-28 on the bubble sheet.
- You may write on this exam booklet, and are strongly encouraged to do so.
- I strongly encourage you to **mark your answers in this test booklet**. You will get this test booklet back (but only if you **write your CID at the top of the first page**).
- In all problems, **ignore friction, air resistance, and the mass of all springs, pulleys, ropes, cables, strings etc.**, unless specifically stated otherwise.
- Use $g = 9.8 \text{ m/s}^2$ only if there are “9.8” numbers in the answer choices; **otherwise use $g = 10 \text{ m/s}^2$** .
- Problems 1-28 will be scaled to be worth 92 total points; problems 29 and 30 are worth 4 points each.

Problem 1. The figure shows a velocity vs time graph of a car moving along a road, and positive means “to the right”. According to the graph, what is the car doing from 0 to 5 seconds?



- moving to the left, slowing down, and stopping
- moving to the left and speeding up
- moving to the right, slowing down, and stopping
- moving to the right and speeding up
- first moving right, then moving left
- first moving left, then moving right

Problem 2. A man holding a rifle at height $y = 0$ tries to hit the side of a large barn 90 m away. The rifle is shot at 24.7° above the horizontal. The initial velocity of the bullet is 200 m/s. What is the y -position in meters of the hole the bullet makes in the side of the barn? Use $\sin(24.7^\circ) = 0.4$, $\cos(24.7^\circ) = 0.9$. Hint: first find the time it will take.

- 33.75 m
- 34.75
- 35.75
- 36.75
- 37.75
- 38.75
- 39.75 m

Problem 3. From the perspective of Newton’s Second Law, what force on a car causes it to accelerate forward when the gas pedal is pushed?

- The car pushing backward on the road
- The car pushing forward on the road
- The road pushing backward on the car
- The road pushing forward on the car

Problem 4. You slide a block of ice down a 45° ramp. There is no friction between the ice and the ramp. How will the acceleration of the ice block down the ramp compare to the standard acceleration of gravity, 9.8 m/s^2 ?

- It will be equal to 9.8 m/s^2 .
- It will be greater than 9.8 m/s^2 .
- It will be less than 9.8 m/s^2 .

Problem 5. A boat moves through the water with two forces acting on it. One is a 2200 N forward push by the water on the propeller, and the other is a 1500 N resistive force due to the water around the bow. What is the acceleration of the 1000 kg boat?

- Less than 0.53 m/s
- 0.53 – 0.63
- 0.63 – 0.73
- 0.73 – 0.83
- 0.83 – 0.93
- More than 0.93 m/s

Problem 6. You need to carry a suitcase up a flight of stairs. In which case will you do the most work on it against gravity?

- a. You carry the suitcase up quickly.
- b. You carry the suitcase up slowly.
- c. Both cases involve the same amount of work.

Problem 7. A woman with a parachute is falling at constant speed. How does the magnitude of the force of gravity pulling down on the woman compare to the magnitude of the force of the parachute pulling up on her?

- a. Gravity is greater
- b. Parachute is greater
- c. They are the same

Problem 8. On a frozen pond, an 8 kg sled has an initial speed of $v_0 = 10$ m/s. The coefficient of kinetic friction between sled and ice is $\mu_k = 0.2$. Find the distance the sled moves before coming to rest.

- a. Less than 9 m
- b. 9 – 15
- c. 15 – 21
- d. 21 – 27
- e. 27 – 33
- f. 33 – 39
- g. More than 39 m

Problem 9. The amount of potential energy possessed by an object that has been lifted up is equal to:

- a. the distance the object is lifted
- b. the force used to lift the object
- c. the object's acceleration due to gravity
- d. the weight of the object
- e. the work done in lifting the object

Problem 10. Jen throws three balls from the top of a building towards a large flat parking lot: one straight up, one straight down and one horizontally, all with the same initial speed. Which ball will have the highest speed just before it hits the ground? (As usual, ignore air resistance.)

- a. The one thrown horizontally
- b. The one thrown straight down
- c. The one thrown straight up
- d. All three will all have the same speed

Problem 11. A box slides down a ramp. The work done on the box by the normal force is:

- a. positive
- b. negative
- c. zero

Problem 12. The parachute on a race car of mass 600 kg opens when the car is traveling at 50 m/s. What average force (magnitude) must be supplied by the parachute to stop the car in a time of 20 seconds?

