1. What are the units of G, the universal constant of gravitation? (G is also known as “Big G”.)

A) \( \frac{N \cdot \text{kg}^2}{m^2} \)  
B) \( \frac{N^2 \cdot \text{kg}}{m^2} \)  
C) \( \frac{N \cdot \text{m}}{s^2} \)  
D) \( \frac{N \cdot m^2}{kg^2} \)  
E) None of these

\[ F = G \frac{m_1 m_2}{r^2} \Rightarrow G = \frac{F r^2}{m_1 m_2} \Rightarrow [G] = \frac{N \cdot m^2}{kg^2} \]

2. A block of mass m, starting at rest, slides a distance L down a plane inclined at an angle \( \theta \) as shown. The block moves with constant acceleration and has a final speed v at the bottom of the ramp. What is the correct expression for the magnitude a of the acceleration?

A) \( g \sin \theta \)  
B) \( \frac{v^2}{2L} \)  
C) \( \sqrt{2gL \sin \theta} \)  
D) \( gL \sin \theta \)  
E) cannot answer without knowing the coefficient of kinetic friction \( \mu_k \)

\[ \text{const} \ a = \Rightarrow v^2 = \frac{v_0^2}{0} + 2a(x-x_0) \]

\[ \Rightarrow v^2 = 2aL \quad a = \frac{v^2}{2L} \]

3. An Atwood’s Machine consists of two blocks suspended over a massless, frictionless pulley with a massless string. The blocks have masses \( m \) and \( 3m \), as shown. A student correctly writes down the following equations of motion for the two blocks, where \( T \) is the magnitude of the tension in the string and \( a \) is the magnitude of the acceleration of the blocks. Solve for the magnitude of the tension \( T \).

\( T - mg = ma \) (1)

\( 3mg - T = 3ma \) (2)

A) \( T = (3/5) mg \)  
B) \( T = (3/2) mg \)  
C) \( T = (2/3) mg \)  
D) \( T = 3 mg \)  
E) None of these

E) from (1), \( ma = (T - mg) \)

\( 2 \)

\[ 3mg - T = 3(T - mg) \]

\[ 3mg - T = 3T - 3mg \]

\[ 6mg = 4T, \quad T = \frac{6}{4} mg = \frac{3}{2} mg \]
4. A hand exerts a constant horizontal force on three blocks, labeled A, B, and C, as shown. The blocks are moving to the right and speeding up. There is friction between the blocks and the table. Blocks A and B have the same mass, block C has twice the mass of A \((m_A = m_B = m, m_C = 2m)\). How do the magnitudes of the net forces on each block compare?

A) \(F_{\text{net on A}} = F_{\text{net on B}} = F_{\text{net on C}}\)

B) \(F_{\text{net on A}} > F_{\text{net on B}} > F_{\text{net on C}}\)

C) \(F_{\text{net on A}} < F_{\text{net on B}} < F_{\text{net on C}}\)

D) \(F_{\text{net on A}} = F_{\text{net on B}} < F_{\text{net on C}}\)

E) \(F_{\text{net on A}} = F_{\text{net on B}} > F_{\text{net on C}}\)

\[ F_A = m \cdot a = F_B = m \cdot a, \quad F_C = 2ma \]

5. Two blocks of mass \(m\) and \(M\) are both being pushed along a frictionless surface by a horizontal external force of magnitude \(F\), as shown. What is the magnitude of the contact force \(F_C\) which the little block (mass \(m\)) exerts on the big block (mass \(M\))?

A) \(\frac{M}{m+M}F\)

B) \(\frac{m}{m+M}F\)

C) \(\frac{m}{M}F\)

D) \(\frac{M}{m}F\)

E) None of these is correct.

\[ \text{Regard } (m + M) \text{ as one big mass} \Rightarrow F = (m + M) a \]

\[ \Rightarrow a = \frac{F}{m + M}, \quad F_{\text{net on } M} = F_C = M \cdot a = \frac{M}{m + M} \cdot F \]

6. A small satellite of mass \(m\) is in circular orbit around a large planet of mass \(M\). The force of gravity on the satellite from the planet has magnitude \(F_{\text{on sat}}\). The force of gravity on the planet from the satellite has magnitude \(F_{\text{on planet}}\). What is the ratio of the sizes of the forces \(\frac{F_{\text{on planet}}}{F_{\text{on sat}}}\)?

