\[
\begin{align*}
\sin 30^\circ &= \cos 60^\circ = \frac{1}{2} \\
\sin 60^\circ &= \cos 30^\circ = \frac{\sqrt{3}}{2} \approx 0.87 \\
\sin 45^\circ &= \cos 45^\circ = \frac{\sqrt{2}}{2}
\end{align*}
\]

1. The mechanical energy of a system is the sum of its kinetic, potential and thermal energy.
   
   (a) True  
   (b) False  
   (c) cannot be answered

2. Gravitational potential energy has the form:
   
   (a) \(-G \frac{Mm}{r}\)  
   (b) \(g \frac{M}{r^2}\)  
   (c) \(G \frac{M}{r^2}\)  
   (d) none of these

3. The potential energy for the force of friction can be expressed as:
   
   (a) \(-\mu_k F_N d\)  
   (b) \(\mu_k F_N d\)  
   (c) \(-\mu_k mg d \cos \theta\)  
   (d) none of these

**Questions 4-5.** A ball of mass \(m=1\) kg, starting from rest, falls a vertical distance \(h=5\) m before striking a vertical spring (spring constant \(k=2\) N/m) which it compresses an amount \(Y\). Take \(g \approx 10\) m/s\(^2\).

![Diagram of ball falling and compressing a spring]

4. The speed of the ball just before it strikes the spring is:
   
   (a) 1 m/s  
   (b) 5 m/s  
   (c) 10 m/s  
   (d) 20 m/s

5. The ball compresses the spring the amount \(Y=\):
   
   (a) 5 m  
   (b) \(5 \sqrt{3}\) m  
   (c) \(5(1+\sqrt{3})\) m  
   (d) \(\sqrt{3}/5\) m
Questions 6-7. A block of mass \( m = 1 \text{ kg} \) moves along a rough surface and strikes a horizontal spring, as shown in the picture. The coefficient of kinetic friction between the block and the surface is \( \mu_k = 0.1 \). The speed of the box just before the contact with the spring is 1 m/s. The spring compresses \( x = 10 \text{ cm} \) due to the impact. Take \( g \approx 10 \text{ m/s}^2 \).

6. What is the work done by the force of friction from the moment the block hits the spring until it comes to a full stop?

(a) -0.1 J   (b) 0.1 J   (c) -0.2 J   (d) 0.2 J

7. What is the potential energy of the system when the block comes to a full stop?

(a) 0   (b) 0.4 J   (c) 0.5 J   (d) none of these

Questions 8-9. A small box of mass \( m = 1 \text{ kg} \) goes down a \( d = 10 \text{-m} \) long slide inclined \( \theta = 30^\circ \) with the horizontal, as in the picture. The coefficient of kinetic friction between the box and the slide is \( \mu_k = 0.1 \). Take \( g \approx 10 \text{ m/s}^2 \).

8. The work done by the force of friction is:

(a) -10 J   (b) 10 J   (c) -8.7 J   (d) 8.7 J

9. If the box starts from rest at the top of the slide, how fast is it traveling when it reaches the bottom?

(a) 10 m/s   (b) \( \sqrt{98.2} \text{ m/s} \)   (c) \( \sqrt{82.6} \text{ m/s} \)   (d) \( \sqrt{50} \text{ m/s} \)
Questions 10–11. The potential energy of the two atoms in a diatomic molecule (the so-called Lennard-Jones potential) can be written as:

\[ U(r) = -\frac{a}{r^6} + \frac{b}{r^{12}} \]

where \( r \) is the distance between the two atoms and \( a \) and \( b \) are positive constants.

10. What is the corresponding force \( F(r) \)?

(a) \(-5a r^5 + 11b r^{11}\)  (b) \(-6a r^7 + 12b r^{13}\)  (c) \(6a r^7 - 12b r^{13}\)  (d) none of these

11. The Lennard-Jones potential energy \( U(r) \) has one stable equilibrium point, which corresponds to the equilibrium distance between the atoms in the molecule. What is this equilibrium distance?

(a) \(\sqrt[3]{\frac{2b}{a}}\)  (b) \(\sqrt[3]{\frac{2b}{a}}\)  (c) \(\sqrt[3]{\frac{2a}{b}}\)  (d) none of these

12. Newton’s second law can be expressed in terms of momentum as?

(a) \(\sum \vec{F} = m\vec{p}\)  (b) \(\sum \vec{F} = \frac{d\vec{p}}{dt}\)  (c) \(\sum \vec{F} = \frac{d\vec{p}}{dx}\)  (d) \(\sum \vec{p} = \frac{d\vec{F}}{dx}\)

13. The law of conservation of momentum states that when the net external force on a system is zero, its total momentum remains constant.

(a) True  (b) False  (c) cannot be answered

14. The recoil velocity of a 5 kg rifle that shoots a 50 g bullet at a speed of 100 m/s is:

(a) 0.1 m/s  (b) 1 m/s  (c) 10 m/s  (d) 100 m/s
**Question 15** Consider the potential energy diagram below:

![](potential_energy_diagram.png)

15. What are the unstable equilibrium points?

(a) B  
(b) B and D  
(c) A, C and E  
(d) B, D and F

16. Three particles, each of mass $m=1$ kg, are located at the corners of an equilateral triangle whose sides have length $a=1$ m, as shown in the picture below.

![](triangle.png)

The center of mass is located at $(x, y)$=:

(a) (0, 0.87)  
(b) (0.5, 0.5)  
(c) (0.5, 0.29)  
(d) (0.5, 0.87)

**Questions 17-18.** A billiard ball of mass $m$ moving with speed $v_1=1$ m/s collides head-on with a second ball of mass $2m$ which is at rest.

17. What is the velocity of the ball of mass $m$ after the collision?

(a) -0.33 m/s  
(b) -0.5 m/s  
(c) -0.67 m/s  
(d) -1 m/s

18. What is the velocity of the ball of mass $2m$ after the collision?

(a) 0.33 m/s  
(b) 0.5 m/s  
(c) 0.67 m/s  
(d) 1 m/s
**Questions 19-20.** A ball of mass $m$ traveling with speed $v_1=1 \text{ m/s}$ collides elastically with a ball of mass $2m$ which is at rest. After the collision the ball of mass $m$ is observed to be scattered at a $60^\circ$ angle, and the ball of mass $2m$ is observed to be scattered at a $30^\circ$ angle, as in the picture:

19. What is the speed of the ball of mass $m$ after the collision?

   (a) 0.25 m/s   (b) 0.43 m/s   (c) 0.5 m/s   (d) 0.87 m/s

20. What is the speed of the ball of mass $2m$ after the collision?

   (a) 0.25 m/s   (b) 0.43 m/s   (c) 0.5 m/s   (d) 0.87 m/s