- a. Less than 1550 N
- b. 1550 – 1650
- c. 1650 – 1750
- d. 1750 – 1850
- e. 1850 – 1950
- f. 1950 – 2050
- g. More than 2050 N

Problem 13. A skier of mass 71 kg is pulled up a 15° frictionless slope by a motor-driven cable at a constant speed of 3 m/s. How many horsepower must a motor have to perform this task? (1 hp = 745.7 W)

- a. $\frac{3}{(71)(9.8)(\sin 15^\circ)745.7}$ hp
- b. $\frac{71}{(9.8)(\sin 15^\circ)(3)745.7}$
- c. $\frac{(\sin 15^\circ)(3)}{(71)(9.8)745.7}$
- d. $\frac{(71)(9.8)(\sin 15^\circ)(3)}{745.7}$
- e. $\frac{(71)(3)}{(9.8)(\sin 15^\circ)745.7}$
- f. $\frac{(71)(9.8)(3)}{(\sin 15^\circ)745.7}$
- g. $\frac{(71)(\sin 15^\circ)(3)}{(9.8)745.7}$ hp

Problem 14. You are a passenger in a car and not wearing your seat belt. Without increasing or decreasing its speed, the car makes a sharp left turn, and you find yourself colliding with the right-hand door. Which is the correct analysis of the situation according to Newton's laws?

- Before and after the collision with the door, there is a rightward force pushing you into the door.
- Starting at the time of collision with the door, the door exerts a leftward force on you.
- Both of the above
- Neither of the above

Problem 15. In the "racing balls" demo, two balls were raced on different tracks. The closer track had a section that was lower for part of the race. Which ball won the race, and why?

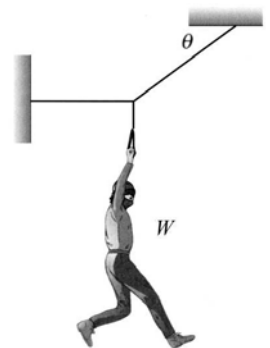
- The closer ball, because it was going a greater speed during the lower section.
- The closer ball, because it had a greater change of potential energy from start to finish.
- The farther away ball, because it was going a greater speed during the lower section.
- The farther away ball, because it had a greater change of potential energy from start to finish.
- The balls tied, because they both ended with the same kinetic energy.

Problem 16. Newton's 3rd Law says that forces come in pairs. A book lying on a table feels a force of gravity and a normal force. What is the Newton's 3rd Law partner force with the force of gravity on the book?

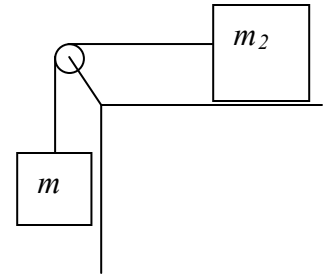
- the gravitational force of the book pulling up on the earth
- the normal force pushing up on the book
- the pressure of the book pushing down on the table
- none of the above

Problem 17. Two cables support a cat burglar of weight W . One cable is at an angle, θ , as shown in the figure. Find the tension in the cable connected to the left wall, in terms of W and θ .

- $\frac{w}{\cos \theta}$
- $\frac{w}{\sin \theta}$
- $\frac{w}{\tan \theta}$
- $w \cos \theta$
- $w \sin \theta$
- $w \tan \theta$



Problem 18. A hanging mass, m_1 , is attached via a pulley to another mass, m_2 , which is resting on a horizontal frictionless table as shown in the figure. Find the acceleration of the masses in terms of m_1 , m_2 , and g .



- a. g
- b. $m_1 g$
- c. $m_2 g$
- d. $\frac{m_1 g}{m_1 + m_2}$
- e. $\frac{m_2 g}{m_1 + m_2}$
- f. $\frac{(m_1 + m_2) g}{m_1}$
- g. $\frac{(m_1 + m_2) g}{m_2}$

Problem 19. Repeat, but with coefficient of friction μ between the table and m_2 . You may take it as given that the friction force is small enough that m_1 still does fall. *Note:* A free body diagram and an equation will be required for this situation, in problem 29.