A) \(m/M\)

B) \(M/m\)

C) \((m/M)^2\)

D) zero

E) 1 (forces have same magnitude)

\[ \text{Also } F = \frac{GMm}{r^2} \leq \text{same } F \text{ on both } M \text{ and } m \]

Vers. A
7. A box of mass $m = 2.0$ kg initially at the bottom of a ramp is given a brief hard shove up the ramp with an initial speed $v_i = 3.00$ m/s. The ramp is 1.50 m long and 0.50 m high. The box slides to the very top of the ramp and then slides back down. At the bottom of the ramp, the final speed of the box is $v_f = 2.00$ m/s. How much thermal energy was generated as the box slid up and down the ramp?

A) None, the ramp is frictionless.  (B) 5.0 J  C) 1.0 J  D) 9.8 J  E) None of these.

\[
E_{\text{tot}} = KE_i + PE_i = KE_f + PE_f + E_{\text{therm}}
\]

\[
E_{\text{therm}} = KE_i - KE_f
\]

\[
= \frac{1}{2} m (v_i^2 - v_f^2)
\]

\[
= \frac{1}{2} \cdot 2 \cdot (3^2 - 2^2)
\]

\[
= 5 \text{ J}
\]

8. A hockey puck slides over the top of a mound of ice, as shown. (The path of the puck is shown with the dashed line.) Assume no friction and assume that the top of the mound has a round circular shape. At the moment when the puck is at the top of the mound, which free-body diagram most accurately represents the directions and relative magnitudes of the forces on the puck.

A)  
B)  
C)  
D)  
E)  

circular motion, const speed $\Rightarrow \vec{a}$ toward center $\Rightarrow F_{\text{net}}$ toward center

Vers. A
9. The velocity of an object, moving in 1D, along the x-axis, is shown as a function of time. Which graph best represents the net force on the object versus time?

\[ \text{slope} = a = \frac{\Delta v}{\Delta t} \]

(A) \hspace{2cm} (B) \hspace{2cm} (C) \hspace{2cm} (D)

\[ F_x = m a_x = m \frac{dv_x}{dt} = m \frac{\Delta v}{\Delta t} \]

10. An object of mass m is suspended by a cord. The magnitude of the tension in the cord is T. The object is moving upward and slowing with a constant acceleration of magnitude \( a = \frac{g}{3} \). What is the magnitude of the tension in the cord? (Hint: what is the direction of the acceleration?)

\[ T = \ldots \]

A) \( \frac{2}{3} mg \) \hspace{1cm} B) \( \frac{1}{3} mg \) \hspace{1cm} C) \( \frac{5}{3} mg \) \hspace{1cm} D) \( mg \) \hspace{1cm} E) \( \frac{3}{5} mg \)

\[ \sum F_y = m a_y \]

\[ mg - T = ma \]

\[ T = mg - ma \]

\[ = mg - \frac{1}{3} mg \]

Vers. A
11. A car is rounding a circular banked curve at the exact speed $v$ such that the force of friction between the tires and the road is zero. The road surface is banked at an angle $\theta$, as shown. The free body diagram for the car is shown, with the forces in the correct directions, but not necessarily with the correct magnitudes. Which equation shows the correct relation between the magnitude of the net force on the car and the magnitudes of the other forces, $N$ and $mg$. (Hint: It may help to first determine the direction of the acceleration.)

A) $F_{net} = mg \cos \theta$
B) $F_{net} = mg \sin \theta$
C) $F_{net} = N \cos \theta$
D) $F_{net} = N \sin \theta$
E) $F_{net} = N \sin \theta + mg \cos \theta$

12. At a particular instant in time, a small star of mass $m$ is directly in between two large stars with masses $2M$ and $3M$, as shown. The small star is a distance $r$ from the nearer star (with mass $2M$) and a distance $2r$ from the farther star (mass $3M$). There are no other masses around. What is the magnitude of the net force on the small star $m$?

A) $\frac{2GMm}{3r^2}$
B) $\frac{4GMm}{3r^2}$
C) zero
D) $\frac{5GMm}{4r^2}$
E) $\frac{1GMm}{3r^2}$

$$|F_{net}| = \left(2 - \frac{3}{4}\right) \frac{GMm}{r^2}$$

Vers. A
13. A matchbox with mass $m$ is sitting and not slipping on a horizontal turntable that is rotating at a constant rate. At the moment when the mass is at the far right (as shown in the diagram), which free-body most accurately represents the forces on the matchbox when viewed from the side?

![Diagram of turntable and matchbox](image)

\[ \text{a toward center} \Rightarrow \text{must have } F_{\text{net}} \text{ toward center} \]

14. A box of mass $M$ is resting in the bed of a truck. The truck is moving forward with a constant acceleration of magnitude $a$. The box is not slipping as the truck accelerates forward (although the box is moving forward, it is remaining stationary relative to the truck bed). Assume that air resistance is negligible. The coefficient of static friction between the box and the truck bed is $\mu_s$ and the coefficient of kinetic friction is $\mu_k$. The magnitude of the force of friction on the box is definitely...