- a. $\frac{m_1 g - \mu m_2 g}{m_1 + m_2}$
- b. $\frac{\mu m_2 g}{m_1 + m_2}$
- c. $\frac{m_2 g - \mu m_2 g}{m_1 + m_2}$
- d. $\frac{m_1 g + \mu m_2 g}{m_1 + m_2}$
- e. $\frac{m_1 g}{m_1 + \mu m_2}$
- f. $\frac{m_1 g - \mu m_2 g}{m_1 + \mu m_2}$
- g. $\frac{m_1 g}{\mu m_2}$

Problem 20. Same situation as the last problem. This time, however, the friction force is strong enough to prevent m_1 from falling. Specifically, $m_1 = 1$ kg, $m_2 = 7$ kg, $\mu = 0.5$, and both masses are at rest. What is the tension in the line connecting the two masses?

- a. Less than 8 N
- b. 8 – 16
- c. 16 – 24
- d. 24 – 32
- e. 32 – 40
- f. 40 – 48
- g. More than 48 N

Problem 21. You want to measure the spring constant of a hanging spring. You add a 0.5 kg mass to the initially unmoving spring and quickly release the mass so that it starts oscillating up and down with no additional forces on it. At the lowest point of the first oscillation, the mass has stretched the spring out to a distance of 20 cm below where it started. What is the spring constant k ?

- a. Less than 30 N/m
- b. 30 – 60
- c. 60 – 90
- d. 90 – 120
- e. 120 – 150
- f. More than 150 N/m

Problem 22. A 3 gram ping-pong ball starts at rest and is pushed 0.5 meters along an evacuated tube by a constant force of 30 N from air entering the tube behind it. How long does it take the ball to exit the tube?

- a. 0.01 s
- b. 0.02 s
- c. 0.03 s
- d. 0.04 s
- e. 0.05 s
- f. 0.06 s
- g. 0.07 s

Problem 23. A block ($m = 0.4$ kg) accelerates down a 37° (typo: exam said 35°) ramp (measured from the horizontal) at a rate of 0.5 m/s^2 . There is friction on the ramp. What is μ_k ?

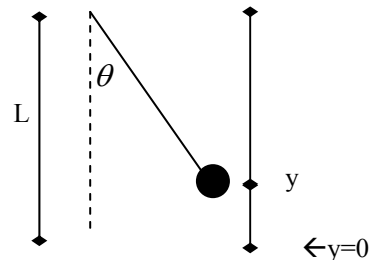
- a. $\frac{0.5}{4(9.8 \cos 37^\circ)}$
- b. $2(9.8 \sin 37^\circ) - 0.5$
- c. $\frac{4(9.8) - 9.8 \cos 37^\circ}{0.5}$
- d. $\frac{9.8 \cos 37^\circ - (0.5)^2}{3}$
- e. $\frac{9.8 \sin 37^\circ - 0.5}{9.8 \cos 37^\circ}$
- f. $9.8 \tan 37^\circ - 0.5$

Problem 24. Two identical cars, coasting from rest down two hills having the same vertical height—but one hill steeper than the other—will arrive at the bottom of the hills with the same speed. Yet the acceleration of the car down the steep hill is greater than the car going down the other hill. What is the best explanation for this seeming contradiction?

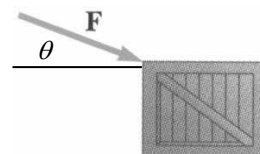
- The acceleration when we neglect friction and air resistance is always 9.8 m/s^2
- The car going down the less-steep hill accelerates for a longer distance.
- The car going down the steeper hill experiences more nonconservative forces.
- There is no contradiction: the cars will arrive at the bottom of the hills at the same time.

Problem 25. Tarzan (80 kg) swings on a vine (length 20 m) initially inclined at an angle of 36.9° from the vertical. He pushes off with an initial speed of 4 m/s. What is his speed at the bottom of the swing? The picture may help; Tarzan is the ball on the end of the vine. *Note:* $\sin(36.9^\circ) = 0.60$, $\cos(36.9^\circ) = 0.80$, $\tan(36.9^\circ) = 0.75$.