![Diagram of truck and box](image)

\[ F_{\text{net}} = F_{\text{fric}} = Ma \]

A) 0  B) $\mu_s Mg$  C) $\mu_k Mg$  D) $Ma$  E) $g$

15. Two constant forces, each of magnitude $F = 2.0 \text{ N}$, act on a mass $m = 10 \text{ kg}$ while it is moving a distance $d = 10 \text{ m}$. One of the forces is opposite the direction of motion; the other force is perpendicular to the motion, as shown. To two-place accuracy, what is the total work done by the two forces together while the object moved through the distance $d$?

![Diagram of forces](image)

A) $-20 \text{ J}$  B) $-28 \text{ J}$  C) $-14 \text{ J}$  D) $+40 \text{ J}$  E) None of these.

\[ W = |F_{\text{1}}| \cdot |d| \cdot \cos \theta \]

\[ \text{vers. A} \]
16. A box is resting in the bed of a truck. At the instant shown, the truck is moving forward with a **constant velocity**. (The box is moving with the same constant velocity as the truck). Neglecting air resistance, which free-body diagram best represents the forces on the box.

![Diagram of forces](image)

\[ \vec{v} = \text{const} \implies \vec{a} = 0 \implies F_{\text{net}} = 0 \]

17. Planet X has a radius of \( R_X \). The acceleration of gravity on the surface of planet X is 12.0 m/s\(^2\). At what distance \( r \) from the center of planet X is the acceleration of gravity 3.0 m/s\(^2\)? (Note that you do not know the mass of planet X, so knowing G will not help with this problem.)

A) \( r = 32 R_X \)  
B) \( r = 16 R_X \)  
C) \( r = 8 R_X \)  
D) \( r = 4 R_X \)  
E) \( r = 2 R_X \)

\[
g = \frac{GMm}{r^2} 
\]

\[
g = \frac{GMm}{R_x^2} = 12 \text{ m/s}^2 
\]

\[
g(r) = \frac{GMm}{r^2} = \frac{GMm}{R_x^2} \cdot \frac{1}{r^2} = 4 
\]

\[
\frac{1}{R_x^2} = 4, \quad \frac{r^2}{R_x^2} = 4 \quad \Rightarrow \quad r = 2R_x
\]

18. Motor 1 lifts a mass \( m \) up a height \( h \) in a time \( \Delta t \). Motor 2 lifts the same-size mass \( m \), the same height \( h \), but it lifts the mass three times faster than motor 1; that is, motor 1 lifts the mass at speed \( v \), while motor 2 lifts the mass at speed \( 3v \). How does the power output of motor 1, \( P_1 \), compare to the power output of motor 2, \( P_2 \), while the mass is being lifted?

A) \( P_2 = P_1 \)  
B) \( P_2 = 3P_1 \)  
C) \( P_2 = \frac{1}{3}P_1 \)  
D) \( P_2 = 9P_1 \)  
E) \( P_2 = \frac{1}{9}P_1 \)

\[
P = \frac{mg \Delta h}{\Delta t} = mg \cdot v 
\]

\[
\frac{P_2}{P_1} = \frac{mg v_2}{mg v_1} = \frac{v_2}{v_1} = \frac{3v}{v} = 3
\]

Vers. A
19. The graph shows the gravitational potential energy of a cart of mass \( m = 200 \, \text{kg} \) on a frictionless roller coaster track as a function of horizontal position \( x \) (in meters). It is known that the cart is at position \( x = 120 \, \text{m} \) and moving to the right at speed \( v = 5 \, \text{m/s} \). What will eventually happen to the cart? (There are no other hills on the track, besides those shown.)

A) The cart will roll back and forth between hills 1 and 2, staying in the valley indefinitely.
B) The cart will make it over the 3rd hill and exit to the right of the graph.
C) The cart will eventually roll back over hill 1 and exit to the left of the graph.
D) The cart will eventually roll back and forth between hills 2 and 3.

\[
E_{\text{tot}} = KE + PE = \frac{1}{2} mv^2 + PE = \frac{1}{2} (200) 5^2 + 1000
= (100)(25) + 1000 = 3500 \, \text{J}
\]

20. A small planet \( P \) of mass \( m \), moving with speed \( v \), is in circular orbit of radius \( R \) around a massive stationary star with mass \( M \). Consider the following two statements:
I. The magnitude of the acceleration of the planet depends on its mass \( m \). \( \checkmark \)
II. The magnitude of the force of gravity on the planet depends on its mass \( m \). \( \checkmark \)
How many of these statements is true?