- $\sqrt{88} \text{ m/s}$
- $\sqrt{92} \text{ m/s}$
- $\sqrt{96} \text{ m/s}$
- $\sqrt{100} \text{ m/s}$
- $\sqrt{104} \text{ m/s}$
- $\sqrt{108} \text{ m/s}$

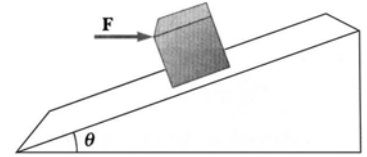


Problem 26. A crate (mass m) is being pushed across a level floor at a constant speed by a force F at an angle of θ below the horizontal as shown in the figure. In terms of F , θ , m , and g , find the coefficient of kinetic friction between the crate and the floor. *Note:* A free body diagram and some equations will be required for this situation, in Problem 30.



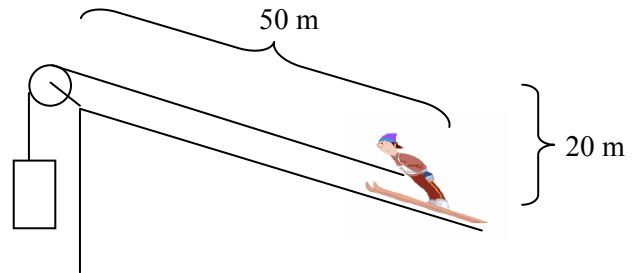
- $\mu = \frac{1}{\tan \theta}$
- $\mu = \frac{F}{mg}$
- $\mu = \frac{F}{mg + F \sin \theta}$
- $\mu = \frac{F}{mg + F \tan \theta}$
- $\mu = \frac{F \cos \theta}{mg}$
- $\mu = \frac{F \cos \theta}{mg + F \sin \theta}$

Problem 27. A block of mass $m = 2.7 \text{ kg}$ is held without moving on a frictionless incline of angle of 19° by the horizontal force F , as shown in the figure. Determine the value of the force F , in Newtons.



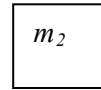
- $2.7 \cdot 9.8$ Newtons
- $\frac{2.7 \cdot 9.8}{\cos 19^\circ}$
- $\frac{2.7 \cdot 9.8}{\sin 19^\circ}$
- $\frac{2.7 \cdot 9.8}{\tan 19^\circ}$
- $2.7 \cdot 9.8 \cdot \cos 19^\circ$
- $2.7 \cdot 9.8 \cdot \sin 19^\circ$
- $2.7 \cdot 9.8 \cdot \tan 19^\circ$ Newtons

Problem 28. Vern, the famous “pulley ski-jumper” is 100 kg , and is pulled via a pulley by a 300 kg hanging block up a 50 m incline that has a vertical height change of 20 m ; see the figure. Friction provides a constant backwards force on Vern of 100 N . How fast will Vern be going when he takes off from the incline, assuming he misses the giant pulley?



- Less than $\sqrt{620}$ m/s
- Between $\sqrt{620}$ and $\sqrt{640}$
- Between $\sqrt{640}$ and $\sqrt{660}$
- Between $\sqrt{660}$ and $\sqrt{680}$
- Between $\sqrt{680}$ and $\sqrt{700}$
- More than $\sqrt{700}$ m/s

Problem 29 (4 pts). (a) Draw a free-body diagram for each mass in Problem 19. Be sure to label all forces.



(b) Write down the N2 “blueprint equation” for the two masses taken as a group, and fill in the blueprint with the given forces. Don’t solve the equation, just take it one or two steps past the blueprint. [If you don’t know how to use N2 for a group, do two N2 equations for the two masses separately.]

Blueprint:

Filled in:

Problem 30 (4 pts). (a) Draw a free-body diagram of the crate from Problem 26. Be sure to label all forces.



(b) Based on your FBD, write down and fill in the N2 “blueprint equations” for the x- and the y-directions. Don’t solve the equations, just take them one or two steps past the blueprint. Be sure to fill in the acceleration(s) if known.

x-direction

y-direction