A) Both are true.
B) Neither are true.
C) Only statement I is true.
D) Only statement II is true.

\[
F_{\text{grav}} = \frac{GMm}{R^2}
\]

\[
a = \frac{F_{\text{net}}}{m} = \frac{1}{m} \frac{GMm}{R^2} = \frac{GM}{R^2}
\]

Vers. A
21. A mass \( m \) is attached to the end of a rigid massless rod of length \( L \). The other end of the rod is attached to a motor which rotates the rod at a constant rate, so that the mass moves in a vertical circle with constant speed \( v \). In the diagram, the acceleration of gravity is downward. Consider these statements:
I. As the mass moves around the circle, the magnitude of its acceleration remains constant.
II. As the mass moves around the circle, the magnitude of the net force on the mass remains constant.

Which of these statements are true?
A) Both are true.  
B) Neither are true.  
C) I is true and II is false.  
D) I is false and II is true.

\[ a = \frac{v^2}{r} = \text{const} \]

\[ |F_{\text{net}}| = m a = \text{const} \]

22. A conical pendulum is a mass hanging from string with the mass moving in a circular path so that the string makes a constant non-zero angle \( \theta \) with the vertical and sweeps out a cone. In the conical pendulum shown, how does the magnitude of the net force \( (F_{\text{net}}) \) on the mass compare to the magnitude of the tension \( (F_T) \) in the string?

A) \( F_{\text{net}} > F_T \)  
B) \( F_{\text{net}} = F_T \)  
C) \( F_{\text{net}} < F_T \)  
D) Impossible to answer without more information

\[ F_{\text{net}} = F_T \sin \theta \]

23. A mass \( m \) is attached to a rigid, massless rod of length \( R \). The rod is pivoted at one end so the mass can swing in a vertical circle. The mass starts at the bottom of its arc and is given an initial speed \( v \), as shown. The mass swings up through a \( 180^\circ \) arc and strikes a horizontal spring, which has spring constant \( k \). The spring compresses an amount \( x \), just stopping the mass at the very top of the arc. What is the maximum compression \( x \) of the spring?

A) \( \frac{1}{k} (mv^2 - 4mgR) \)  
B) \( \frac{1}{2} mv^2 - 2mgR \)
C) \( \frac{1}{k} (v^2 - 2gR) \)  
D) \( \sqrt{\frac{1}{k} (mv^2 + 2mgR)} \)
E) None of these.

\[ KE_i + PE_i = KE_f + PE_f \]
\[ \frac{1}{2} mv^2 + 0 = 0 + mg(2R) + \frac{1}{2} k x^2 \]
\[ \frac{1}{2} k x^2 = \frac{1}{2} mv^2 - 2mgR, \quad k x^2 = mv^2 - 4mgR \]

Vers. A
24. A projectile of mass $m$ is **fired straight up** with an initial speed $v_o$ from the surface of an airless planet of mass $M$ and radius $R_0$. The initial speed is less than the escape speed, so the projectile rises to a maximum height and falls straight back toward the surface of the world. What is the correct expression for the **potential energy** of the projectile when it is at its maximum height above the world? (As usual, we put the zero of potential energy at $r = \infty$.)

A) $-\frac{GMm}{R_0}$  
B) $\frac{1}{2}mv^2 - \frac{GMm}{R_0}$  
C) $\frac{1}{2}v^2 - \frac{GM}{R_0}$  
D) $\sqrt{\left(\frac{1}{2}mv^2\right)^2 + \left(\frac{GMm}{R_0}\right)^2}$  
E) None of these

\[ KE_i + PE_i = KE_f + PE_f \]
\[ \frac{1}{2}mv^2 - \frac{GMm}{R_0} = 0 + PE_f \]

25. Two sleds are being pulled across a frictionless ice rink by two motors. The mass of sled 2 is twice as large as the mass of sled 1. The sleds start at rest and each is pulled with the **same** constant force of magnitude $F$ for the **same** distance $d$.

Consider the following two statements:
I. After the sleds have each traveled the same distance $d$, they have the same speed.  
II. After the sleds have each traveled the same distance $d$, they have the same kinetic energy.  

Which statements are true? (Hint: Consider the work done)

A) Neither are true.  
B) Both are true.  
C) Only I is true.  
D) Only II is true.

\[ W_{\text{net}} = \Delta KE \]
\[ \Rightarrow F \cdot d = KE_f = \text{same for both} \]
\[ \text{Same } KE, \text{ different } m's \Rightarrow \text{ must have different } v's \]